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ORIGINAL ARTICLE

Comparison Between Radiographs, White and Fluorescent Images in the Diagnosis and Treatment Decisions for Occlusal Caries: An *Ex Vivo* Study

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ABSTRACT

Objective: To compare the agreement of images in white light (WL), fluorescence (FL), and digital radiographs (DR), on the diagnosis and treatment decisions for occlusal caries lesions against a micro-CT gold standard. **Material and Methods:** Ten extracted third molars, with enamel and/or dentin caries (ICDAS 2-4), were included. Occlusal surface images were acquired with an intraoral camera (SoproLife®) in WL and FL modes. DR was obtained using an intraoral X-ray and a semi-direct digital system. A total of 780 images were needed, organized in a template, to be later examined by twenty-six dentists invited to compose the study. The Generalized Estimation Equations model was used to compare the proportions of the correct answers between the three methods and the gold standard. When significant, Bonferroni post-hoc test was used to identify differences ($\alpha=5\%$). **Results:** Most of the examiners were specialists (76.9%) with 14.5 years of experience. All diagnostic methods were similar and showed low agreement (DR 12.7%, WL 16.5%, and FL 16.5%) compared with gold standard caries diagnostic scores. Regarding treatment decisions, mean agreement for all diagnostic methods was higher (43.2%; $p<0.001$), and among all methods, WL (48.1%) and FL (51.2%) modes performed better than DR (30.4%, $p<0.001$). **Conclusion:** SoproLife® images could help clinicians to propose rational, minimally invasive treatments for occlusal caries lesions.

Keywords: Diagnostic Imaging; Clinical Decision-Making; X-Ray Microtomography; Dental Caries.

Introduction

Diagnosing the occlusal surface is still a challenge for clinicians in practice, but the current accuracy of visual examination in detecting the full extent of the lesions can be considered good if a well-established index is used by trained examiners [1]. However, results from another recent systematic review on the subject performed by the same authors pointed out that studies on the accuracy of the visual method for caries detection should consider clinically relevant outcomes [2] since a "correct" diagnosis made by clinicians is not necessarily translated into a direct benefit for patients in terms of more conservative treatment approaches [3]. The gap between an accurate diagnosis and a rational and minimally invasive operative treatment decision should be bridged if patient-centered outcomes are being put into the spotlight of evidence-based dentistry.

Clinical guidelines still recommend intraoral radiographs as an auxiliary method to the visual clinical examination in detecting caries lesions [4,5] with the claim that solely; its use may result in failure to detect some lesions. Therefore, the combination of both visual and radiographic methods would provide greater diagnostic sensibility while keeping good sensitivity [6]. However, although a digital radiographic examination is easy to perform and provides images in a few seconds, it has strict indications because of health risk hazards associated with ionizing radiation [7]. In this context, it is important to validate and implement diagnostic methods that do not use ionizing radiation sources to minimize exposure to patients and professionals [8,9]. Moreover, as mentioned, desirable clinical diagnostic aids should also improve treatment decisions towards more rational and minimally invasive approaches, resulting in a clear benefit for patients [2].

SoproLife® intraoral camera (Acteon Group Ltd., La Ciotat, France) is a light-induced fluorescence caries diagnostic system based on the auto-fluorescence of dental tissues when illuminated by a wavelength of 450 nanometers [10]. It offers two lighting modes: white and fluorescent (blue color). The fluorescent mode is indicated for caries diagnosis, with the colors blue and acid green indicating sound enamel and dentin, while the colors bright red and black green indicate the presence and activity of the lesion, active and inactive, respectively [11]. Caries activity assessments are essential to propose rational treatment plans for occlusal caries lesions because, for example, arrested caries generally do not need operative treatment [12].

To measure the sensitivity, specificity, and accuracy of digital diagnostic alternatives for caries, a micro-CT technique has been proposed as a gold standard to validate caries severity under laboratory conditions [13,14], especially because histological methods have low accuracy in detecting the real depth of dentin lesions [15]. Thus, the aim of the present *ex vivo* study was to compare the agreement on caries diagnosis and treatment decisions of occlusal surfaces images of permanent carious teeth obtained by SoproLife®, in white light and fluorescence mode, and digital radiographs, against a micro-CT gold standard. The hypothesis tested was that all caries diagnostic methods result in similar agreement when used for detecting/diagnosing lesions or when used to help define treatment decisions.

