Original Article

Assessment of diagnostic accuracy of a direct digital radiographic-CMOS image with four types of filtered images for the detection of occlusal caries

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Abstract

Background: Digital imaging has the potential to improve diagnostic accuracy and make quantitative diagnoses. In the recent decades, software for radiographic analysis has been investigated and developed for the detection of lesions and the quantitative assessment of the depth of a caries lesion. In addition, the accuracy of diagnosis may also be enhanced by programs that filter the images. These programs can adjust the brightness and contrast, determine the gray level, invert the shades of gray, and apply pseudocolors. Few studies compared different types of digital images in the diagnosis of changes in the tooth crown. **Aim:** The main aim of this study was to assess the the diagnostic accuracy of a direct digital radiography (DDR)-CMOS image with four types of filtered images for the detection of occlusal caries. **Materials and Methods:** Fifty randomly selected patients' teeth were clinically examined and digitally radiographed. Radiographed images are converted into four filter images with the help of software. Filtered images were then selected for inter- and intraobserver examination and the result was subjected to statistical analysis. **Conclusion:** DDR-CMOS and negative image were found to be more useful in diagnosing occlusal caries.

Keywords: Dental caries, digital radiography, enhancement filter

Introduction

Dental caries has been recorded since times immemorial. It has been mentioned in *sushruta samhita* under disorder of mouth "mukha roga" "krimi dantaka."[1] The word caries derives from the Latin for rot or rotten. In 1728, Pierre Fauchard, a French military surgeon, wrote the first text on dental diseases and treatment entitled, "Le Chirurgien Dentiste."[2] It was around 1900 that the first statistics on dental decay was published, which was approximately the time when the first university dental institutes were training students in dentistry.[3] Over the past few decades, a trend of declining caries in developed countries and increasing caries experience in developing countries has been reported.[4-7] The prevalence of dental caries is approximately 60%–65% in India.[8,9] It is the primary cause of oral pain and tooth loss. It can be arrested and potentially reversed in its early stages, but is often not self-limiting and without proper care caries can progress until the tooth is destroyed.[10] Recent data indicate that about 90% of carious lesion occurs in the pits and fissures of permanent posterior teeth and that molar tooth are most susceptible to caries.[11,12] Advances in knowledge about caries have allowed for more conservative treatments with the development of nonoperative/preventive care for the initial stages of caries lesions.[13] However, diagnosis must be performed

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Received: 23-10-2019 **Revised:** 04-12-2019
Accepted: 12-12-2019 **Published:** 28-01-2020

Access this article online

Quick Response Code:

Website: www.jfmpc.com

DOI: 10.4103/jfmpc.jfmpc_934_19

How to cite this article: Sahu RK, Rajguru JP, Pattnaik N, Bardhan D, Nayak B. Assessment of diagnostic accuracy of a direct digital radiographic-CMOS image with four types of filtered images for the detection of occlusal caries. J Family Med Prim Care 2020;9:206-14.

early at the non-cavitated stage, when the dynamic nature of lesion progression still makes the arrest of further mineral loss possible.[14] At this stage, remineralization therapy can be applied to reverse incipient lesions.[15] This leads to changes in mineral quality and quantity. Clinicians need resources of high diagnostic accuracy for both detecting incipient caries and monitoring remineralization of lesions.[16] Wenzel[17] reported that conventional radiography has limited ability to detect lesions confined to enamel, and there is little information available about the use of digital systems in clinical practice. Digital imaging has the potential to improve diagnostic accuracy and make quantitative diagnoses.[18,19]

In recent decades, software for radiographic analysis has been investigated and developed for the detection of lesions and the quantitative assessment of the depth of a caries lesion.[20-22]

Despite the advantages of digital system, the efficacy of some software enhancement features is still questionable because in some cases software manipulation of digital radiographs may result in false-positive caries detection and lead to incorrect diagnosis and treatment.[23]

In addition, the accuracy of diagnosis may also be enhanced by programs that filter the images. These programs can adjust the brightness and contrast, determine the gray level, invert the shades of gray, and apply pseudocolors.[24-26] Few studies compared different types of digital images in the diagnosis of changes in the tooth crown.[27] This study sought to assess the diagnostic accuracy of a direct digital radiography (DDR)-CMOS image with four types of filtered images for the detection of occlusal caries.

Materials and Methods

Fifty randomly selected individuals were explained the nature and objective of the study. The entire procedure of the study was explained to the individual in a language they understood. Only those individuals who gave informed consent were included in the study and subjected to detailed case history, clinical, and radiographic procedures. Only the lower first and second molars of both sides were selected for the study. In the clinical examination, the teeth selected were first completely air-dried using three ways syringe fixed in the dental chair. Then using the ball end of explorer, food debris were cleaned so that the caries lesion could be clearly visible. After that, codes were given to the carious tooth by following the International Caries Detection and Assessment system (ICDAS) codes and criteria [Figure 1] for occlusal caries determination through visual examination clinically:

Code 4 (An underlying dark shadow from dentin with or without localized enamel breakdown) and Code 5 (Distinct cavity with visible dentin) criteria were chosen for this study.

