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REVIEW ARTICLE

Adjunct methods for caries detection: A systematic review of literature

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Abstract

Objective. To assess the diagnostic accuracy of adjunct methods used to detect and quantify dental caries. ***Study design.*** A systematic literature search for relevant papers was conducted with pre-determined inclusion and exclusion criteria. Abstracts and full text articles were assessed independently by two reviewers. The study characteristics were compiled in tables and quality graded according to the QUADAS tool. The level of evidence for each diagnostic technology (fiber-optic methods, fluorescence methods, electrical methods) was based on studies of high or moderate quality according to the GRADE approach. ***Results.*** Twenty-five reports fulfilled the inclusion criteria. One study was of high quality, 10 were graded as moderate, while the remaining 14 reports were of low quality. Electrical methods (ECM) and laser fluorescence (DIAGNOdent) displayed sensitivities and specificities around 70–80% regarding occlusal dentin lesions with a mean Youden's index of 0.52–0.54. The mean accuracy of laser fluorescence for detecting enamel and dentin lesions was 0.68 and 0.91, respectively. The heterogeneity of the published reports hampered the analysis. ***Conclusions.*** There was insufficient scientific evidence for diagnostic accuracy regarding fiber-optic methods and quantitative light-induced fluorescence (+OOO). The electrical methods and laser fluorescence could be useful adjuncts to visual-tactile and radiographic examinations, especially on occlusal surfaces in permanent and primary molars, but evidence was graded as limited (++OO). No conclusions could be drawn regarding the cost-effectiveness of the methods. There is an obvious need to standardize study designs for in vitro and in vivo validation of the different methods.

Key Words: *accuracy, dental caries, diagnostic accuracy, sensitivity, specificity*

Introduction

Caries is a common biofilm-mediated chronic disease that affects all ages [1]. Untreated, it can lead to pain, loss of teeth and impaired quality-of-life. The development of a caries lesion is the result of a complicated interplay of many factors. In most cases, caries develops slowly and the process may arrest spontaneously. However, the disease is not usually self-limiting and without adequate treatment the process can continue until the tooth is destroyed. Therefore, there is increasing emphasis on the importance of effective early intervention [2] and a prerequisite is reliable assessment of the presence and activity of a lesion at an early non-cavitated stage of the disease process.

The term 'caries' is used to embrace both the disease process and its consequences, i.e. the tissue damage caused by the disease process. Traditionally, only frank cavities within the dentin were registered with the aid of visual examination and radiographs, exhibiting a fair sensitivity and high specificity [3]. Adjunct methods based on fiber-optics, fluorescence or electrical impedance have been developed and introduced during the past decades. Their accuracy and reliability has been reviewed in many recent excellent papers [4–10], but the use and value in everyday practice is, however, still disputed. The purpose of the present systematic review of literature, initiated by The Swedish Council on Health Technology Assessment [11], was to assess the scientific evidence with reference to the following questions: (i)

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How effective are different adjunct methods for disclosing the presence of a caries lesion, compared with a reference method?, (ii) Are there side-effects or risks associated with the methods reviewed? and (iii) Which diagnostic method is the most cost-effective?

Methods

Literature search and selection of articles

The electronic literature search was performed by an information specialist and included the databases PubMed, The Cochrane Central Register of Controlled Trials and Cochrane Reviews from January 1985 to April 2005. An additional search was made in May 2011. Articles in English, German, Danish, Norwegian and Swedish were accepted. The complete search strategy is given Table I. The electronic searches resulted in 194 abstracts that were evaluated independently by two reviewers (STw and STr). An article was read in full text if at least one examiner considered the abstract to be of potential relevance. In addition to the electronic search, hand search was made and references of narrative reviews, text books and articles in international journals not identified in the main search were included. The hand search resulted in two additional articles. Grey literature was not included. The pre-determined inclusion/exclusion criteria are given in Table II. Altogether 125 articles were read in full text and assessed independently by the same two reviewers. If a reviewer was co-author of a paper, a third person performed the evaluation. One hundred publications did not fulfil the inclusion criteria and were excluded from further analysis. A list of the excluded articles together with the main reason for exclusion is presented in Supplementary Appendix A [A1–A69]

Table I. Terms and strategies for the Pubmed-Medline and Cochrane-Central search.