Material and Methods

Ethical Aspects and Study Design

This study was approved by the institution's Research Ethics Committee (#3.442.162). This was an in vitro accuracy study with a cross-sectional design, which followed the recommendations of the Standard for Reporting of Diagnostic Accuracy (STARD) steering committee [16].

Sample Power

Prior to the beginning of this study, a power calculation was performed using WinPepi v.11.65 [17] to estimate the sample size needed to compare the proportion of correct answers given by examiners using three diagnostic methods. For each individual evaluating 30 images of the same teeth (10 images per diagnostic method group), a total of 690 images of teeth would be needed to disclose significant results and thus, 23 individuals would have to be recruited for this study. This calculation would detect a 15% difference between the proportions of the methodologies as significant, with the estimated hit ratio of the image without fluorescence of 84.9% [18] with a power of 90% and a significance level of 5%. Approximately an extra 10% of images were added to this calculation to prevent possible losses, resulting in a total of 780 images of the same teeth, and thus, 26 examiners were needed for the present study.

Tooth Specimens

Initially, 20 third molars presenting enamel and/or dentin caries lesions on the occlusal surface ranging from ICDAS 2-4 [19], previously detected by an experienced and calibrated examiner (MMA), were selected from a biorepository organized for this specific study. Tooth specimens presenting enamel defects other than carious lesions (hypomineralization, hypoplasia, etc) were excluded from the sample. The selected teeth were kept in saline, to avoid dehydration for a maximum of three months before the start of the study [20]. Sound, restored or teeth presenting changes not related to carious involvement were not considered for the study.

Ten teeth were randomly drawn from this selection (page: https://sorteador.com.br/) and included in the sample (3 teeth with ICDAS 2, two with ICDAS 3 and five with ICDAS 4). After selection, the specimens were cleaned with ultrasonic tips to remove calculus and debris and were subsequently incorporated by the roots using utility wax on a plastic base to facilitate manipulation. Each specimen was placed in approximal contact with two other sound molars, one on each side, in order to simulate the position of a second permanent molar in the oral cavity, as shown in Figure 1. The 10 tooth specimens sets were kept in a closed container under 100% humidity conditions during the study.

Figure 1. Example of one sample assembled for photography and radiographic examination, simulating positions in the oral cavity.

Visual and Image-Based Examination

Acquisition of occlusal surface images was performed with the SoproLife® intraoral camera (Acteon Group Ltd., La Ciotat, France) using a dark box, both in white light (WL) and fluorescent light (FL) mode, with the flat surface of the camera slightly touching the occlusal surface of the tooth. In addition, digital radiographic (DR) images were acquired by means of an interproximal incidence, using a Focus® intraoral X-ray device (Instrumentarium Imaging, Tuusula, Finland) and a semi-direct digital system Kavo Express® (DK Equipamentos, São Paulo, Brazil).

The images were acquired by an experienced operator (LPS), exported in "TIFF" format and were later organized into presentation blocks in a PowerPoint® template (Office 365, Microsoft Corporation, United States) in order to be scored by the examiners. All examinations were performed using the same computer (Dell notebook, model Inspiron 5570, Dell, Brazil) in the same location, using identical brightness and contrast settings for all participants. The monitor was placed on a flat surface, which could not be moved and the focal distance between the evaluator and the monitor was 40 centimeters. The images were presented in sequence to one examiner at a time, who should keep them confidential from the others.

The PowerPoint® template presentation was divided into three blocks in the following sequence: (1) 10 digital radiographs; (2) 10 images in WL; (3) 10 images in FL. For each presentation block, the images were presented in turn, from the first to the tenth image, after which a new presentation block was started. Within each presentation block, the images were mixed (page: https://sorteador.com.br/) to avoid sequential bias on the part of the examiners.

The examiners were instructed to score the images of the occlusal surface of each selected tooth in each set (middle tooth) acquired with each method (DR, WL and FL) using a modified dental caries scores (Table 1). These scores included just five simple progressive categories, from sound surfaces to dentin cavitation. After that, and for each tooth specimen image, the examiners should also score one best treatment option for each examined tooth (no specific treatment, preventive treatment, non-operative and operative treatment) based on the most recent and comprehensive guidelines [21] (Table 1).

