10.5005/jp-journals-10024-2510

ORIGINAL RESEARCH

Effect of Pseudocolor Filter in Micro-computed Tomography Images for Detection of Proximal and Occlusal Caries Lesions in Primary Molars

[1]Sérgio AP Freitas, [2]Francine K Panzarella, [3]Roseli H Karia, [4]Mariana RM Cavaletti, [5]José Luiz C Junqueira, [6]Luciana B Oliveira

ABSTRACT

Aim: This study aimed to evaluate the effect of pseudocolor filter in micro-computed tomography (CT) images for the detection of proximal and occlusal caries lesions in primary molars.

Materials and methods: For this in vitro analysis, 26 extracted human primary teeth were scanned using a compact micro-CT device (Skyscan 1172, Bruker micro-CT, Kontich, Belgium) and the projection images were reconstructed into cross-sectional slices (NRecon v.1.6.9, Bruker micro-CT, Kontich, Belgium). The original and pseudocolor images were evaluated twice by three calibrated radiologists. The tooth surfaces were scored according to Mejàre et al. criteria. The agreement was assessed by the Kappa coefficient, and the Chi-square test was used to evaluate the association between radiolucent lesion depth in enamel and dentin.

Results: There was a good intra-observer agreement for detecting proximal caries lesions with or without using pseudocolor filter (k >0.60). The inter-examiner agreement had similar results, and the agreement rates were good or moderate for the proximal surfaces. There were no statistically significant differences between the original and pseudocolor images (p >0.05). The pseudocolor filter showed high sensitivity and specificity when compared with the original image with the exception of the occlusal face in enamel.

Conclusion: The pseudocolor filter appears to be a promising enhancement tool for micro-CT images used for the detection of caries lesions in primary molars; even if it was not significantly different from the original images.

[1-5]Division of Oral Radiology, Faculdade São Leopoldo Mandic, Instituto de Pesquisas São Leopoldo Mandic, Campinas, Brazil

[6]Division of Pediatric Dentistry, Faculdade São Leopoldo Mandic, Instituto de Pesquisas São Leopoldo Mandic, Campinas, Brazil

Corresponding Author: Francine K Panzarella, Division of Oral Radiology, Faculdade São Leopoldo Mandic, Instituto de Pesquisas São Leopoldo Mandic, Campinas, Brazil, Phone: +55 19 3211-3695, e-mail: francine.panzarella@gmail.com

Clinical significance: The pseudocolor filter converts grey scale images into color images. It is present in micro-CT software and must increase the diagnostic capacity of detecting caries lesion in occlusal and proximal surfaces.

Keywords: Dental caries, Diagnostic imaging, Primary molars, X-ray microtomography.

How to cite this article: Freitas SAP, Panzarella FK, Karia RH, Cavaletti MRM, Junqueira JLC, Oliveira LB. Effect of Pseudocolor Filter in Micro-computed Tomography Images for Detection of Proximal and Occlusal Caries Lesions in Primary Molars. J Contemp Dent Pract 2019;20(3):279-284.

Source of support: Nil

Conflict of interest: None

INTRODUCTION

X-ray micro-CT is a high-resolution, non-destructive imaging method, which has been increasingly used in dental researches exploring mineral density distribution patterns of dental tissues,[1,2] for morphometric analysis,[3,4] and microstructure of dental materials.[5-7] In addition, it has been used in the detection of mineral changes in artificial and natural caries lesions.[8-10]

Micro-CT has been cited as the most nondestructive and appropriate instrument to validate caries diagnosis due to its high-resolution tool to assess mineralized tissues in (2) and 3-dimensional (3D) analysis.[11,12] However, there are very few investigations on the validity of micro-CT for in vitro caries detection in permanent and in primary teeth. In addition, there are few studies evaluating the potential of micro-CT as a substitute for the histological exam as the gold standard.[13-19] It has been shown that this method to be very sensitive for the detection of caries lesions in enamel and for differentiation of lesions in enamel and dentin *in vitro*,[15,17,18,20] affirming that micro-CT and histological analysis function as the gold standard in a similar manner. Image noise is a particularly important

artifact in micro-CT imaging which reduces the contrast resolution and degrades the image quality.[13]

Use of the pseudocolor filter present in the majority of digital systems converts grey scale images into color images, increases the diagnostic capacity, bearing in mind that it is possible for the human eye to differentiate millions of colors, and its limitation to see grey. The digital image manipulation tools using filters in different imaging modalities have been considered by some authors[21-24] as being responsible for increasing diagnostic capacity, representing promising instruments for the detection of caries lesions.