Dental Caries/ diagnosis	AND	Fluorescence		
Dental Caries activity tests		FOTI/TW	AND	Trans Illumination/ TW
		Fiber Optics		Trans Illumination/ TW
		Electric Conductivity		
Limit: English/LA				
German/LA				
Danish/LA				
Norwegian/LA				
Swedish/LA				
Human				

Table II. Pre-determined inclusion criteria.

Studies on extracted teeth	Clinical studies
Method available to the clinician	Method available to the clinician
≥60 teeth	≥30 teeth
—	Description of population and selection criteria
Disease prevalence given	Disease prevalence given
At least three observers/examiners	At least two observers/ examiners
Histological evaluation	Some form of validation, at least radiographical
Sensitivity/specificity reported*	Sensitivity/specificity reported
Other end-points: prediction, likelihood	Other end-points: prediction, likelihood

*For studies of QLF, correlation was accepted.

for studies in vitro and Supplementary Appendix B [B1–B32] for clinical investigations.

Quality rating and level of evidence

The remaining reports (n = 25) included in this review were assessed using the QUADAS tool [12]. Each included study was rated as being of high, moderate or low quality according to pre-specified criteria presented in Table III. The diagnostic accuracy (validity) of a test (index test) required a reference standard (reference test) for comparison. The main outcome measures were sensitivity and specificity of the individual studies, simply because these values were the most commonly reported. Sensitivity relates to the ability of the detection method to identify positive results and was defined as the number of true positive tests divided by the total number of positive cases. Conversely, specificity was the number of true negative tests divided by the total number of non-diseased (healthy) cases and expressed the ability of the detection method test to identify negative results. Any disagreements on inclusion/exclusion criteria, rating quality of individual studies or quality of evidence of test methods were solved by consensus within the working group.

The quality of evidence of the diagnostic accuracy of each method/test was graded in four levels according to GRADE [13].

- High (⊕⊕⊕⊕). Based on high or moderate quality studies containing no factors that weaken the overall judgement.
- Moderate (⊕⊕⊕○). Based on high or moderate quality studies containing isolated factors that weaken the overall judgement.
- Limited (⊕⊕○○). Based on high or moderate quality studies containing factors that weaken the overall judgement.

Table III. Criteria of high, moderate and poor study quality, mainly according to QUADAS [12].

High: small risk of bias	• Adequately described teeth or patients involving a representative and clinically relevant sample • Independent and blinded comparison between the index test and the reference test • Different categories of teeth included • Observer reliability test presented • Histological validation of all teeth • Validation reliability tested • Small and explained drop-out
Moderate: moderate risk of bias	• Less adequately described teeth or patients involving a representative and clinically relevant sample • Partly independent and comparison between the index test and the reference test or independence or blinding not described • One category of teeth included • Observer reliability test partly performed • Histological validation of all teeth • Validation reliability partly tested • Drop-out not explained
Poor: high risk of selection and/or verification bias	• Description of teeth or patients unclear • Description of categories of teeth included unclear • Observer reliability test not performed or reported • Other type of validation • Validation reliability partly tested • Drop-out not explained

- Insufficient (⊕OOO). The evidence base is insufficient when scientific evidence is lacking, quality of available studies is poor or studies of similar quality are contradictory.

Statistical methods

Data were processed with the IBM-SPSS software (version 19.0, Chicago, IL) for descriptive analyses.

Results

Twenty-five reports from 23 publications fulfilled the inclusion criteria [14–36]. Their main characteristics and quality rating are presented in Tables IV,V,VI. One study was assessed of high quality, 10 were of moderate quality and the remaining 14 were graded as being of low quality. A summary of the findings with the various adjunct methods are presented in Table VII. No information concerning the economical aspects on caries detection with any of the adjunct methods was identified.

Fiber-optic methods (FOTI and DiFOTI)

Four publications on FOTI and occlusal caries detection were included, as presented in Table IV [14–17]. Only one of the studies was considered of moderate quality [15], the rest were assessed as low. The specificity was clearly higher than the sensitivity in three of the studies. The exception was DIFOTI for proximal cavitations in adults [14]. Due to the low number and quality of the trials, the level of evidence was graded as insufficient.

Laser fluorescence (DIAGNOdent)

Studies on extracted teeth. Five studies fulfilled the inclusion criteria [17,24,28,30,32], of which one was of high quality [24] and two [30,32] of moderate quality (Table V). A relatively high sensitivity (~ 80%) for both enamel and dentin caries detection was reported, while the specificity was low for enamel caries and moderate for caries lesions in the dentin.