Table 1. Scores for dental caries and treatment options used by the examiners to evaluate the sample.

Dental Caries Scores	Description
0	Sound teeth surface
1	Enamel-limited demineralization without enamel cavitation
2	Enamel-limited demineralization with enamel cavitation
3	Dentin demineralization without dentin cavitation
4	Dentin demineralization with dentin cavitation
Treatment Options Scores	
0	No specific treatment
1	Preventive treatment (patient education and oral hygiene instructions)
2	Non-operative treatment (fluoride varnish and/or sealant applications)
3	Operative treatment (caries removal and restoration)

Selection of Examiners

From a universe of thirty dentists working in a public clinical setting, twenty-six with routine experience of diagnosing carious lesions, but without a specific academic background in the field of Cariology were approached by convenience and were invited to participate in the study. They all provided their written consent before enrolling in the study procedures. Sociodemographic data were collected, such as gender, educational level (specialist, master, and Ph.D.), age and time since graduation. They were individually provided with a 10-minute explanation of how to score the tooth images using the proposed scores (Table 1) and the interpretation of the fluorescent colors.

Gold Standard for Dental Caries and Treatment Options

After the acquisition of the occlusal surface images and radiographs, the teeth were scanned in a high-energy 1173 micro-CT (Bruker Belgium SA, Kontich, Belgium) using the following acquisition parameters: 100kV, 80μA, 6.47μm pixel size, 1mm thick Al filter, 1s exposure, 0.5° rotation step at 360°, and 20 lines random movements. After this, the acquired projections were reconstructed using the NRecon software (version 1.7.0.4, NRecon, Bruker Corporation, Billerica, MA, USA) using standardized parameters: ring artifact correction (10), beam hardening correction (52%), and standardized contrast limits between 0 and 0.05. After reconstruction, the teeth were aligned with the occlusal surface parallel to the ground using a dedicated software (Data Viewer, Bruker Corporation, Billerica, MA, USA) and the slice with the deepest part of the lesion was detected. This slice was classified according to the dental caries scores presented in Table 1 by an experienced operator (LPS), and defined as the gold standard for caries presence in this study (Figure 2).

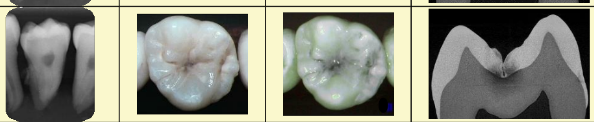
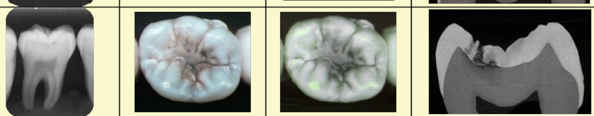
	Digital images			Gold standard		
Tooth	DR	WL	FL	Micro-CT representative slice	Dental caries score	Treatment decision scores
1					1	1, 2
2					3	1, 2
3					3	1, 2
4					3	1, 2
5					3	1, 2
6					4	3
7					4	3
8					4	3
9					3	1, 2
10					3	1, 2

Figure 2. DR, WL, and FL images of the selected teeth, their respective representative slices, gold standard classification of caries lesions and respective treatments.

Possible gold standard for treatment options were defined based on the summary of the best available evidence [21]. Table 2 shows corresponding matched dental caries and treatment option scores.

Table 2. Gold standard treatment options related to the dental caries scores.

Dental Caries Scores	Treatment Options Scores
0	0, 1
1	1, 2
2	1, 2
3	1, 2
4	2, 3

Statistical Analysis

Categorical variables related to demographic data of the examiners were represented by absolute and relative frequencies. The variable "age" and "time since graduation" were represented by mean, standard deviation (SD) and amplitude. The Generalized Estimation Equations model (GEE Model) [22,23] was used to compare the proportions of the correct answers between the three methods evaluated by the same examiner. This analysis was chosen because it considers related samples. The model was composed by an independent work correlation matrix, and a robust estimator covariance matrix. When significant, the Bonferroni post-hoc test was used to identify the different categories. The level of significance adopted was 5%. All analyses were performed in SPSS software, version 25.0 (IBM Corporation, Armonk, NY, USA).