To the best of our knowledge, no study has been conducted to assess the effect of pseudocolor filter in micro-CT images for detection of proximal and occlusal caries lesions. Therefore, the aim of this study was to evaluate the effect of pseudocolor filter in micro-CT images for detection of proximal and occlusal caries lesions in primary molars.

MATERIALS AND METHODS

Sample Preparation and Selection

This research was approved by the local ethics committee (N° 2011/0025). For this *in vitro* analysis, 26 primary molars which were exfoliated or extracted for orthodontic purposes were evaluated. Samples were positioned in plastic containers and frozen at –20ºC until their use. Before starting the experiment, the selected primary molars were cleaned with a rotating brush and pumice/water slurry and stored in distilled water. Exclusion criteria for sample surfaces were the presence of restorations, the presence of large caries lesions on smooth or occlusal surfaces, the presence of sealants and presence of hypoplasic pits.

Micro-CT Analysis

The samples were scanned using a compact micro-CT device (Skyscan 1172, Bruker micro-CT, Kontich, Belgium) at 100 kV, 100 µA, 7.96 µm pixel size, with Al 1.0 mm filter. Mean time of scanning was 45 minutes. The projection images were reconstructed into cross-sectional slices using NRecon software (NRecon v.1.6.9, Bruker micro-CT, Kontich, Belgium).

Three calibrated examiners conducted the examinations independently. Before the study, a rehearsal session was held in which observers became familiar with the scores. The digitized images were coded and displayed in random order in a high-resolution format–tagged image file format (TIFF) for the analysis. As shown in Figure 1, two subsamples of micro-CT images were compared: the original images and those with the pseudocolor filter. Proximal and occlusal surfaces were visually scored using Mejàre et al.[25] criteria: 0—no radiolucency; 1—radiolucency in the outer half of the enamel; 2—radiolucency in the inner half of the enamel; 3—broken EDJ without radiolucency obvious spread in the dentine; 4—radiolucency in the outer half of the dentine; and 5—radiolucency in the inner half of the dentine. These criteria were also adopted in a previous study conducted by Soviero et al.[13] The interval between duplicated examinations was from two to three weeks. To establish the definition of gold-standards for caries detection, each micro-CT scan was reviewed by the main investigator and coauthor experienced with caries ground truth assessment.

Statistical Analysis

Kappa coefficients were estimated to assess intra- and inter-observer agreement and statistic was interpreted as per Landis and Koch:[26] >0.81 (very good), 0.61–0.80 (good), 0.41–0.60 (moderate), 0.21–040 (fair) and <0.20 (poor) agreement, respectively. Sensitivity (true positive ratio), specificity (true negative ratio) and overall accuracy values were calculated.

