Clinical and Laboratorial Research in Dentistry

Laser fluorescence as an alternative for digital radiography in detecting caries lesions: a literature review

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ABSTRACT | Diagnosis of caries lesions consists of visual/tactile methods following the International Caries Detection and Assessment System (ICDAS) and radiographic methods (BW), however these methods have limitations for detecting caries at different depths and locations and is usually influenced by the examiner's experience. New technologies have emerged to improve caries diagnosis methods, among these are methods that use optical principles to quantify differences between healthy and demineralized tissues, for example: quantitative light-induced fluorescence (QLF), the "DIAGNOdent" caries detection pen, and VistaProof (fluorescence camera). This literature review aims to provide up-to-date information on the applicability of fluorescence-based methods in the diagnosis of caries. The results show that DIAGNOdent pen was the most effective method for diagnosing caries, wherein some authors indicate that it can be used as the only diagnostic method, but most recommend using it as a complementary method to ICDAS and BW. LFpen must be used in association with ICDAS and 2 articles indicate near-infrared light transillumination (NILT) as a substitute for BW, however there is still a need for further studies to reach a concrete decision. In conclusion, digital methods for the diagnosis of caries are efficient, but they do not replace visual/tactile methods and bitewing radiographs. Therefore, they should be used as a complementary diagnostic method to those already known and widely used and studied.

DESCRIPTORS | Transiluminescense; Laser Fluorescence; Diagnosis; Dental Caries.

RESUMO | **Fluorescência a laser como alternativa para radiografia digital na detecção de lesões de cárie: uma revisão da literatura** • O diagnóstico das lesões de cárie consiste dos métodos visual/tátil, pelo Sistema Internacional de Detecção e Avaliação de Cárie (Icdas) e radiográfico (BW), no entanto, esses métodos têm limitações para a detecção de cárie em profundidades e localizações diferentes e normalmente são influenciados pela experiência do examinador. Novas tecnologias surgiram para tentar melhorar os métodos de diagnóstico de cárie, entre el as há as que utilizam princípios ópticos para quantificar diferenças entre tecidos saudáveis e desmineralizados, por exemplo: a fluorescência quantitativa induzida pela luz (QLF); a caneta de detecção de cárie "DIAGNOdent"; e o VistaProof (câmera fluorescente). Esta revisão de literatura tem o objetivo de fornecer informações atualizadas sobre a aplicabilidade dos métodos baseados na fluorescência no auxílio de diagnóstico de cáries. Os seguintes resultados são: DIAGNOpen foi o método mais eficaz no diagnóstico de cárie, alguns autores indicam que pode ser utilizado como único método de diagnóstico, no entanto, a maioria recomenda utilizar como método complementar ao Icdas e ao BW. A LFpen deve ser utilizada em associação ao Icdas e dois artigos indicam a transiluminação por luz infravermelha próxima (Nilt) como substituta das BW, embora haja necessidade de mais estudos para chegar a uma decisão concreta. Em conclusão, os métodos digitais para o diagnóstico de cárie são eficientes, mas não substituem os métodos visual/tátil e as radiografias *bitewing*. Portanto devem ser utilizados como métodos complementares de diagnóstico aos já conhecidos e amplamente utilizados e estudados.

DESCRITORES | Transiluminação; Fluorescência a Laser; Diagnóstico; Cárie Dental.

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INTRODUCTION

Caries is a destructive disease to dental structures, affecting all age groups and social classes. This may lead to pulp infections culminating in severe pain and irreversible damage, which can result in other diseases of the maxillofacial complex.[1] Even with the advent of numerous preventive programs in favor of population health, caries and its symptoms are still one of the biggest reasons for patients to go to a dental clinic and its early detection is also a preventive measure.[2]

The caries detection exam is based mainly on visual and radiographic examination. However, visual inspection presents some challenges in detecting cavities in different forms and locations, mainly at the proximal regions of the teeth and nuances that are different from normal for each individual.[3] It is therefore subjective and can be influenced by the examiner's experience, making it highly specific with low reproducibility and sensitivity.[4] With radiographic examination, the real depth of the lesion can be underestimated, and thus is more suitable for detecting them in the dentin region, also showing high specificity and low sensitivity for non-cavitated lesions.[5-7]