Results

Most of the examiners were female, (n=21; 80.8%), with an average age of 38.4 years. The most prevalent education level was that of specialist (n=20; 76.9%), with a mean of 14.5 years of experience, as shown in Table 3.

Table 3. Socio-demographic characterization of the evaluators (n=26).

Variables	N (%)	
Gender		
Female	21 (80.8)	
Male	5 (19.2)	
Education Level		
PhD	1 (3.8)	
Specialist	20 (76.9)	
Master	5 (19.2)	
	Mean (SD)	**Min-Max**
Age (Years)	38.4 (5.6)	31-53
Graduate Time (Years)	14.5 (5.4)	8-28

SD = Standard Deviation.

Figure 2 illustrates the teeth included in the study, its respective DR, WL and FL images, and the corresponding micro-CT slice showing the deepest part of the caries lesion. For each tooth, the gold standard dental caries and treatment options scores are also detailed.

Table 4 shows a comparison of the proportions of correct answers (as agreed with the gold standard scores) given by the examiners on the diagnosis of caries at the occlusal surface of the specimens. In general, no difference was found among the three methods (p=0.415), with a general low agreement (mean 15.3%) between the assigned caries scores and the gold standard for caries diagnosis. However, in tooth 6 (ICDAS 4), the evaluators responded better to the images in WL (50% correct answers) compared to DR (15.4%) and FL (19.2%) while in tooth 8 (ICDAS 4), DR underperformed compared to FL, while this was better than WL. As tooth 4 (ICDAS 3) resulted in no correct answers for DR and FL, it was not possible to estimate the p-value.

Table 4. Comparison of the proportions of correct answers in the diagnosis of occlusal caries in each tooth and diagnostic method.

Tooth	All Methods % [IC 95%]	Methods DR (n=26) % [IC 95%]	WL (n=26) % [IC 95%]	FL (n=26) % [IC 95%]	p-value
1	15.4 [8.7; 24.6]	11.5 [3.4; 28.5]	7.7 [1.6; 23.7]	26.9 [12.9; 46.1]	0.163
2	5.1 [1.8; 11.7]	3.8 [0.4; 18.9]	7.7 [1.6; 23.7]	3.8 [0.4; 18.9]	0.789
3	11.5 [5.9; 20]	15.4 [5.4; 33.2]	0 [0; 0]	19.2 [7.7; 37.6]	0.739
4	2.6 [0.5; 8]	0 [0; 0]	7.7 [1.6; 23.7]	0 [0; 0]	-
5	29.5 [20.3; 40.2]	30.8 [15.7; 50.1]	34.6 [18.6; 54]	23.1 [10.2; 41.9]	0.588
6	28.2 [19.1; 38.8]	15.4[a] [5.4; 33.2]	50[b] [31.5; 68.5]	19.2[a] [7.7; 37.6]	0.003
7	5.1 [1.8; 11.7]	3.8 [0.4; 18.9]	7.7 [1.6; 23.7]	3.8 [0.4; 18.9]	0.52
8	20.5 [12.7; 30.4]	7.7[a] [1.6; 23.7]	15.4[ab] [5,4; 33,2]	38.5[b] [21,7; 57,8]	0.005
9	15.4 [8.7; 24.6]	26.9 [12.9; 46.1]	7.7 [1.6; 23.7]	11.5 [3.4; 28.5]	0.217
10	19.2 [11.7; 29]	11.5 [3.4; 28.5]	26.9 [12.9; 46.1]	19.2 [7.7; 37.6]	0.353
Mean	15.3 [12.9; 17.9]	12.7 [8.8; 17.7]	16.5 [11.7; 22.5]	16.5 [12.4; 21.4]	0.415

DR = Digital Radiographic; WL: White Light; FL: Fluorescent Light; GEE Model: The Generalized Estimation Equations model; TP = Total Proportion; Post-hoc comparison using the Bonferroni test; Different letters represent statistically different proportions; IC95% = 95% Confidence Interval.

Table 5 shows the comparison of the proportions of correct answers given by the evaluators in relation to treatment decisions proposed for the specimens. The mean percentage of correct answers among the methods was higher for WL (48.1%) and LF (51.2%) compared to DR (30.4%) ($p<0.001$). The total proportion of correct answers was different among the methods also in teeth 4, 6 and 8 ($p<0.05$). For tooth 4 (ICDAS 3), the examiners responded better to the images in WL (88.5%) and FL (80.8%) compared to DR (11.5%). For tooth 6 (ICDAS 4), the evaluators responded better to the images in WL (84.6%) compared to FL (53.8%), but without difference from DR (57.7%). As for tooth 8 (ICDAS 4), the evaluators responded better to the images in FL (88.5%) compared to DR (34.6%) and WL (50%). The remaining teeth did not show a more assertive method.