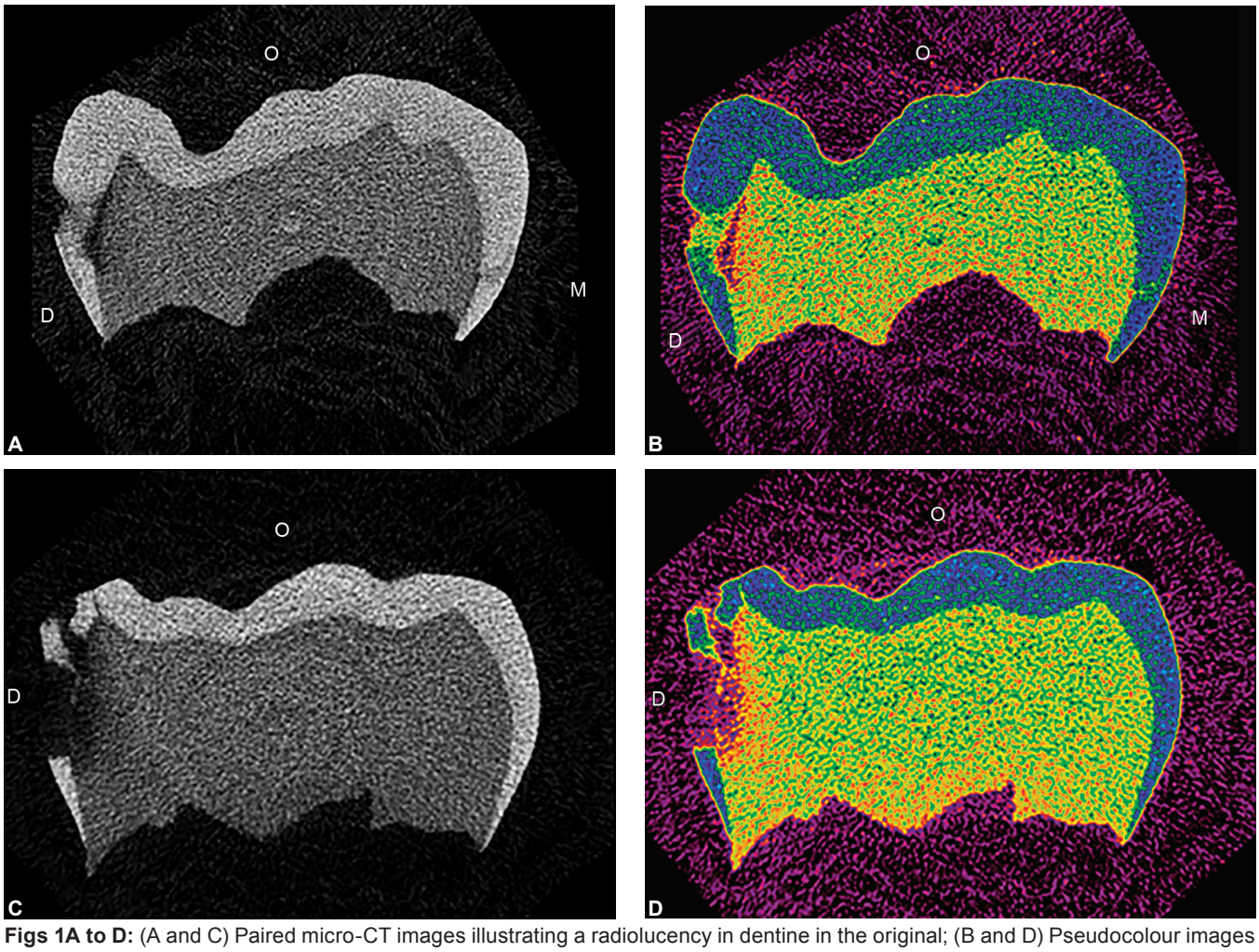
The data were grouped as sound, enamel caries, and dentine caries. In addition, the Chi-square test was used to evaluate the association between radiolucent lesion depth in enamel and dentin and the presence or absence of caries lesions was also evaluated. The statistical analyses were carried out using the statistical package for social sciences (SPSS) 21.0 (SPSS Inc., Chicago, IL) and Graph Pad Prism 6.0 (GraphPad Software, San Diego, California, USA, www.graphpad.com) software. The level of significance was 95% ($\alpha = 5\%$) for all tests.

RESULTS

Tables 1 and 2 present distribution of absolute and relative frequencies of diagnosis of the three observers. The Chi-square test showed there was a lower proportion of diagnosis in the scores for caries in enamel by observer 3 than by the other observers, both with the original ($p = 0.0419$) and pseudocolor filter ($p = 0.0303$), and there were no statistically significant differences ($p > 0.05$) between the other proportions.

There was good agreement (k >0.6) between observers 1 and 2 (Kappa = 0.65 ± 0.05), 1 and 3 (Kappa = 0.68 ± 0.05) and 2 and 3 (Kappa = 0.57 ± 0.05). The influence of tooth surfaces and filters together on the interobserver agreement is presented in Table 3.

Table 4 presents the distribution of classifications considering the presence or absence of caries lesions in dentin or enamel, without considering filters or tooth surfaces, revealing that the Kappa test showed excellent agreement among the observers, both for dentin and enamel.