In the radiological examination, the selected tooth was radiographed using a dental X-ray machine

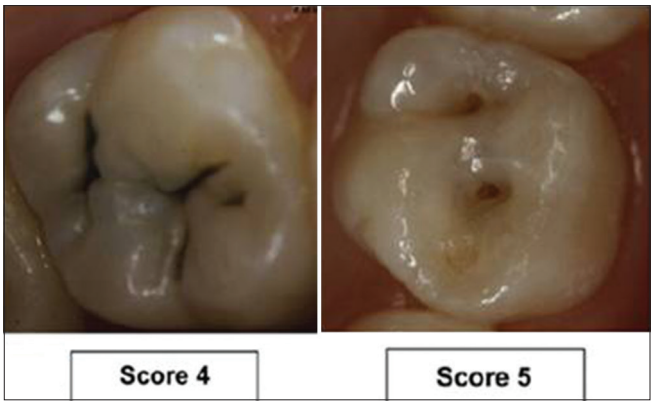


Figure 1: ICDAS codes and criteria

(Confident 70 kVp, 7 mA) with constant exposure time as given by the manufacturer for the mandibular molar teeth. Kodak RVG 5100 sixth-generation sensor was used to obtain a digital image of the selected carious tooth in an Intel core i3 computer. Parallel line angle technique was followed using Rinin XCP digital sensor holder [Figure 2].

Kodak dental imaging 6.1 software was used for generating image and converting the image into four filter images. The first image produced was in the Endo mode which was considered as the normal mode image. After that, the image was converted into four filter images [Figure 3] as follows:

1. Perio mode
2. Negative mode
3. Color 1 mode
4. Color 2 mode.

A total of 250 images were generated. Images were randomized and evaluated by two experienced dental radiologists with a minimum of 4 years of experience. Inter- and intra-evaluation of the images was presented on a slide show in a dimmed room with no time limit. A 5-point scale was used to detect enamel defects with number ranges as follows:

1. Definitely present
2. Probably present
3. Uncertain
4. Probably absent
5. Definitely absent.

Results

In this study, the samples were distributed (N = 50) into two groups as per ICDAS coding. In code category 4, there were 23 (46%) samples, while category 5 had 27 (54%) samples [Table 1]. Evaluator #1 at time T_1 evaluated [Table 2] that in the DDR-CMOS mode, a maximum of, that is, 30 (60%) samples had score 1 indicating caries definitely present, followed by 11 (22%) with score 2 indicating caries probably present. In the Perio mode, 17 (34%) had score 1 and 12 (24%) had score 2. The Negative mode had 32 (64%) samples with score 1, which could be definitely identified with caries. In the Color 1 mode,

Figure 2: Parallel line angle technique

Table 1: Distribution of samples as per ICDAS code

ICDAS code	*n*	%
4	23	46
5	27	54
Total	50	100

ICDAS: International caries detection and assessment system

there were 18 (36%) samples with score 2 and 12 (24%) samples with score 3. In the Color 2 mode, there were 22 (44%) samples in which caries were definitely identified, while in 15 (30%) samples, caries were probably present. The median scores for the DDR-CMOS and Negative modes were 1, indicating that a majority of the samples could be identified with caries using these two modes. Evaluator #1 at time T_2 again revaluated the images and found [Table 3] that in the DDR-CMOS mode, a maximum of, that is, 34 (68%) samples could be definitely identified with caries, followed by 14 (28%) with score 2 indicating caries probably present. In the Perio mode, 21 (42%) had score 1, while 12 (24%) had score 2. In the Negative mode, 34 (68%) samples could be identified with caries, while 10 (20%) probably had caries as per the evaluator. In the Color 1 mode, there were 20 (40%) samples with score 1 and 12 (24%) samples with score 3 indicating uncertainty regarding presence of caries. In the Color 2 mode, there were 31 (62%) samples in which caries were definitely identified, while in 12 (24%) samples, caries were probably present. The median scores for the DDR-CMOS, Negative, and Color 2 modes were 1, indicating that a majority of the samples could be identified with caries using these modes by the evaluator at time T_2.

The distribution of samples by scores and the descriptive statistics of scores given by Evaluator #2 at time T_1 were evaluated [Table 4]. In the DDR-CMOS mode, a maximum of, that is, 19 (38%) samples could be definitely identified with caries, followed by 14 (28%) with score 2 indicating caries probably present. In the Perio mode, 18 (36%) had score 4 indicating caries probably absent in these samples, while 11 (22%) had score 2 indicating caries probably present in the samples. The Negative mode had 19 (38%) samples that