Table 5. Comparison of the proportions of correct answers in the treatment decision.

Tooth	All Methods % [IC 95%]	Methods DR (n=26) % [IC 95%]	WL (n=26) % [IC 95%]	FL (n=26) % [IC 95%]	p-value
1	51.3 [40.3; 62.2]	50 [31.5; 68.5]	50 [31.5; 68.5]	53.8 [35; 71.9]	0.823
2	39.7 [29.4; 50.8]	26.9 [12.9; 46.1]	38.5 [21.7; 57.8]	53.8 [35; 71.9]	0.089
3	33.3 [23.6; 44.3]	23.1 [10.2; 41.9]	42.3 [24.9; 61.4]	34.6 [18.6; 54]	0.281
4	60.3 [49.2; 70.6]	11.5[a] [3.4; 28.5]	88.5[b] [71.5; 96.6]	80.8[b] [62.4; 92.3]	<0.001
5	28.2 [19.1; 38.8]	11.5 [3.4; 28.5]	38.5 [21.7; 57.8]	34.6 [18.6; 54]	0.086
6	65.4 [54.4; 75.2]	57.7[ab] [38.6; 75.1]	84.6[a] [66.8; 94.6]	53.8[b] [35; 71.9]	0.005
7	17.9 [10.7; 27.5]	11.5 [3.4; 28.5]	23.1 [10.2; 41.9]	19.2 [7.7; 37.6]	0.602
8	57.7 [46.6; 68.2]	34.6[a] [18.6; 54]	50[a] [31.5; 68.5]	88.5[b] [71.5; 96.6]	<0.001
9	38.5 [28.2; 49.5]	38.5 [21.7; 57.8]	26.9 [12.9; 46.1]	50 [31.5; 68.5]	0.259
10	39.7 [29.4; 50.8]	38.5 [21.7; 57.8]	38.5 [21.7; 57.8]	42.3 [24.9; 61.4]	0.949
Mean	43.2 [39.8; 46.7]	30.4[a] [24; 37.5]	48.1[b] [42.3; 53.9]	51.2[b] [44.7; 57.6]	<0.001

DR = Digital Radiographic; WL: White Light; FL: Fluorescent Light; GEE Model: The Generalized Estimation Equations model; TP = Total Proportion; Different letters represent statistically different proportions; IC95% = 95% Confidence Interval.

Discussion

The results of the present study confirm that imaging methods alone underperform in the diagnosis of occlusal caries, with a general low mean of correct hits (15.3%) based on the golden standard used. However, regarding treatment options, the image obtained by the intraoral camera in WL (48.1%) or FL (51.2%) resulted in statistically significant higher correct hits than DR alone in establishing an acceptable treatment plan. Thus, these imaging methods have aided the examiners in making rational treatment decisions for occlusal caries based on minimally invasive approaches.

The reasons for the low agreement among the diagnostic methods in relation to the diagnosis of caries are probably related to the definition of lesion severity provided by the golden standard used in the present study (microtomography). Although histological processing and analysis is still used as a gold standard for dental caries detection, it is fundamentally a destructive method because it requires sectioning of the sample for microscopic examination. Therefore, the micro-CT technique used as the golden standard in the present study has been recently proposed and validated to define caries severity under laboratory conditions [13,14,24,25], especially because histological methods have generally low accuracy in detecting the depth of dentin lesions [15].

Evaluation of tooth 4 (ICDAS 3) resulted in no correct answers for caries diagnosis for DR and FL. This could be explained by the fact that a small dentin demineralization area, very near to the threshold between ICDAS 2 and 3, was detected by the micro-CT. This technique has, indeed an improved accuracy in detecting the actual depth of the lesion [24]. However, in line with the general findings of this study, treatment decisions were much better scored using the WL (88.5%) and FL (80.8%) mode, compared to the DR (11.5%) mode ($p<0.001$).