Figs 1A to D: (A and C) Paired micro-CT images illustrating a radiolucency in dentine in the original; (B and D) Pseudocolour images

Table 1: Distribution of absolute and relative frequencies of diagnosis of the three observers according to Soviero et al. criteria and filters

	Observer 1		*Observer 2*		*Observer 3*	
Score	*Original*	*Pseudocolour*	*Original*	*Pseudocolour*	*Original*	*Pseudocolour*
0	43 (55.8%)	32 (41.6%)	41 (53.2%)	35 (45.5%)	47 (61%)	43 (55.8%)
1	9 (11.7%)	9 (11.7%)	13 (16.9%)	11 (14.3%)	3 (3.9%)	3 (3.9%)
2	5 (6.5%)	13 (16.9%)	4 (5.2%)	12 (15.6%)	5 (6.5%)	6 (7.8%)
3	7 (9.1%)	9 (11.7%)	5 (6.5%)	1 (1.3%)	3 (3.9%)	8 (10.4%)
4	8 (10.4%)	7 (9.1%)	8 (10.4%)	10 (13%)	11 (14.3%)	10 (13%)
5	5 (6.5%)	7 (9.1%)	6 (7.8%)	8 (10.4%)	8 (10.4%)	7 (9.1%)

Table 2: Distribution of absolute and relative frequencies of diagnosis of the three observers according three diagnostic thresholds (sound, enamel caries and dentin caries) and filters

Diagnosis	*Original*	*Pseudocolour*	*Original*	*Pseudocolour*	*Original*	*Pseudocolour*
0–sound	43 (55.8%)	32 (41.6%)	41 (53.2%)	35 (45.5%)	47 -61%	43 (55.8%)
1, 2, 3–enamel caries	21 (27.3%)	31 (40.3%)	22 (28.6%)	24 (31.2%)	11 (14.3%)	17 (22.1%)
4 e 5–dentin caries	13 (16.9%)	14 (18.2%)	14 (18.2%)	18 (23.4%)	19 (24.7%)	17 (22.1%)

Table 5 shows the values of sensitivity, specificity, accuracy, false-negative, false-positive, positive predictive values, and negative predictive value of the pseudocolor filter. As may be observed, the pseudocolor filter showed high sensitivity and specificity, and with the exception of the occlusal face in enamel. However, no statistical differences were observed between the original and pseudocolor micro-CT images ($p > 0.05$).

Table 3: Interobserver Kappa coefficients [Kappa ± standard error (CI 95%)] considering filters and tooth surfaces

		Original		*Pseudocolour*	
Surfaces		*Observer 1*	*Observer 2*	*Observer 1*	*Observer 2*
Mesial	Observer 2	0.74 (± 0.14) [0.47 a 1.01]	–	0.68 (± 0.15) [0.39 a 0.97]	–
	Observer 3	0.73 (± 0.15) [0.44 a 1.02]	0.55 (± 0.18) [0.2 a 0.9]	0.75 (± 0.13) [0.5 a 1]	0.74 (± 0.14) [0.47 a 1.01]
Distal	Observer 2	0.6 (± 0.12) [0.36 a 0.84]	–	0.6 (± 0.12) [0.36 a 0.84]	–
	Observer 3	0.5 (± 0.12) [0.26 a 0.74]	0.54 (± 0.12) [0.3 a 0.78]	0.9 (± 0.07) [0.76 a 1.04]	0.69 (± 0.11) [0.47 a 0.91]
Occlusal	Observer 2	0.68 (± 0.15) [0.39 a 0.97]	–	0.39 (± 0.14) [0.12 a 0.66]	–
	Observer 3	0.51 (± 0.22) [0.08 a 0.94]	0.31 (± 0.2) [0 a 0.7]	0.39 (± 0.14) [0.12 a 0.66]	0.23 (± 0.15) [0 a 0.52]

Table 4: Distribution of absolute and relative frequencies of caries diagnosis of the three observers according to presence or absence of caries lesions in dentin or enamel