Clinical studies. Twelve publications were included [18-23,25-27,29,31,32], of which seven dealt with caries detection on occlusal surfaces of primary [25] and permanent molars [18,19,21,22,29,31]. Two of the latter were of moderate quality, albeit restricted to third molars from the same study population. Also, two studies on primary molars were of moderate quality, but the findings were not in harmony with those from the permanent dentition. For occlusal dentin caries in permanent teeth, the sensitivity was higher than the specificity (75% vs 55%), whereas it was the other way around for the primary teeth (73% vs 95%). The results concerning enamel caries detection were similarly contradictive. As a general rule, the laser fluorescence technique displayed mean sensitivities and specificities around 70–80% with respect to enamel and non-cavitated occlusal caries lesions (Table VII). Youden's index on dentin level was 0.54. The mean accuracy, as reported in six papers, for detecting enamel and dentine lesions was 0.68 (SD = 0.09) and 0.91 (SD = 0.07), respectively. Since the moderate-quality reports pointed in somewhat different directions, we found limited evidence for the laser fluorescence method. The fact that the clinical materials were rather small and the contrasting findings between for permanent and primary teeth call for further studies for safe conclusions.

Quantitative light-induced fluorescence (QLF)

The high reliability of the quantitative light-induced fluorescence method has been established in a

Table IV. List of included studies with FOTI or DIFOTI.

Reference, Country	Study design	Blinding	Number of observers	Observer reliability	Population, material	Caries prevalence and type of lesions	Number of individuals, Number of teeth	Drop-out/missing data	Method or technique	Reference method	End-point measure	Results enamel caries	Results dentin caries	Quality and relevance comments
Bin-Shuwaish et al. [14] Saudi-Arabia	Validity, *In vivo*	No	2	NR	Patients at a dental school	100% interproximal lesion to or beyond DEJ. No frank cavitations	n = 21 51 surfaces	NR	DIFOTI	Clinical excavation	Sensitivity, specificity, correlation	NR	SE: 0.84 Proximal cavitation: SE: 0.83 SP: 0.15 Corr: 0.43	Low No reliability test and no blinding
Hintze et al. [15] Denmark	Validity, *In vivo*	Yes	4	Kappa: Inter: 0.14–0.26	Dental students	7% cavitated	n = 53 338 surfaces	52 surfaces	FOTI	Separation and visual inspection	Sensitivity, specificity, NPV, PPV	NR	SE: 0.04 (0.01–0.28) SP: 0.99 (0.97–1.0) NPV: 0.94 PPV: 0.33	Moderate
Grossman et al. [16] South Africa	Validity, *In vitro*	Yes	4	Repeated diagnoses but reliability not reported	Extracted teeth	42% sound 26% enamel 32% dentin	139 teeth/surfaces	NR	FOTI	Histology Kappa: 0.82	Sensitivity, specificity	SE: 0.39 SP: 0.92	SE: 0.54 SP: 0.90	Low Insufficient description of material and methods
Manton & Messer [17] Australia	Validity, *In vitro*	NR	6	NR	Extracted 3rd molars	% cavitated	67 teeth, 204 surfaces, occlusal sites	NR	FOTI	Histology	Sensitivity, specificity correlation	NR	SE: 0.36 SP: 0.93 Corr: 0.42	Low

DEJ, dentin-enamel junction; DIFOTI, Digitized fiberoptic transillumination; FOTI, fiberoptic transillumination; NR, not reported; NPV, Negative predictive value; PPV, Positive predictive value; SE, sensitivity; SP, Specificity.

number of trials [9,10], but none of the published papers identified in the literature search could be included in the present review. The main reason was that the QLF-method hitherto has been applied as a research tool for measuring the effect of various preventive measures on enamel de- and remineralization. Studies with histological or radiological validation according to inclusion criteria were simply lacking.

Electrical methods

Four studies with Electrical Caries Monitoring (ECM) were included [33–36], of which three were of moderate quality (Table VI). One was clinical [34] and two were conducted on extracted teeth [33,35]. The fourth study was assessed as being of low quality [36]. For dentin caries detection, the moderate rated studies exhibited a sensitivity ranging between 57–90%, but the latter value was obtained for more advanced lesions [33]. The specificity was also high in the publications based on extracted teeth (85%), while it was considerably lower in the clinical trial (62%). The mean Youden's index was 0.52. Collectively, there was limited evidence for the ECM method for detecting dentin caries in permanent teeth.