Tooth 6 (ICDAS 4) resulted in a better agreement for caries diagnosis when WL was used and this was probably because the FL pushed the diagnosis towards the activity of the lesion (inactive – color black). Another study has, in fact, not been able to confirm the validity of SoproLife® in determining the actual lesion activity [20]. Caries severity and activity are two different criteria and ideally, treatment options should include both. However, in tooth 6, the enamel cavitation evidenced by WL favored the correct treatment decision – operative treatment focused on the cavitation.

Tooth 8 (ICDAS 4) was favored by the FL mode also due to the lesion activity. In this tooth, the red color of the dentin cavitation area would have called the attention of the examiner towards more correct hits for caries diagnosis and treatment decisions. For the other teeth, no statistically significant differences were detected, but in general, FL and WL resulted in higher correct hits for treatment decisions in the present study.

Fluorescent caries diagnostic devices are considered attractive for their simplicity of use, compact size and absence of exposure to radiation [26]. By combining the advantages of a fluorescent device with an intraoral camera, SoproLife® proves to be a non-destructive and clinically applicable diagnostic method to aid in caries detection. In fact, compared to a gold standard visual examination based on ICDAS, sensitivity values of both SoproLife® imaging modes range from 0.75-0.86 while specificity values are around 0.81-0.89 [27,28]. Indeed, SoproLife® has an acceptable accuracy in detecting the presence (sensitivity) and absence (specificity) of lesions [29], but the gold standard caries detection used are based on clinically scored teeth. In the present study, however, no sensitivity/specificity values were calculated. We have rather employed an agreement evaluation using a laboratory and “true” gold standard for caries detection, as mentioned before.

Although the location where the images were presented was the same for all examiners, with the screen calibrated with the same amplitude and brightness, there were still concerns expressed by the examiners regarding the difficulty in detecting occlusal caries through digital images in view of the activity and depth of pigmented grooves. Although most professional evaluators were specialists (n=20; 76%) with experience in caries diagnosis, they reported a lack of intimacy with the digital fluorescent device and the practice of diagnosing and treatment decision for occlusal caries using digital images. A previous study reported that the ability to evaluate intraoral photographs on a screen at a convenient time and place was considered advantageous by a cohort of dentists with experience in epidemiological studies [30] and to facilitate distance diagnosis, such as remote and difficult to access areas [31].

The limitations of this study include the *ex vivo* conditions in which the evaluations were carried out, that may be different from the *in vivo* dynamic complex of caries initiation and arrestment. Indeed, it is known that caries activity detection can be facilitated in the clinical situation when characteristics such as biofilm accumulation and gingival inflammation can be used as surrogates to whether the lesion is active or inactive [32]. However, it is still possible to detect caries activity by considering some lesion characteristics, such as luster, roughness and staining of the surface [33], and these characteristics were considered in the present study. Moreover, treatment decision gold standards in the present study were broader (more options) due to the nature of the minimally invasive approaches, what could have influenced higher agreement for treatment decisions compared to caries diagnosis. Finally, it is important to mention that the initial implementation costs generally associated with improved imaging detection methods may soon be worth its effectiveness in reducing the cost of care and preventing unnecessary operative treatments for the patient and the healthcare services.

Conclusion

The total proportion of correct answers was greater for all diagnostic methods relative to the treatment decisions compared to the current diagnosis of carious lesion in permanent molars. White-light or fluorescent SoproLife® images may help clinicians to propose rational minimally invasive treatments for occlusal caries lesions.

Authors' Contributions

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All authors declare that they contributed to critical review of intellectual content and approval of the final version to be published.

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Conflict of Interest

The authors declare no conflicts of interest.

Data Availability

The data used to support the findings of this study can be made available upon request to the corresponding author.