		Dentin (n = 154)		*Enamel (n = 154)*	
		Absence	*Presence*	*Absence*	*Presence*
1 *vs* 2	Absence	121 (78.6%)	1 (0.6%)	71 (46.1%)	5 (3.2%)
	Presence	6 (3.9%)	26 (16.9%)	4 (2.6%)	74 (48.1%)
	Agreement	0.853 ± 0.05 (0.76 a 0.95)		0.883 ± 0.04 (0.8 a 0.96)	
1 *vs* 3	Absence	118 (76.6%)	–	75 (48.7%)	15 (9.7%)
	Presence	9 (5.8%)	27 (17.5%)	–	64 (41.6%)
	Agreement	0.821 ± 0.06 (0.7 a 0.94)		0.806 ± 0.05 (0.71 a 0.9)	
2 *vs* 3	Absence	117 (76%)	1 (0.6%)	74 (48.1%)	16 (10.4%)
	Presence	5 (3.2%)	31 (20.1%)	2 (1.3%)	62 (40.3%)
	Agreement	0.887 ± 0.05 (0.79 a 0.98)		0.767 ± 0.05 (0.67 a 0.86)	

Table 5: Predictive values (%) of the pseudocolor filter when compared with original image for the detection of caries lesions

	Dentin			*Enamel*		
Tooth surfaces	*Distal*	*Mesial*	*Occlusal*	*Distal*	*Mesial*	*Occlusal*
Sensitivity	95	100	100	97.5	100	100
Specificity	91.4	97.3	100	90	97.4	55.6
Accuracy	93.3	97.4	100	96	98.1	69.2
False-negative	5	0	0	2.5	0	0
False-positive	8.6	2.7	0	10	2.6	44.4
Positive predictive values	92.7	60	100	97.5	93.3	50
Negative predictive values	94.1	100	100	90	100	100

DISCUSSION

The use of micro-CT has been increased in dental research on the validity for *in vitro* caries detection in permanent and in primary teeth.[15,27-30] Previous studies reported that a significantly higher agreement was obtained by observers with micro-CT images.[13,14] It is important to emphasize that caries misdiagnoses in such cases can lead to unnecessary invasive treatments. To the best of our knowledge, this is the first study which assessed the effect of pseudocolor filter in micro-CT images for detection of proximal and occlusal caries lesions in primary molars. It was not possible to compare directly the results of the present study with previous studies. Moreover, comparisons between studies should be interpreted with caution due to the lack of uniformity in sample selection (permanent and primary teeth), number of surfaces, number of raters and scoring categories and data analysis.

In the present study, it was possible to verify from data in Tables 1 and 2 that there were discrepancies between the scores attributed by the observers, however, the three attributed the lowest percentage score 0 (zero), which may be explained by the fact that more caries lesions were seen in pseudocolor than in original images. Moreover, it was observed that the observers attributed more caries in enamel scores in pseudocolor, which may justify the reduction in the findings of score 0, also through this filter, bearing

in mind that an increase in the findings of caries in dentin was also observed through pseudocolor filter. According to Kositbowornnchai et al.,[31] the pseudocolor mode assigns different colors to certain grey levels, which can enhance small local contrasts. In addition, Shahmoradi et al.,[16] de-noising of the images with the total variation method enhanced the results of the colorization process which led to the recognition of structural details in caries lesions.

There was the influence of filters and tooth surfaces, because although the agreements had remained good and moderate for the mesial and distal faces, the occlusal face showed a lower Kappa value, particularly through the pseudocolor filter; and the values were also lower than the others for the original image. This result may be attributed to the presence of sinuosities inherent to the occlusal surface, by virtue of the fissures, which can be exacerbated with the use of pseudocolor filter.

Table 4 presents the distribution of classifications considering the presence or absence of caries lesions in dentin or enamel, without considering filters or tooth surfaces, revealing that the Kappa test showed excellent agreement among the observers, both for dentin and enamel, which validates the micro-CT data as a diagnostic test for caries as the gold standard. The worst agreement values were also found for caries lesions in enamel on the occlusal surface. It is important to emphasize that the low agreement values were found for both original and pseudocolor images, which led us to ratify that the pseudocolor filter did not change the detection of caries lesions on this surface.

As may be observed in Table 5, the pseudocolor filter showed high sensitivity and specificity, and with the exception of the occlusal face in enamel. As has previously been shown, the authors perceived that the pseudocolor filter did not change the traditional interpretation of the micro-CT original images, with the exception of the evaluation of occlusal caries lesions in enamel, a fact previously justified by the presence of fissures.