Adverse/side effects of the methods

No adverse/side-effects or complications were reported for any of the diagnostic methods included in this review. However, it is important to note that the eyes should be protected on both patient and operator when using laser light in all its forms. Both the QLF and the ECM methods have a limited distribution in general dentistry and the equipments that have been tested were in many cases prototypes.

Discussion

A systematic search of literature followed by data extraction and quality assessment is today a well-established part of evidence-based dentistry. In this process, the inclusion criteria of eligible papers are crucial and can always be discussed and especially in this case since a large number of publications were excluded. The formal criteria used here were pre-determined in consensus by a working group at The Swedish Council on Health Technology Assessment and applied similarly for the basic methods used in dental practice (visual-tactile inspection and bitewing radiographs) in order to establish evidence on solid ground [11]. The most common reason for exclusion was few examiners (60%) followed by a small sample size (20%) and no acceptable validation (9%), the latter predominantly in the clinical trials. The number of examiners are of highest importance for the external validity and the reason for the small numbers in

Table V. List of included studies with laser fluorescence (LF).

Reference, Country	Study design	Blinding	Number of observers	Observer reliability	Population	Caries prevalence and type of lesions	Number of individuals Number of teeth	Drop-out/ missing data	Method or technique	Reference method	End-point measure	Results enamel caries	Results dentin caries	Quality and relevance comments
Alkurt et al. [18] Turkey	Validity, *In vivo*	Yes	3	NR	adults 18–30 yr	44 intact occlusal srfaces	$n = 11$ 44 teeth, occlusal sites	NR	DD	careful minimal excavation, lesion depth	Spearman correlation	NR	0.46	Low Small sample
Angnes et al. [19] Brazil	Validity, *In vivo*	Partly	2	Kappa: 0.53	Adult volunteers, 3rd molars for extraction	18% sound 22% D1 45% D2 13% D3 2% D4	$n = 38$ 57 teeth 110 sites	NR	DD	Hemisection, histology	Sensitivity, specificity	NR	SE: 0.75 SP: 0.55	Moderate Limited to 3rd molars
Chen et al. [20] China	Validity, *In vivo*	NR	2	Inter-ICC: 1.0 Intra-ICC: 0.99.	5–9 yr, primary molars	No obvious proximal lesions	$n = 96$, 216 teeth, proximal sites	NR	DD	Invasive treatment	Sensitivity, specificity, accuracy	SE: 0.56 SP: 0.95 A = 0.75	SE: 0.92 SP:0.98 A = 0.94	Low Partial validation
Costa et al. [21] Brazil	Validity, *In vivo*	NR	2	Kappa: 0.74	10–13 yr, molars	Non-cavitated	$n = 26$ 199 teeth, occlusal sites	NR	DD	Invasive treatment	Sensitivity, Specificity PPV, NPV	NR	SE: 0.93, SP: 0.75 PPV: 0.63 NPV: 0.96	Low Partial validation
Huth et al. [22] Germany	Validity, *In vivo*	Yes	4	Inter-ICC: 0.88–0.98 Intra-ICC: 0.94–1.0	6–51 yr, occlusal	Sound or non-cavitated	$n = 120$, 120 teeth	0	DD	Sites opened ($n = 86$)	Sensitivity, specificity, AUC	SE: 0.88 SP: 0.85 AUC: 0.92	SE: 0.67 SP: 0.79 AUC: 0.78	Low Partial validation
Huth et al. [23] Germany	Validity, *In vivo*	Yes	4	Inter-ICC: 0.97 Intra-ICC: 0.84–0.98	8–54 yr, proximal sites	Sound or non-cavitated	$n = 117$, 117 surfaces	NR	DDpen	Sites opened ($n = 43$)	Sensitivity, Specificity	SE: 0.68 SP: 0.70	SE: 0.60 SP:0.84	Low Partial validation
Kordic et al. [24] Switzerland	Validity, *In vitro*	Yes	4	Kappa: 0.6–0.75	10–38 yr, premolars and molars	21% sound 61% enam. 18% dentin	61 teeth	NR	DD	SEM, quantitative image analysis	Sensitivity, specificity, ROC, accuracy, PPV, NPV	SE: 0.95 SP: 0.52 PPV: 0.33 NPV: 0.98	SE: 0.91 SP: 0.76 PPV: 0.40 NPV: 0.98	High
Manton & Messer [17] Australia	Validity, *In vitro*	NR	6	NR	Extracted 3rd molars	% cavitated	67 teeth, 204 surfaces	NR	DD	Histology	Sensitivity, specificity correlation	NR	SE: 0.49 SP: 0.83 Corr: 0.41	Low
Matos et al. [25] Brazil	Validity, *In vivo*	NR	2	Inter-ICC: 0.92 Intra-ICC: 0.99	4–12 yr, primary molars	No obvious occlusal cavities	$n = 68$ 407 molars occlusal surfaces	3%	DD	VI	Sensitivity specificity Accuracy	SE: 0.98 SP: 0.81 A = 0.78	SE: 0.97 SP: 0.87 A: 0.97	Low partial validation
Novaes et al. [26] Brazil	Validity, *In vivo*	Yes	2	Inter-ICC: 0.75	5–12 yr, primary molars	No frank cavities, proximal	$n = 50$ 621 proximal surfaces	4%	DDpen	VI after separation	Sensitivity, specificity, Accuracy	SE: 0.16, SP: 0.95 A = 0.59	SE: 0.60, SP: 1.00 A: 0.99	Moderate
Novaes et al. [27] Brazil	Validity, *In vivo*	Yes	2	Inter-ICC: 0.62 Intra-ICC 0.61	4–12 yr, proximal surfaces of prim molars	No frank cavitaions	$n = 76$ 592 surfaces	5%	DD	VI after separation	Sensitivity, specificity, Accuracy	SE: 0.27 SP: 0.82 A = 0.55	SE: 0.47 SP: 0.95 A: 0.82	Moderate
Pourhashemi et al. [28] Iran	Validity, *In vitro*	Yes	3	Inter-ICC: 0.78 Intra-ICC: 0.84	Extracted premolars	Intact or primary lesions	80 teeth	NR	DD	Histology	PPV, NPV	NR	PPV: 0.94 NPV: 0.95	Low Insufficient data reporting