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References

[1] Gimenez T, Piovesan C, Braga MM, Raggio DP, Deery C, Ricketts DN, et al. Visual inspection for caries detection: a systematic review and meta-analysis. J Dent Res 2015; 94(7):895-904. https://doi.org/10.1177/0022034515586763
[2] Gimenez T, Piovesan C, Braga MM, Raggio DP, Deery C, Ricketts DN, et al. Clinical relevance of studies on the accuracy of visual inspection for detecting caries lesions: a systematic review. Caries Res 2015; 49(2):91-8. https://doi.org/10.1159/000365948
[3] Mendes FM, Novaes TF, Matos R, Bittar DG, Piovesan C, Gimenez T, et al. Radiographic and laser fluorescence methods have no benefits for detecting caries in primary teeth. Caries Res 2012; 46(6):536-43. https://doi.org/10.1159/000341189
[4] Kuhnisch J, Ekstrand KR, Pretty I, Twetman S, van Loveren C, Gizani S, et al. Best clinical practice guidance for management of early caries lesions in children and young adults: an EAPD policy document. Eur Arch Paediatr Dent 2016; 17(1):3-12. https://doi.org/10.1007/s40368-015-0218-4
[5] Martignon S, Pitts NB, Goffin G, Mazevet M, Douglas GVA, Newton JT, et al. CariesCare practice guide: consensus on evidence into practice. Br Dent J 2019; 227(5):353-62. https://doi.org/10.1038/s41415-019-0678-8
[6] Pontes LR, Novaes TF, Lara JS, Gimenez T, Moro BL, Camargo LB, et al. Impact of visual inspection and radiographs for caries detection in children through a 2-year randomized clinical trial: the caries detection in children-1 study. J Am Dent Assoc 2020; 151(6):407-15.e1. https://doi.org/10.1016/j.adaj.2020.02.008
[7] American Academy Pediatric Dentistry. Guidelines on prescribing dental radiographs for infants, children, adolescents, and individuals with special health care needs. Pediatr Dent 2017;39(6):205-7.
[8] Schaefer G, Pitchika V, Litzenburger F, Hickel R, Kuhnisch J. Evaluation of occlusal caries detection and assessment by visual inspection, digital bitewing radiography and near-infrared light transillumination. Clin Oral Investig 2018; 22(7):2431-38. https://doi.org/10.1007/s00784-018-2512-0
[9] Macey R, Walsh T, Riley P, Glenny AM, Worthington HV, Fee PA, et al. Fluorescence devices for the detection of dental caries. Cochrane Database Syst Rev 2020; 12(12):CD013811. https://doi.org/10.1002/14651858.CD013811
[10] Terrer E, Koubi S, Dionne A, Weisrock G, Sarraquigne C, Mazuir A, et al. A new concept in restorative dentistry: Light-induced fluorescence evaluator for diagnosis and treatment. Part 1: Diagnosis and treatment of initial occlusal caries. J Contemp Dent Pract 2009; 10(6):E086-94.
[11] Terrer E, Raskin A, Koubi S, Dionne A, Weisrock G, Sarraquigne C, et al. A new concept in restorative dentistry: LIFEDT-light-induced fluorescence evaluator for diagnosis and treatment: part 2 - treatment of dentinal caries. J Contemp Dent Pract 2010; 11(1):E095-102.
[12] Banerjee A. Minimum intervention oral healthcare delivery - is there consensus? Br Dent J 2020; 229(7):393-95. https://doi.org/10.1038/s41415-020-2235-x
[13] Neves AA, Coutinho E, Vivan Cardoso M, Jaecques SV, Van Meerbeek B. Micro-CT based quantitative evaluation of caries excavation. Dent Mater 2010; 26(6):579-88. https://doi.org/10.1016/j.dental.2010.01.012
[14] Oliveira LB, Massignan C, Oenning AC, Rovaris K, Bolan M, Porporatti AL, et al. Validity of micro-CT for in vitro caries detection: A systematic review and meta-analysis. Dentomaxillofac Radiol 2020; 49(7):20190347. https://doi.org/10.1259/dmfr.20190347
[15] de Sousa FB, da Silva PF, Chaves AM. Stereomicroscopy has low accuracy for detecting the depth of carious lesion in dentine. Eur J Oral Sci 2017; 125(3):229-31. https://doi.org/10.1111/eos.12350
[16] Bossuyt PM, Reitsma JB, Bruns DE, Gatsonis CA, Glasziou PP, Irwig LM, et al. Towards complete and accurate reporting of studies of diagnostic accuracy: the STARD initiative. BMJ 2003; 326(7379):41-4. https://doi.org/10.1136/bmj.326.7379.41
[17] Abramson JH. WINPEPI updated: Computer programs for epidemiologists, and their teaching potential. Epidemiol Perspect Innov 2011; 8(1):1. https://doi.org/10.1186/1742-5573-8-1
[18] Carvalho RN, Letieri AD, Vieira TI, Santos T, Lopes RT, Neves AA, et al. Accuracy of visual and image-based ICDAS criteria compared with a micro-CT gold standard for caries detection on occlusal surfaces. Braz Oral Res 2018; 32:e60. https://doi.org/10.1590/1807-3107bor-2018.vol32.0060
[19] Ismail AI, Sohn W, Tellez M, Amaya A, Sen A, Hasson H, et al. The International Caries Detection and Assessment System (ICDAS): an integrated system for measuring dental caries. Community Dent Oral Epidemiol 2007; 35(3):170-8. https://doi.org/10.1111/j.1600-0528.2007.00347.x
[20] Drancourt N, Roger-Leroi V, Pereira B, Munoz-Sanchez ML, Linas N, Vendittelli F, et al. Validity of Soprolife camera and Calcivis device in caries lesion activity assessment. Br Dent J 2020. https://doi.org/10.1038/s41415-020-2316-x
[21] Banerjee A, Frencken JE, Schwendicke F, Innes NPT. Contemporary operative caries management: consensus recommendations on minimally invasive caries removal. Br Dent J 2017; 223(3):215-22. https://doi.org/10.1038/sj.bdj.2017.672
[22] Zeger SL, Liang KY. Longitudinal data analysis for discrete and continuous outcomes. Biometrics 1986; 42(1):121-30.
[23] Guimarães LS, Hirakata VN. Use of the generalized estimating equation model in longitudinal data analysis. Rev HCPA 2012; 32(4):503-11.
[24] Soviero VM, Leal SC, Silva RC, Azevedo RB. Validity of MicroCT for in vitro detection of proximal carious lesions in primary molars. J Dent 2012; 40(1):35-40. https://doi.org/10.1016/j.jdent.2011.09.002