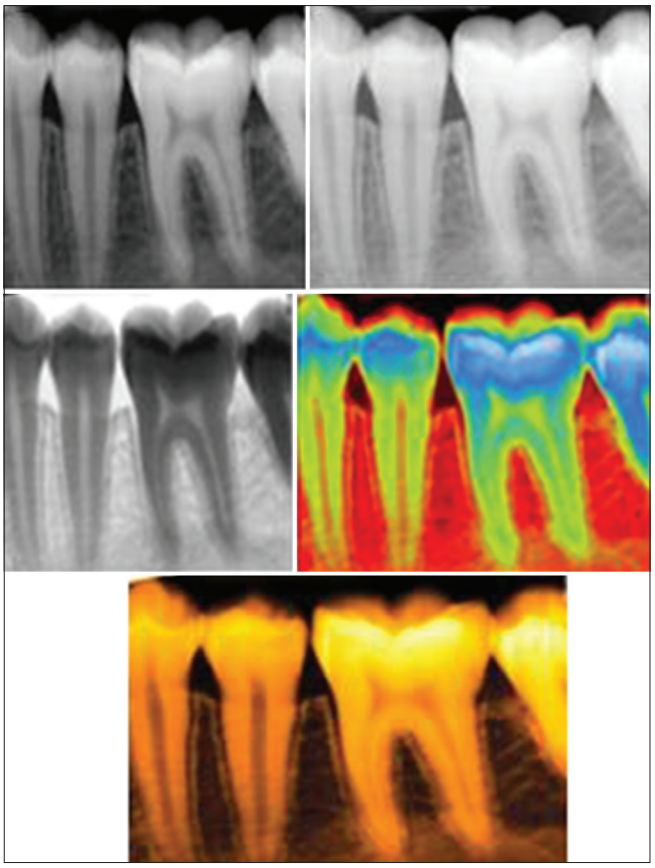


Figure 3: Filter and pseudocolor images

could be identified with caries, while 13 (26%) probably had caries absent as per this evaluator. In the Color 1 mode, there were 18 (36%) samples with score 3, about which the presence of caries was uncertain, and 14 (28%) samples with score 4, indicating probable absence of caries. In the Color 2 mode, there were 14 (28%) samples in which caries were probably identified, while in 13 (26%) samples, the presence of caries was uncertain. Also in 13 (26%) cases, caries were probably absent. The median scores for the DDR-CMOS and Negative modes were 2 each, indicating that a majority of the samples probably had caries as per these modes. The distribution of samples by scores and the descriptive statistics of scores given by Evaluator #2 at time T_2 were evaluated [Table 5]. In the DDR-CMOS mode, a maximum of, that is, 22 (44%) samples could be definitely identified with caries, followed by 13 (26%) with score 2 indicating caries probably present. In the Perio mode, 20 (40%) had score 3 indicating uncertainties about caries in these samples, while 14 (28%) had score 4 indicating probably absence of caries in these samples. The Negative mode had 22 (44%) samples that could be identified definitely with caries, while 12 (24%) samples were identified with probably no caries. In the Color 1 mode, there were 28 (56%) samples with score 3 about which the presence of caries was uncertain and 12 (24%) samples with score 4 indicating probable absence of caries. In the Color 2 mode, there were 24 (48%) samples in which the presence of caries was uncertain, while in 13 (26%) samples, caries were probably absent as per the evaluator. The median

Table 2: Distribution of samples and descriptive statistics of scores given by Evaluator #1 at time T_1 as per ICDAS code and type of modes

ICDAS code	Score	Type of mode [*n* (%)]				
		DDR-CMOS	Perio	Negative	Color 1	Color 2
4 and 5	1	30 (60)	17 (34)	32 (64)	9 (18)	22 (44)
	2	11 (22)	12 (24)	9 (18)	18 (36)	15 (30)
	3	3 (6)	8 (16)	4 (8)	12 (24)	5 (10)
	4	4 (8)	6 (12)	3 (6)	5 (10)	2 (4)
	5	2 (4)	7 (14)	2 (4)	6 (12)	6 (12)
	Mean	1.74	2.48	1.68	2.62	2.1
	Median	1	2	1	2	2
	SD	1.14	1.43	1.11	1.24	1.34
	Minimum	1	1	1	1	1
	Maximum	5	5	5	5	5
4	1	4 (17.39)	0	8 (34.78)	1 (4.35)	3 (13.04)
	2	10 (43.48)	5 (21.7)	6 (26.09)	6 (26.09)	7 (30.43)
	3	3 (13.04)	5 (21.7)	4 (17.39)	6 (26.09)	5 (21.74)
	4	4 (17.39)	6 (26.1)	3 (13.04)	4 (17.39)	2 (8.70)
	5	2 (8.70)	7 (30.4)	2 (8.70)	6 (26.09)	6 (26.09)
	Mean	2.57	3.65	2.35	3.35	3.04
	Median	2	4	2	3	3
	SD	1.24	1.15	1.34	1.27	1.43
	Minimum	1	2	1	1	1
	Maximum	5	5	5	5	5
5	1	26 (96.30)	17 (63)	24 (88.89)	8 (29.63)	19 (70.37)
	2	1 (3.70)	7 (25.9)	3 (11.11)	12 (44.44)	8 (29.63)
	3	0	3 (11.1)	0	6 (22.22)	0
	4	0	0	0	1 (3.70)	0
	5	0	0	0	0	0
	Mean	1.04	1.48	1.11	2.00	1.30
	Median	1	1	1	2	1
	SD	0.19	0.70	0.32	0.83	0.47
	Minimum	1	1	1	1	1
	Maximum	2	3	2	4	2

ICDAS: International caries detection and assessment system; DDR: Direct digital radiographic; SD: Standard deviation