Table V. (*Continued*).

Reference, Country	Study design	Blinding	Number of observers	Observer reliability	Population	Caries prevalence and type of lesions	Number of individuals Number of teeth	Drop-out/ missing data	Method or technique	Reference method	End-point measure	Results enamel caries	Results dentin caries	Quality and relevance comments
Reis et al. [29] Brazil	Validity, *In vivo*	Partly	2	Kappa: 0.57 *In vivo–in vitro* Intra: 0.28 Inter: 0.28	Adult volunteers, 3rd molars for extraction	18% sound 22% D1 45% D2 13% D3 2% D4	n = 38 57 teeth 110 sites	NR	DD	Hemisection, histology	Sensitivity, specificity, accuracy	SE: 0.80 SP: 0.43 A: 0.65	SE: 0.75 SP: 0.52 A: 0.82	Moderate Same material as [19]
Rocha et al. [30] Brazil	Validity, reliability *In vitro*	Yes	2	Kappa: Intra: 0.66 Inter: 0.61	10–11 yr, molars under exfoliation or extracted	42% sound 32% D1 12% D2 10% D3 4% D4	n = 29 30 teeth 50 sites	NR	DD	Histology	Sensitivity, specificity, accuracy	SE: 0.60 SP: 0.90 A: 0.73	SE: 0.73 SP: 0.95 A: 0.90	Moderate
Tranæus et al. [31] Sweden	Validity, reliability, *In vivo*	Yes	2	Spearman: Inter: 0.79 Intra: 0.86	Adult patients at a dental school	0% sound 13% enamel 31% D2 56% D3–D4	30 individuals, 52 lesions	None	DD, 2 instruments	Clinical excavation, consensus of 2 observers	ANOVA, correct diagnoses, Spearman correlation	NR	Spearman corr: <0.15	Low insufficient data reporting
Tranæus et al. [31] Sweden	Validity, reliability, *In vivo*	Yes	2	Spearman: Inter mean: 0.83 Intra mean: 0.94	Adolescent patients at a public dental clinic	30 enamel smooth surface caries lesions	30 individuals, 30 lesions	None	DD, 2 instruments	QLF	Spearman correlation	Mean: 0.64	NR	Low Not validated to histology
Valera et al. [32] Brazil	Validity, treatment decision, *In vitro*	NR	3	Kappa: Inter mean: 0.72 Intra mean: 0.82	Extracted molars and premolars	Visible intact	72 teeth, occlusal surfaces	None	DD	Sectioning, microscope	Sensitivity, specificity, PPV, NPV	NR	SE: 0.33 SP: 1.0 PPV: 1.0 NPV: 0.73	Low