As new technologies emerge in favor of efficiency, cost-effectiveness and practicality, researchers take advantage of these advancements to develop new methodologies which have high validity and reliability for detecting cavities, offering high specificity and sensitivity. Fluorescence-based methods such as laser have emerged as an alternative proposed in recent years in order to increase the accuracy in the diagnosis of caries.[8]

Different methods using optical principles to quantify differences between healthy and demineralized tissues are being used, for example: the quantitative light-induced fluorescence (QLF), the "DIAGNOdent" caries detection pen, and VistaProof, each with its benefits and limitations. The QLF method can detect cavities by radiating teeth with light in the visible blue wavelength range, with decayed tissues being less fluorescent than other regions of the tooth. The DIAGNOdent pen can capture the fluorescence emitted by oral metabolites and can be used as a complement for the diagnosis of proximal tooth decay. VistaProof uses violet light with a light-emitting diode (LED) to generate red fluorescence from a bacterial metabolite that appears in decayed dentin and plaque.[9-11]

Therefore, the purpose of this literature review is to provide updated information on the applicability of fluorescence-based methods contributing in the diagnosis of caries, as they are a possible alternative to radiographs.

MATERIALS AND METHODS

The research was conducted based on MEDLINE and the National Library of the United States (PubMed), for the period from 2015 to 2020, with studies providing information on the use of fluorescence-based methods to assist in the diagnosis of caries and that effectively address their characteristics, applicability and influence on treatment. The study was restricted to publications in the English language.

The articles were selected by three independent reviewers. Three reviewers initially screened the titles and abstracts, and then they evaluated the full text of each article to choose the eligible studies. For confirmation, a fourth reviewer checked each study previously considered as eligible. Disagreements between the reviewers were resolved by discussion, and when an agreement could not be reached, two other collaborators were consulted.

The search strategy was based on a combination of qualified MESH terms (Medical Subject Headings terms) as well as nonspecific words in simple or multiple conjunctions that have not yet been included as Mesh terms: "Transiluminescense" AND "Lasers (MESH) fluorescence (MESH)" AND "Dental Caries (MESH) diagnosis (MESH)".

For inclusion and exclusion criteria, only original articles indexed in the last 5 years that deal exclusively with the use of fluorescent laser in the diagnosis of caries were considered. Summaries of conferences and correspondence and systematic reviews were excluded from the study.

The search strategy resulted in 81 articles in the PubMed database. Of these, after reading their titles and abstracts, 31 were immediately excluded because they were not articles of dentistry, resulting in 50 articles that potentially meet our inclusion criteria. Finally, 9 articles were excluded because after reading their full texts, they did not use exclusively fluorescent laser. Therefore, 41 articles were identified as eligible for our review (Figure 1). After that, we constructed a table (Table 1) summarizing the recommendations for the use of laser fluorescence in each article with use of Microsoft Excel.

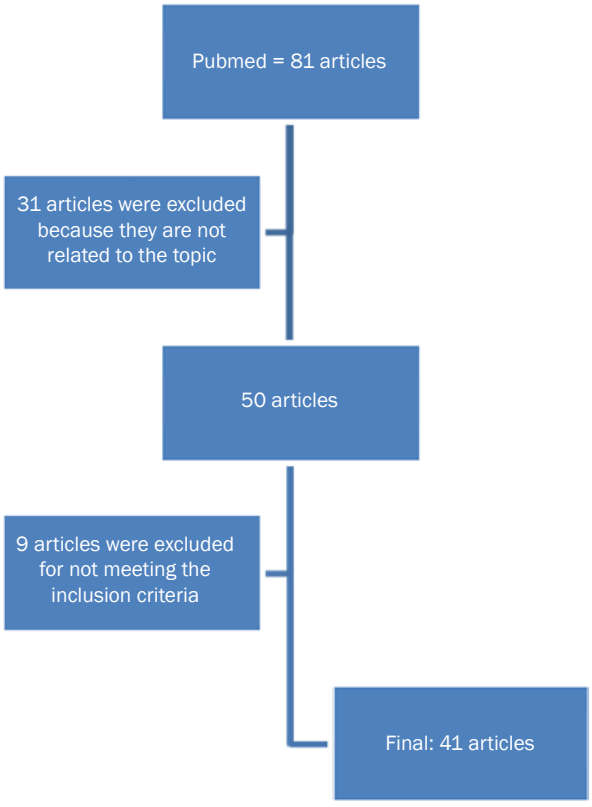

FIGURE 1 | Flowchart of the search strategy

DISCUSSION

Lasers have been increasingly used in dentistry both as a treatment option with anti-inflammatory and regenerative characteristics and an option for diagnosing non-cavitated cavities.