Table 3: Distribution of samples and descriptive statistics of scores by Evaluator #1 at time T_2 as per ICDAS code and type of modes

ICDAS code	Score	Type of mode				
		DDR-CMOS	Perio	Negative	Color 1	Color 2
4 and 5	1	34 (68)	21 (42)	34 (68)	20 (40)	31 (62)
	2	14 (28)	12 (24)	10 (20)	10 (20)	12 (24)
	3	0	2 (4)	4 (8)	2 (4)	0
	4	1 (2)	10 (20)	1 (2)	12 (24)	3 (6)
	5	1 (2)	5 (10)	1 (2)	6 (12)	4 (8)
	Mean	1.42	2.32	1.5	2.48	1.74
	Median	1	2	1	2	1
	SD	0.7848	1.45	0.88641	1.5151	1.2423
	Minimum	1	1	1	1	1
	Maximum	5	5	5	5	5
4	1	12 (52)	3 (13)	12 (52)	5 (22)	9 (39)
	2	9 (39)	8 (35)	7 (30)	6 (26)	8 (35)
	3	0	0	2 (9)	1 (4)	0
	4	1 (4)	8 (35)	1 (4)	6 (26)	3 (13)
	5	1 (4)	4 (17)	1 (4)	5 (22)	3 (13)
	Mean	1.70	3.09	1.78	3.00	2.26
	Median	1	4	1	3	2
	SD	1.02	1.41	1.09	1.54	1.45
	Minimum	1	1	1	1	1
	Maximum	5	5	5	5	5
5	1	22 (81)	18 (67)	22 (81)	15 (56)	22 (81)
	2	5 (19)	4 (15)	3 (11)	4 (15)	4 (15)
	3	0	2 (7)	2 (7)	1 (4)	0
	4	0	2 (7)	0	6 (22)	0
	5	0	1 (4)	0	1 (4)	1 (4)
	Mean	1.19	1.67	1.26	2.04	1.30
	Median	1.00	1.00	1.00	1.00	1.00
	SD	0.40	1.14	0.59	1.37	0.82
	Minimum	1	1	1	1	1
	Maximum	2	5	3	5	5

ICDAS: International caries detection and assessment system; DDR: Direct digital radiographic; SD: Standard deviation

score for the DDR-CMOS mode was 1, and the Negative mode was 2, indicating that a majority of the samples could have caries as per these modes.

Agreement statistics for intra- and interevaluator comparisons according to the modes is made [Table 6]. For Evaluator #1, the maximum intracomparison (at T_1 and T_2) agreement was observed for the Color 1 mode, that is, 0.4746 [95% confidence interval (CI): 0.3339–0.6153]. This was followed by Perio with 0.4121 (95% CI: 0.2391–0.5850), then Negative with 0.3533 (95% CI: 0.0627–0.6438), and DDR-CMOS with 0.3169 (95% CI: 0.0492–0.5847). For Evaluator #2, the maximum intracomparison agreement was observed for the DDR-CMOS mode, that is, 0.6294 (95% CI: 0.4797–0.7791), followed by Negative with 0.569 (95% CI: 0.3832–0.7547), Perio with 0.5455 (95% CI: 0.3624–0.7285), and Color 2 with 0.5149 (95% CI: 0.3160–0.7138). Also, the intercomparison agreement between two evaluators was obtained with the results shown in table. The agreement was maximum for the DDR-CMOS mode with kappa coefficient of 0.4108 (95% CI: 0.1124–0.7091). This was followed by the Negative mode with coefficient of 0.3065 (95% CI: 0.0344–0.5768) and then Perio with 0.2343 (95% CI: 0.0423–0.4262). A graphical representation of the kappa values according to the evaluator and type of mode has been given through the bar chart in Graphs 1-3.

Table 7 provides the descriptive statistics for the median scores derived from two evaluators according to the modes. The mean for the DDR-CMOS mode was smallest (1.77) with smallest median of 1.5, indicating that a majority of the samples could be identified with caries by both the evaluators in this mode. The next larger mean was obtained for the Negative mode with a mean of 1.97 and median of 2, followed by Color 2 with a mean of 2.49 and median of 2.25. The results for the Perio and Color 1 mode were nearly the same as indicated by the median values.

The difference between the distribution of scores across modes was evaluated for statistical significance using Kruskal–Wallis

Table 4: Distribution of samples and descriptive statistics of scores by Evaluator #2 at time T_1 as per ICDAS code and type of modes