[25] Ozkan G, Kanli A, Baseren NM, Arslan U, Tatar I. Validation of micro-computed tomography for occlusal caries detection: an in vitro study. Braz Oral Res 2015; 29(1):S1806-83242015000100309. https://doi.org/10.1590/1807-3107BOR-2015.vol29.0132
[26] Gimenez T, Braga MM, Raggio DP, Deery C, Ricketts DN, Mendes FM. Fluorescence-based methods for detecting caries lesions: systematic review, meta-analysis and sources of heterogeneity. PLoS One 2013; 8(4):e60421. https://doi.org/10.1371/journal.pone.0060421
[27] Muller-Bolla M, Joseph C, Pisapia M, Tramini P, Velly AM, Tassery H. Performance of a recent light fluorescence device for detection of occlusal carious lesions in children and adolescents. Eur Arch Paediatr Dent 2017; 18(3):187-95. https://doi.org/10.1007/s40368-017-0285-9
[28] Terrer E, Slimani A, Giraudeau N, Levallois B, Tramini P, Bonte E, et al. Performance of Fluorescence-based Systems in Early Caries Detection: A Public Health Issue. J Contemp Dent Pract 2019; 20(10):1126-31.
[29] Domejean S, Rongier J, Muller-Bolla M. Detection of occlusal carious lesion using the SoproLife® camera: a systematic review. J Contemp Dent Pract 2016; 17(9):774-79. https://doi.org/10.5005/jp-journals-10024-1928
[30] Boye U, Foster GR, Pretty IA, Tickle M. The views of examiners on the use of intra-oral photographs to detect dental caries in epidemiological studies. Community Dent Health 2013; 30(1):34-8.
[31] Kohara EK, Abdala CG, Novaes TF, Braga MM, Haddad AE, Mendes FM. Is it feasible to use smartphone images to perform telediagnosis of different stages of occlusal caries lesions? PLoS One 2018; 13(9):e0202116. https://doi.org/10.1371/journal.pone.0202116
[32] Kidd EA, Fejerskov O. What constitutes dental caries? Histopathology of carious enamel and dentin related to the action of cariogenic biofilms. J Dent Res 2004; 83 Spec No C:C35-8. https://doi.org/10.1177/154405910408301s07
[33] Thylstrup A, Bruun C, Holmen L. In vivo caries models: Mechanisms for caries initiation and arrestment. Adv Dent Res 1994; 8(2):144-57. https://doi.org/10.1177/08959374940080020401