Diagnosis of interproximal caries has been carried out using the visual-tactile method and bitewing radiographs. However, these methods present only an estimate of the depth of the lesion and do not quantify the amount of mineral loss caused by the imbalance of the demineralization and remineralization process. Infrared waves have the ability to penetrate objects with greater depth, which helps in the diagnosis of deeper injuries.[12-16]

Laser diagnostic devices such as DIAGNOdent (DIAGNOpen and DIAGNOcam) identify the region of demineralization of dental enamel, since bacterial porphyrins and other chromophores present in this region emit fluorescence when excited by a light source with a specific wavelength.[17] Studies have shown this method as being the most effective.[18,19]

More recent research suggests complementing this method with photosensitizers and thus increasing the sensitivity and specificity of the resource, thereby achieving efficient detection of initial enamel lesions.[20] The VistaProof intraoral fluorescence camera emits blue light at 405 nm to capture and digitize images of the teeth while emitting fluorescence. In carious lesions, porphyrin fluorescence is emitted, whereas this fluorescence is not emitted by healthy enamel.[21,22]

Unlike other auxiliary diagnostic methods, infrared transillumination demonstrated the ability to differentiate between demineralization and other enamel changes such as pigmentation, developmental problems, fluorosis, calculations and fracture lines. The big problem with this type of device is that each prototype works with different wavelengths, type of light irradiation and sensors, thus making it difficult to standardize this diagnostic method.[23]

Recent studies have suggested the development of resources to accomplish caries diagnosis, but each one works with different wavelengths, types of feasible light radiation and use of this technology requires practice and still must be studied. Several studies propose to evaluate the identification of the first changes in the enamel that is hindered by the sensitivity of visual and radiographic examinations, which justifies the development of new auxiliary methods that enable early diagnosis and provide reliable results. Those articles are summarized in Table 1.

TABLE 1 | Recommendations for the use of laser fluorescence in each article

Article	Recommended as a diagnostic tool	Recommended as a complement to visual inspection	Not recommended as a diagnostic tool
Mansour et al.[3]		X	
Bozdemir et al.[8]		X	
Melo et al.[9]	X		
Alves de Souza et al.[10]		X	
Diniz et al.[11]			X
Schwendicke et al.[12]		X	
Yoon et al.[13]	X		
Ozsevik et al.[14]	X		
Tagliaferro et al.[15]			X
Abogazalah et al.[16]			X
Markowitz et al.[17]	X		
Iranzo-Cortés et al.[18]			X
Luczaj-Cepowicz et al.[19]		X	
NouhzadehMalekshaha et al.[20]	X		
Iranzo-Cortés et al.[22]		X	
Diniz et al.[24]	X		
Rodrigues et al.[25]		X	
Castilho et al.[26]		X	
Jablonski-Momeni et al.[27]			X
Diniz et al.[28]		X	
Diniz et al.[29]			X
Menem et al.[30]	X		
Bizhang et al.[31]	X		
Anauate-Netto et al.[32]			X
Bussanelli et al.[33]		X	
Sichani et al.[34]	X		
Tassokera et al.[35]	X		
Bahrololoomi et al.[36]		X	
Ko et al.[37]		X	
Shwetha et al.[38]			X
Akgul et al.[39]		X	

continues...

TABLE 1 | Continuation

Article	Recommended as a diagnostic tool	Recommended as a complement to visual inspection	Not recommended as a diagnostic tool
Alomari et al.[40]			X
Novaes et al.[41]			X
Silvertown et al.[42]			X
Pontes et al.[43]			X
Subka et al.[44]			X
Kühnisch et al.[45]	X		
Ozkan et al.[46]	X		X
Singh et al.[47]		X	
Abdel Gawad et al.[48]	X		
El-Sharkawy et al.[49]	X		

In a first study using a bacterial model for caries generation the ability of the LF, LFpen, and FC devices to detect initial caries-like lesions in enamel was evaluated and their progression monitored.[24] The FC device showed good performance with regard to indicating incipient non-cavitated caries lesions, while the LFpen device performed better at indicating deep non-cavitated caries lesions.[24,25] The same method did not show any effect in monitoring enamel lesion progression after three cycles of demineralization.[25] Searching for the same results in a trial involving primary molars, Diniz et al.[11] compared the performance of different methods ICDAS, LF, QLF, and MID (laser device) but concluded that methods using fluorescence-based and light-based devices are time-consuming and do not improve diagnostic outcomes; meticulous visual examination may be recommended as the method of choice in clinical dental practice.