ICDAS code	Score	Type of mode				
		DDR-CMOS	Perio	Negative	Color 1	Color 2
4 and 5	1	19 (38)	8 (16)	19 (38)	4 (8)	4 (8)
	2	14 (28)	11 (22)	9 (18)	6 (12)	14 (28)
	3	3 (6)	8 (16)	6 (12)	18 (36)	13 (26)
	4	8 (16)	18 (36)	13 (26)	14 (28)	13 (26)
	5	6 (12)	5 (10)	3 (6)	8 (16)	6 (12)
	Mean	2.06	3.02	2.44	3.32	3.06
	Median	2	3	2	3	3
	SD	1.35	1.29	1.39	1.13	1.17
	Minimum	1	1	1	1	1
	Maximum	5	5	5	5	5
4	1	7 (30.43)	0	4 (17.39)	2 (8.70)	2 (8.70)
	2	5 (21.74)	3 (13.04)	5 (21.74)	1 (4.35)	3 (13.04)
	3	3 (13.04)	5 (21.74)	4 (17.39)	4 (17.39)	4 (17.39)
	4	4 (17.39)	11 (47.83)	8 (34.78)	9 (39.13)	9 (39.13)
	5	4 (17.39)	4 (17.39)	2 (8.70)	7 (30.43)	5 (21.74)
	Mean	2.70	3.70	2.96	3.78	3.52
	Median	2	4	3	4	4
	SD	1.52	0.93	1.30	1.20	1.24
	Minimum	1	2	1	1	1
	Maximum	5	5	5	5	5
5	1	17 (62.96)	8 (29.63)	15 (55.6)	2 (7.41)	2 (7.41)
	2	8 (29.63)	8 (29.63)	4 (14.8)	5 (18.5)	11 (40.74)
	3	1 (3.70)	3 (11.11)	2 (7.41)	14 (51.9)	9 (33.33)
	4	0	7 (25.93)	5 (18.5)	5 (18.5)	4 (14.81)
	5	1 (3.70)	1 (3.70)	1 (3.70)	1 (3.70)	1 (3.70)
	Mean	1.52	2.44	2.00	2.93	2.67
	Median	1	2	1	3	3
	SD	0.89	1.28	1.33	0.92	0.96
	Minimum	1	1	1	1	1
	Maximum	5	5	5	5	5

ICDAS: International caries detection and assessment system; DDR: Direct digital radiographic; SD: Standard deviation

Table 5: Distribution of samples and descriptive statistics of scores by Evaluator #2 at time T_2 as per ICDAS code and type of modes

ICDAS code	Score	Type of mode				
		DDR-CMOS	Perio	Negative	Color 1	Color 2
4 and 5	1	22 (44)	7 (14)	22 (44)	3 (6)	3 (6)
	2	13 (26)	7 (14)	10 (20)	5 (10)	8 (16)
	3	3 (6)	20 (40)	4 (8)	28 (56)	24 (48)
	4	9 (18)	14 (28)	12 (24)	12 (24)	13 (26)
	5	3 (6)	2 (4)	2 (4)	2 (4)	2 (4)
	Mean	1.86	2.94	2.24	3.10	3.06
	Median	1	3	2	3	3
	SD	1.28	1.08	1.35	0.86	0.91
	Minimum	1	1	1	1	1
	Maximum	5	5	5	5	5
4	1	10 (43.48)	0	6 (26.09)	1 (4.35)	1 (4.35)
	2	7 (30.43)	2 (8.70)	5 (21.74)	1 (4.35)	1 (4.35)
	3	0	12 (52.17)	3 (13.04)	11 (47.83)	12 (52.17)
	4	3 (13.04)	7 (30.43)	7 (30.43)	8 (34.78)	7 (30.43)
	5	3 (13.04)	2 (8.70)	2 (8.70)	2 (8.70)	2 (8.70)
	Mean	2.22	3.39	2.74	3.39	3.35
	Median	2	3	3	3	3
	SD	1.48	0.78	1.39	0.89	0.88
	Minimum	1	2	1	1	1
	Maximum	5	5	5	5	5
5	1	18 (66.67)	7 (25.93)	16 (59.26)	2 (7.41)	2 (7.41)
	2	6 (22.22)	5 (18.52)	5 (18.52)	4 (14.81)	7 (25.9)
	3	1 (3.70)	8 (29.63)	1 (3.70)	17 (62.96)	12 (44.44)
	4	1 (3.70)	7 (25.93)	5 (18.52)	4 (14.81)	6 (22.22)
	5	1 (3.70)	0	0	0	0
	Mean	1.56	2.56	1.81	2.85	2.81
	Median	1	3	1	3	3
	SD	1.01	1.15	1.18	0.77	0.88
	Minimum	1	1	1	1	1
	Maximum	5	4	4	4	4

ICDAS: International caries detection and assessment system; DDR: Direct digital radiographic; SD: Standard deviation

test, resulting into a *P* value < 0.0001 implying highly significant difference [Graph 4].

Table 8 provides the pair-wise comparison of scores between types of modes using Wilcoxon rank-sum test. It shows that the difference in the distribution of the DDR-CMOS and Negative modes was insignificant ($P = 0.1657$), while that of the DDR-CMOS and Perio, DDR-CMOS and Color 1, and DDR-CMOS and Color 2 were highly significant as indicated by *P* values <0.0001. The difference in score distribution between Perio and Color 1 as well as Perio and Color 2 was insignificant with $P = 0.3814$ and $P = 0.2379$, respectively. The difference between Perio and Negative was, however, significant with *P* value of 0.0003. The distribution of scores in the Negative mode differed significantly from that of Color 1 and Color 2 with *P* values <0.0001 and 0.0026, respectively. Also, the difference between Color 1 and Color 2 differed significantly with *P* value of 0.0293.