A, accuracy; ANOVA, Analysis of variances; AUC, Area under the curve; DD, DIAGNOdent; ICC, intra-class correlation coefficient; NR, not reported; NPV, Negative predictive value; PPV, Positive predictive value; QLF, Quantitative light-induced fluorescence; ROC, Receiver operating characteristics; SE, sensitivity; SP, specificity.

Table VI. List of included studies with ECM.

Reference, Country	Study design	Blinding	Number of observers	Observer reliability	Population	Caries prevalence and type of lesions	Number of individuals Number of teeth	Drop-out/ missing data	Method or technique	Reference method	End-point measure	Results enamel caries	Results dentine caries	Quality and relevance comments
Ekstrand et al. [33] Denmark	Validity, *In vitro*	NR	3	Kappa: Intra mean: 0.73 Inter mean: 0.54	Extracted teeth	24% sound; 13% <$^1/_2$ enamel; 24% <1/3 dentin; 23% <2/3 dentin; 16% > 2/3 dentin	80 molars and 20 premolars, 100 surfaces	NR	ECM	Histology, 2 observers	Sensitivity, specificity, correlation	NR	Threshold between score 2 and 3. SE: 0.90 SP: 0.85	Moderate Based on 2 × 2 tables for any caries: SE: 0.80 SP: 0.83
Ie et al. [34] The Netherlands	Validity, *In vivo*	NR	2	Kappa: Inter: 0.76	5–15 yr, patients at a pediatric dentistry clinic	NR	n = 50	2 subjects	ECM	Clinical excavation, sound/enamel, dentine	ROC, sensitivity, specificity, Az	NR	SE: 0.77 SP: 0.62	Moderate
Kühnisch et al. [35] Germany	Validity, Reliability, *In vitro*	NR	ECM: 6	Kappa: Intra mean: 0.69 Inter mean: 0.62	Extracted teeth	11% sound 40% D1+D2 31% D3 18% D4	117 extracted sound and non-cavitated third molars	NR	ECM	Hemisection, histology, 1 observer consulting the other when in doubt	Sensitivity, specificity, ROC, AUC	NR	ECM: SE: 0.57 SP: 0.85 AUC: 0.74	Moderate Few sound surfaces
Verdonschot et al. [36] The Netherlands	Validity, *In vitro*	NR	4	NR	Molars from Danish recruits, 18–20 yr	33% no sign of caries; 32% small lesions in dentin; 35% large lesions in inner dentin	81 teeth	NR	ECM	Histology	Sensitivity, specificity, AUC	NR	SE: 0.67 SE: 0.82	Low No reliability test

ANOVA, Analysis of variances; AUC, Area under the curve; ECM, Electronic caries measurement, electrical conductance measurements; NR, not reported; NPV, Negative predictive value; PPV, Positive predictive value; ROC, Receiver operating characteristics; SE, sensitivity; SP, specificity.

Table VII. Summary of sensitivity, specificity and grading of evidence of the accuracy of fiber-optic methods (FOTI, DIFOTI), laser fluorescence (LF), electrical caries monitor (ECM) and quantitative light-induced fluorescence (QLF).

Test method	No of studies	Sensitivity mean (SD)	Specificity mean (SD)	Youden's index[a]	Grade of evidence
FOTI, Di-FOTI	4	0.44 (0.33)	0.74 (0.40)	0.18	⊕○○○
LF (enamel level) LF	9 14	0.66 (0.29)	0.77 (0.19)	0.43	⊕⊕○○
(dentin level)		0.72 (0.20)	0.82 (0.16)	0.54	⊕⊕○○
ECM (dentin level)	4	0.73 (0.14)	0.79 (0.11)	0.52	⊕⊕○○
QLF	0	—	—	—	⊕○○○

[a]Youden's index was calculated as (sensitivity + specificity) − 1.
SD, standard deviation.

the in vitro projects, carried out on extracted teeth, is obscure; for the clinical trials we accepted anything but a single examiner. Likewise, a mix of teeth and various grades of lesion severity as well as an accepted gold standard for comparisons were considered minimum requirements [37]. It should however be stressed that it is generally difficult to 'copy' the real life situation with a representative mixture of lesions in studies with extracted teeth, a fact that may affect sensitivity. Notably, relatively more in vitro studies than clinical trials were excluded. With the high exclusion rate in mind, this review strongly underlines the need to standardize study design and performance for both *in vitro* and *in vivo* tests of the different methods for caries detection. In addition, studies covering the cost-effectiveness aspect of caries detection with the adjunct methods are called for.