The lower proportion of diagnosis in the scores for caries in the enamel can be seen as a limitation of this study. Dental caries lesions in primary teeth tend to progress rapidly due to enamel lower thickness. Soviero et al.[13] reported that micro-CT is not reliable for the detection of caries lesions restricted to the enamel. This method was found to be sensitive in detecting enamel lesions and in differentiating enamel from dentine caries lesions, thus appearing to be an important tool for detection and assessment of the depth of proximal caries. Taylor et al.[32] also reported that the correlation in enamel is poorer. It seems likely that this was caused by a difficulty distinguishing fissures from lesions, confounded by the thinness of the enamel, which means small numbers of voxels can have a disproportionate effect on the caries progression index. To solve this, the researchers affirmed that increasing the resolution of the scan would amplify the difference between step and gradual changes, and reducing noise would allow the resolution of smaller features including some fissures. On the other hand, Kamburoğlu et al.[33] concluded that micro-CT was found to be the best imaging method for the *ex vivo*.

Considering the small number of publications on the subject; and the increasingly frequent use of micro-CT in dental research, further studies are required to assess and compare the accuracy of diagnosing caries lesions in original and pseudocolor micro-CT images.

CONCLUSION

There were good intra- and inter-examiner agreement about the detection of caries lesions in primary molars, in original and pseudocolor micro-CT images, and that the latter filter presented high sensitivity and specificity values when compared with the original images. However, no statistical differences were found between the original and pseudocolor images.

REFERENCES

1. Hamba H, Nikaido T, Sadr A, et al. Enamel lesion parameter correlations between polychromatic Micro-CT and TMR. J Dent Res. 2012;91:586-591.
2. Swain MV, Xue J. State of the art of Micro-CT applications in dental research. Int J Oral Sci. 2009;1:177-188.
3. Souza-Flamini LE, Leoni GB, et al. The radix entomolaris and paramolaris: a micro-computed tomographic study of 3 -rooted mandibular first molars. J Endod. 2014;40:1616-1621.
4. Rodrigues CT, Oliveira-Santos C, Bernardineli N, et al. Prevalence and morphometric analysis of three-rooted mandibular first molars in a Brazilian subpopulation. J Appl Oral Sci. 2016;24:535-542.
5. De Souza ET, Nunes Tameirão MD, Roter JM, et al. Tridimensional quantitative porosity characterization of three set calcium silicate-based repair cements for endodontic use. Microsc Res Tech. 2013;76:1093-1098.
6. Gandolfi MG, Parrilli AP, Fini M, et al. 3D micro-CT analysis of the interface voids associated with Thermafil root fillings used with AH Plus or a flowable MTA sealer. Int Endod J. 2013;46:53-63.
7. Huang Y, Orhan K, Celikten B, et al. Evaluation of the sealing ability of different root canal sealers: a combined SEM and micro-CT study.J Appl Oral Sci. 2018 Jan 15;26:e20160584.
8. Mitropoulos P, Rahiotis C, Stamatakis H, et al. Diagnostic performance of the visual caries classification system ICDAS II versus radiography and micro-computed tomography for proximal caries detection: an in vitro study. J Dent. 2010; 38:859-867.
9. Cochrane NJ, Anderson P, Davis GR, et al. An X-ray microtomographic study of natural white-spot enamel lesions. J Dent Res. 2012; 91:185-191.