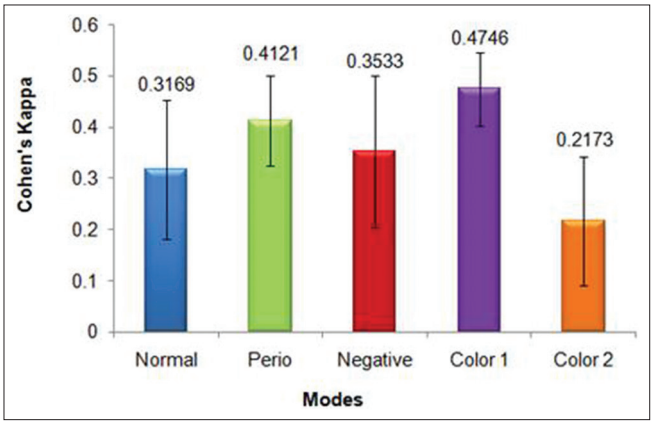
Discussion

Dental caries has to be controlled lifelong if a functional dentition is to be maintained. It was appreciated that diagnosis should be performed at noncavitated stages because the dynamic nature of lesion progression allows for arrest of further mineral loss by restoring physiological equilibrium between tooth mineral and oral fluids.[14] Wenzel[17] suggests that laboratory diagnosis can be better than clinical diagnosis, and that the interpretation of the results obtained in the laboratory experiments, despite the attempt to recreate clinical conditions, may not be reliable. However, Hintze *et al.*[28] concluded, in 1996, that the clinical results of radiographic diagnoses of occlusal and proximal carious lesions were comparable to those obtained in laboratory. Conventional radiography has been used in detection of caries for decades. It has limited ability to detect lesions confined to enamel. With the introduction of digital imaging, a significant advancement in detection of caries is possible.

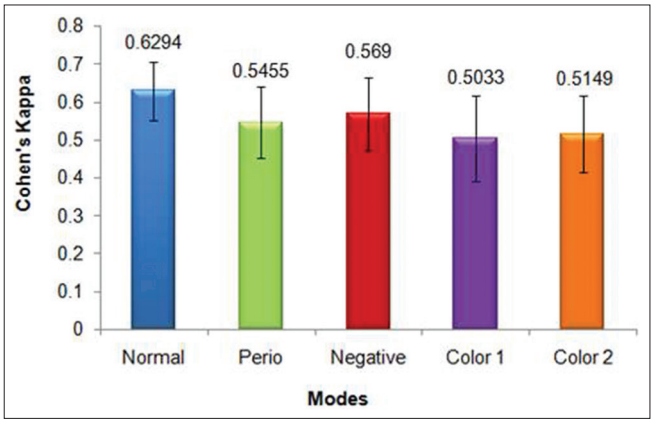
Table 6: Agreement statistics for intra- and interevaluator comparisons based on scores for each type of mode

Comparison	Agreement Statistics*	Type of mode				
		DDR-CMOS	Perio	Negative	Color 1	Color 2
Evaluator #1	Cohen's kappa	0.3169	0.4121	0.3533	0.4746	0.2173
Times: T1 and T2	Std. error	0.1366	0.0883	0.1482	0.0718	0.1252
	95% CI	0.0492-0.5847	0.2391-0.5850	0.0627-0.6438	0.3339-0.6153	-0.0282-0.4627
Evaluator #2	Cohen's kappa	0.6294	0.5455	0.569	0.5033	0.5149
Times: T1 and T2	Std. error	0.0764	0.0934	0.0948	0.114	0.1015
	95% CI	0.4797-0.7791	0.3624-0.7285	0.3832-0.7547	0.2798-0.7268	0.3160-0.7138
Evaluator #1	Cohen's kappa	0.4108	0.2343	0.3065	0.1206	0.0633
and	Std. error	0.1522	0.0979	0.1388	0.0922	0.0836
Evaluator #2	95% CI	0.1124-0.7091	0.0423-0.4262	0.0344-0.5786	−0.0601-0.3013	−0.1006-0.2272

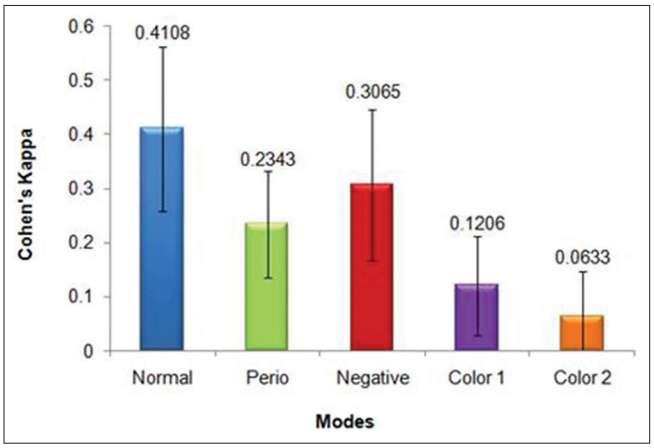
DDR: Direct digital radiographic; CI: Confidence interval. *0-0.20: slight; 0.21-0.40: fair; 0.41-0.60: moderate; 0.61-0.80: substantial; 0.81-1.00: almost perfect