The FOTI method uses a high-intensity white light to enhance shadows between sound and carious enamel and dentin [10]. Narrative reviews have displayed high specificities, but low sensitivities for both occlusal and proximal surfaces [6,8] and this was confirmed here. There were, however, still no studies of acceptable quality available with the digital version. It was concluded that no major benefits compared with visual or radiographic methods were evident apart from the fact that FOTI and DIFOTI do not use ionizing radiation.

The fluorescence-based methods LF and QLF have attracted much research during recent decades. The intra-oral QLF-camera is primarily intended to detect enamel lesions on smooth surfaces and attempts to detect occlusal caries lesions have been disappointing [9,38]. No studies of moderate or high quality were retrieved due to improper validation. A novel QLF-device for improved clinical handling has been marketed in recent years that awaits scientific evaluation. Studies based on laser fluorescence dominated the hits in this search for literature. The vast numbers were conducted with the DIAGNOdent, a diode laser that emits a red light that is absorbed by organic and bacterial by-products [9]. Thus, it is important to stress that the method does not quantify the mineral content in the lesions *per se*. As the method can be confounded by staining in fissures, there is an obvious risk for false positive indications [7,9]. From a clinical point of view, LF has the potential to detect hidden dentine lesions rather than early enamel lesions. One study of high quality and five of moderate quality were included and, consequently, the evidence was graded as limited according to the GRADE scale for detecting occlusal caries with acceptable (>0.75) sensitivity and specificity. However, considering the small clinical sample sizes and the contradictory findings reported from primary and permanent teeth, there is a great need for further studies with the fluorescence technologies.

The electrical methods quantify the bulk resistance in tooth tissues and measurements can be made from both enamel end exposed dentin surfaces, albeit not proximal sites. Consistently acceptable values for sensitivity and specificity were reported in the trials of moderate quality, but any major advantage in accuracy compared with the conventional methods did not seem apparent. However, new and updated developments based on the ECM-technique have become available such as Alternated Current Impedance Spectroscopy [10]. To develop and test clinical methods is a timely and economically long-term project; the time span from initial idea to a clinically useful instrument is often 10–20 years [39]. The important thing is that the methods are not uncritically used by so-called 'early adopters', but validated and evaluated in clinical studies with low risk of bias. Another issue of interest is when the different adjunct technologies are combined on top of a conventional visible inspection. In general, the adjunct methods displayed an improved sensitivity and an impaired specificity for dentin caries detection when compared to visible-tactile and bitewing radiographs [3,11]. A high sensitivity is most crucial for severe, life-threatening medical conditions, while a high specificity is preferred for the restrictive non-operative approach in modern cariology as the false positive findings are minimized. This issue was addressed by Pereira et al. [40], who clearly demonstrated that information from multiple methods of detection did not improve the accuracy of detecting early occlusal caries lesions. In fact, the use of adjunct methods increased the numbers of surfaces indicated for operative treatment and, thereby, a possible overtreatment. Thus, the present review reinforces the fact that operative treatment decisions should not be made on adjacent methods alone.

Conclusions

Within the limitations of this systematic review, it may be concluded that there was insufficient scientific evidence for diagnostic accuracy regarding fiber-optic methods and quantitative light-induced fluorescence (+OOO). Electrical methods (ECM) and laser fluorescence (DIAGNOdent) display sensitivities and specificities between 70–80% regarding early enamel and occlusal dentin caries lesions, but evidence is still limited (++OO). No conclusions could be drawn regarding the safety and cost-effectiveness of the methods. There is a need to standardize the study design for in vitro and in vivo tests of the different methods.

Declaration of interest: The authors report no conflicts of interest. Declarations are available at The Swedish Council on Health Technology Assessment, PO Box 3657, SE 10359 Stockholm, Sweden.

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Supplementary material available online

Appendix A and B.