10. Elfrink ME, Kalin K, van Ruijven LJ, et al. MicroCTstudy on the enamel mineral density of primary molars. Eur J Paediatr Dent. 2016;17:60-64.
11. Huysmans MC, Longbottom C. The challenges of validating diagnostic methods and selecting appropriate gold standards. J Dent Res. 2004;83:C48-C52.
12. Davis GR, Mills D, Anderson P. Real-time observations of tooth demineralization in 3 dimensions using X-ray microtomography.J Dent. 2018 Feb;69:88-92.
13. Soviero, VM, Leal SC, Silva RC, et al. Validity of MicroTC for in vitro detection of proximal carious lesions in primary molars. J Dent. 2012;40:35-40.
14. De Souza AL, Bronkhorst EM, Creugers NH, et al. The caries assessment spectrum and treatment (CAST) instrument: its reproducibility in clinical studies. Int Dent J. 2014; 64:187-194.
15. Özkan G, Kanli A, Başeren NM, et al. Validation of micro-computed tomography for occlusal caries detection: an in vitro study. Braz Oral Res. 2015;29(1):S1806-83242015000100309.
16. Shahmoradi M, Lashgari M, Rabbani H, et al. A comparative study of new and current methods for dental micro-CT image denoising. Dentomaxillofac Radiol. 2016;45:20150302.
17. Gray BM, Mol A, Zandona A, et al. The effect of image enhancements and dual observers on proximal caries detection.Oral Surg Oral Med Oral Pathol Oral Radiol. 2017 Apr;123(4):e133-e139.
18. Lederer A, Kunzelmann KH, Hickel R, Litzenburger F.Transillumination and HDR Imaging for Proximal Caries Detection.J Dent Res. 2018 Jul;97(7):844-849.
19. Rovaris K, Ferreira LM, Sousa TO, et al. Feasibility of micro-computed tomography to detect and classify proximal caries lesions *in vitro*. Dent Res J (Isfahan). 2018;15(2): 123-129.
20. Schwass DR, Swain MV, Purton DG, et al. A system of calibrating microtomography for use in caries research.Caries Res. 2009;43(4):314-321.
21. Haiter-Neto F, dos Anjos Pontual A, Frydenberg M, et al. Detectionofnon-cavitatedapproximalcarieslesionsindigitalimagesfromsevensolid-state receptors with particular focus on task-specific enhancement filters. An ex vivo study in human teeth. Clin Oral Investig. 2008;12:217-223.
22. Haiter-Neto F, Casanova MS, Frydenberg M, et al. Task-specific enhancement filters in storage phosphor images from the Vistascan system for detection of proximal caries lesions of known size. Oral Surg Oral Med Oral Pathol Oral Radio Endod. 2009;107:116-121.
23. Belém MDF, Ambrosano GMB, Tabchoury CPM, et al. Performance of digital radiography with enhancement filters for the diagnosis of proximal caries. Braz Oral Res. 2013;27:245-251.
24. Deprá LC, Iwaki LCV, Chicarelli M, et al. Influence of Image Filters and Variation in Horizontal Angle of Incidence of X-ray Beam in Digital Interproximal Radiographs for Diagnosis of Secondary Caries in Esthetic Restorations. J Contemp Dent Pract. 2015;16:805-812.
25. Mejàre I, Källestål C, Stenlund H. Incidence and progression of approximal caries from 11 to 22 years of age in Sweden: a prospective radiographic study. Caries Res. 1999;33: 93-100.
26. Landis JR, Koch GG. The measurement of observer agreement for categorical data. Biometrics. 1977;33:159-174.
27. Kucuk EB, Malkoc S, Demir A. Microcomputed tomography evaluation of white spot lesion remineralization with various procedures.Am J Orthod Dentofacial Orthop. 2016;150(3): 483-490.
28. Abogazalah N, Eckert GJ, Ando M. *In vitro* performance of near infrared light transillumination at 780-nm and digital radiography for detection of non-cavitated approximal caries. J Dent. 2017;63:44-50.
29. AlHumaid J, Al-Harbi F, El Tantawi M, et al. X-ray microtomography assessment of Carisolv and Papacarie effect on dentin mineral density and amount of removed tissue.Acta Odontol Scand. 2018;76(4):236-240.
30. Mijan MC, Frencken JE, Schwass DR, et al. Microcomputed Tomography Evaluation of Dentine Mineral Concentration in Primary Molars Managed by Three Treatment Protocols. Caries Res. 2018;52(4):303-311.
31. Kositbowornnchai S, Basiw M, Promwang Y, et al. Accuracy of diagnosing occlusal caries using enhanced digital images. Dentomaxillofac Radiol. 2004;33:236-240.
32. Taylor AM, Satterthwaite JD, Ellwood RP, et al. An automated assessment algorithm for micro-CT images of occlusal caries. Surgeon. 2010;8:334-340.
33. Kamburoğlu K, Kurt H, Kolsuz E, et al. Occlusal caries depth measurements obtained by five different imaging modalities. J Digit Imaging. 2011;24:804-813.