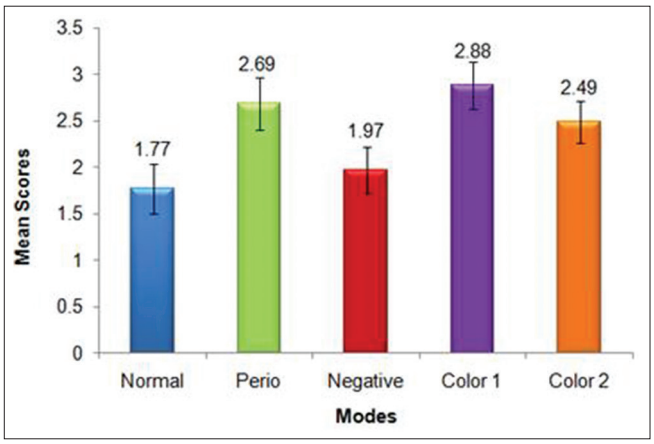
Graph 1: Bar chart showing Cohen's kappa values for Evaluator #1 at time points T1 and T2 according to mode (normal = DDR-CMOS)



Graph 2: Bar chart showing Cohen's kappa values for Evaluator #2 at time points T1 and T2 according to modes (normal = DDR-CMOS)



Graph 3: Bar chart showing Cohen's kappa values for Evaluators #1 and #2 according to modes (normal = DDR-CMOS)



Graph 4: Bar chart showing mean scores according to modes (normal = DDR-CMOS)

A major advantage of digital system is the possibility to alter the display option for image interpretation. The use of image enhancement algorithms offers a variety of approaches to modify diagnostic images to achieve visually acceptable images. Also, there is little information available about the use of digital systems in clinical practice. Digital imaging has the potential to improve diagnostic accuracy and make quantitative diagnosis.[17] Diagnosis of occlusal caries is crucial in preventing dental loss and radiographic examination is the best way to evaluate the problem. This study used a digital radiography system to obtain X-ray images, given that its features provide greater dynamism to the images, which facilitates diagnosis and interpretation of occlusal changes. Filters developed to help identification of changes are one of the features that enhance the diagnosis of occlusal caries. However, few studies have investigated whether filters are, in fact, a resource for diagnosis.[29-31]

Table 7: Descriptive statistics for median scores derived from two evaluators

Scores	DDR-CMOS	Perio	Negative	Color 1	Color 2
Mean	1.77	2.69	1.97	2.88	2.49
Median	1.5	2.75	2	2.75	2.25
SD	0.93	0.99	0.86	0.89	0.80
Min	1	1	1	1.5	1
Max	5	4.25	3.75	4.75	4
*P**	<0.0001 (HS)				

DDR: Direct digital radiographic; SD: Standard deviation. *Obtained using Kruskal-Wallis test: HS: Highly significant

Table 8: Pair-wise comparison of scores between types of mode

Comparison	*P**
DDR-CMOS and Perio	<0.0001 (HS)
DDR-CMOS and Negative	0.1657 (NS)
DDR-CMOS and Color 1	<0.0001 (HS)
DDR-CMOS and Color 2	<0.0001 (HS)
Perio and Negative	0.0003 (S)
Perio and Color 1	0.3814 (NS)
Perio and Color 2	0.2379 (NS)
Negative and Color 1	<0.0001 (HS)
Negative and Color 2	0.0026 (S)
Color 1 and Color 2	0.0293 (S)

DDR: Direct digital radiographic. *Obtained using Wilcoxon rank-sum test; S: Significant; NS: Not significant; HS: Highly significant

In this study, DDR was used to obtain images ($n = 50$) of lower posterior molar teeth with caries (ICDAS Codes 4 and 5) using Kodak 5100 sensor and algorithms of Kodak Dental Imaging Software 6.01 at set exposure time. The images were not altered using density and contrast tools. Two evaluators examined the DDR-CMOS images using four image filters at two separate time intervals. Kappa test ranges from <0 to 1.00, with almost perfect agreement varying between 1.00 and 0.81 and considerable agreement between 0.80 and 0.61. In this study, the results of inter- and intraexaminer agreement are fair to moderate for the DDR-CMOS and Negative mode images and slight for Color 1 and Perio mode images. Pair-wise comparisons between the modes Normal and Perio, Normal and Color 1, Normal and Color 2, Negative and Color 1 show highly significant results. In accordance with this study, pseudocolor mode by Kositbowornchai *et al.*[29] tended to show the lowest diagnostic accuracy in detecting occlusal caries carried out in 100 extracted human third molar. The average intraobserver kappa value was 0.58. The kappa values for interobserver agreement were higher and averaged 0.70.

The kappa value agreement ratios were calculated by Booshehry *et al.*[26] and it was found that pseudocolor filter on digital radiographic images failed to result in significantly improved caries detection. The kappa correlation coefficient of observers demonstrated good observer agreement which is similar to the findings of this study. This suggests that caries was detected on the DDR-CMOS mode, that is, grey scale image when compared with the color modes (Colors 1 and 2) which might be explained by unfamiliarity of the clinician's eyes with colored images, their conception, analysis, and interpretation. Therefore, as shown in the results, inter-observer agreement in gray-scale images was better than this value in colored images and had better diagnostic accuracy.

M Torman Alkurt *et al.*[32] investigated the efficiency of different speeds of conventional intraoral films and a direct digital system for proximal caries detection using 48 extracted human posterior permanent teeth. The results of this study showed that the diagnostic performance of E- and F-speed films and DDR was similar for proximal caries detection.

Abbas Shokri *et al.*[33] assessed the diagnostic accuracy of original and enhanced digital radiographs for the detection of approximal and occlusal caries by creating incipient carious lesions artificially on 120 proximal and occlusal surfaces of human extracted permanent molar and premolar teeth. After mounting the teeth in wax, digital radiographs were obtained using photostimulable phosphor plates and enhanced by enhancement filters 1, 2, and 3 with/without denoising. No significant difference was noted among different filters for detection of carious and sound surfaces, but enhanced and original radiographs were significantly different in visualization and detection of caries. However, it was concluded that application of enhancement filters, particularly enhancement filter 2 with/without denoising, increases the accuracy of caries detection on digital radiographs.

In contrast to this study, Takeshita *et al.*[22] found the comparison between images with filters and DDR-CMOS revealed that Color 1 showed better diagnostic accuracy. But similar findings were found in comparison with the above study to those of İlgüy *et al.*[34] who also used teeth with artificially produced defects.

Masteriner *et al.*[35] found that visual inspection is an important diagnostic method; conventional bitewing and digital radiography aid the diagnosis and are equally efficient to diagnose carious lesions in the dentine of teeth without visible cavitation. The calculated kappa was found average for interobserver agreement.

In this study, descriptive statistics for the median scores derived from two evaluators came as highly significant ($P < 0.0001$) using Kruskal–Wallis test. Lesion type significantly influenced the validity of caries depth measurements: enamel lesions were less underestimated than dentine lesions. Similarly, in this study, Code 4 caries are less accurately identified in comparison to Code 5 caries according to the ICDAS criteria in all the modes used by the inter- and intraobserver examination. This may be attributed to the cavity formation and increases the depth of carious process. Examiners were able to better diagnose caries on the DDR-CMOS and Negative images when compared with Perio, Color 1, and Color 2 image modes. One of the reasons behind this might be the ease and habit of diagnosing the images in the mode when compared with other modes. There was good agreement between both evaluators on diagnostic accuracy of images in pseudocolors and Perio image mode which was in

fact limited and was found to be least useful in diagnosis of occlusal caries. The diagnostic accuracy slightly increased in the second evaluation by the same evaluator. This may be attributed to the habitual process of screening and diagnosing a carious process. Time management is crucial in modern dental practices and operator time is an expensive area where savings can be made. However, clinicians must be reminded that the digital imaging system is not a toy and that manipulating images to entertain the patient will erode any cost benefit. Manufacturers of digital imaging systems should concentrate on producing a user-friendly machine with a fully utilizable image which needs no manipulation or enhancement in future.[36]

Implications for clinical practice

Currently, regardless of the method by which an image is captured, once it has been digitized, several computerized enhancements can be performed on the image. When a clinician looks at a radiographic image, he or she knows what the relationship of the different gray levels means. The addition of color without an understandable gradient provides no new information. Obviously, if a digital system could identify carious lesions as red, this enhancement would be of great value.[37] The results obtained suggest digital radiology to be effective in the diagnosis of dental caries. The interpretation of digital images differs from that of conventional film because they are displayed on-screen, and therefore are affected by screen resolution, image file type, and size. Thus, in this study, the comparisons between images with filters and DDR-CMOS revealed that Negative and DDR-CMOS images are more useful and Color 1 and Perio images are least useful images for the detection of occlusal caries. In this era of evidence-based dentistry, systematic reviews and validation studies of caries detection methods have been addressed in some studies, but there is still need for more studies in the future to clearly determine the best and most accurate ways of caries diagnosis.

Conclusion

Caries is a dynamic process that develops due to biochemical and ultrastructural changes. Early diagnosis of caries is of great importance so that preventive and conservative actions can be taken. In this study, the diagnostic accuracy of direct digital radiograph image was compared with four enhanced filter images for the determination of occlusal caries. The selected teeth were radiographed from the randomly selected patients using the digital intraoral sensor and then inter- and intraobserver examination was done. Within the limitations of this study, the following conclusions are made:

- DDR-CMOS and Negative image were found to be more useful in diagnosing occlusal caries
- Perio, Color 1, and Color 2 filters had limited use in diagnosing caries
- Color 2 was found to be better in diagnosing caries than Color 1 and Perio modes
- The accuracy of diagnosing caries increased with the depth of caries.

Declaration of patient consent

The authors certify that they have obtained all appropriate patient consent forms. In the form the patient(s) has/have given his/her/their consent for his/her/their images and other clinical information to be reported in the journal. The patients understand that their names and initials will not be published and due efforts will be made to conceal their identity, but anonymity cannot be guaranteed.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

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