In order to validate the DIAGNOdent laser fluorescence method and ICDAS classifications against histological examinations for detecting occlusal caries on permanent molars, Castilho et al.[26] conducted an *in vivo* study with non-impacted third molars erupted or partially erupted. They proved to be reproducible methods with similar performance in the detection of occlusal carious lesions in dentine. The ability of DIAGNOdent to detect initial enamel lesions was higher than that of ICDAS, but with low specificity. Similar results were achieved with orthodontic, periodontal, and surgical indications extracted from permanent teeth by Luczaj-Cepowicz et al.[19] High specificity values of the ICDAS II were also noted by Iranzo-Cortés et al.[22] and Jablonski-Momeni et al.[27] As the LFpen showed a tendency to underestimate enamel and dentin carious lesions, the ICDAS criteria showed a tendency to overestimate the presence of caries around amalgam restorations when no caries were present, indicating that ICDAS should be interpreted with care when assessing amalgam restorations when the gold standard involved microscopic examinations.[28,29]

Menem et al.[30] observed the difference in the mean of LFpen readings between the three groups of approximal surfaces (intact, with white/brown spots and cavitated) and the standard deviation. This study showed a 100% sensitivity of the LFpen device in detecting approximal cavitated caries lesions in posterior permanent teeth. The diagnostic accuracy of the LFpen device was also higher than digital bitewing radiology at the non-cavitation threshold and shows that the LFpen device is an accurate diagnostic method in detecting approximal carious lesions in posterior permanent teeth, both at the cavitation and non-cavitation thresholds.

Clinical compatibility of commercial light or laser fluorescence tests with conventional radiography was investigated. Descriptive statistics and frequency analysis were performed to examine the distribution of sound teeth and carious teeth as well as the distribution of fluorescence losses in QLF-D and maximum values in DIAGNOdent according to the criteria of caries diagnosis. The results indicated that bitewing radiography has a higher concordance with QLF-D than with DIAGNOdent. Considering that only the statistical relationships between the diagnostic readings of three different methods were evaluated using bitewing radiography as a reference test (considered by the author a limitation of this study) to assess the diagnostic performance of three detection methods for proximal caries, further studies including standardized histological evaluations are necessary, as well as additional studies involving more examiners in consideration of learning curve are needed to recommend these clinical procedures in daily practice.[13]

Considering ethical concerns, some studies including *in vivo* samples used BW (bitewing) as a gold standard[3,9,12,30-32] and others used ICDAS.[10,33] Based on their results Melo et al.,[9] Menem et al.,[30] Bizhang et al.[31] affirms that DIAGNOpen is an alternative to avoid ionizing radiation for the patients, but despite having similar findings, Schwendicke et al.[12] and Anauate-Neto et al.[32] indicates it only as a complement.

The gold standard for *in vitro* studies was histological analysis, and likely either because of the samples, different resources or the training of the examiners, there were a variety of results. Indication for replacing BW for LFpen occurred by those authors that found high levels for sensitivity and specificity[9,13,14,20,24,34,35] but many others recommend it as adjunct method for ICDAS exams.[8,18,19,22,25,26,36-39] However, weak specificity and sensitivity results led other authors to not indicate its use without BW or CT, invalidating the aim of the studies about these appliances.[18,22,27-29,40-44]

A study by Subka et al.[44] included a table with the relationship between the histological scores and the codes and criteria of clinical and radiographic examination and the LF pen at each level of diagnosis, shown in Figure 2.

Kühnisch et al.[45] and Ozkan et al.[46] used NILT (near-infrared light transillumination) resource to access carious lesion to confirm the diagnosis (Figure 3). They both revealed similar diagnostic accuracy for interproximal dentin caries detection when using digital radiography and NILT, so considering ionizing exposure of radiographs, they recommend NILT as a substitute for BW examination.

Histological section	Histological Score	ICDAS score (visual)	RE score	LF pen score	Level of analysis
	Score 0, no enamel demineralisation	0 Sound tooth surface	0	0-7	Sound
	Score 1 demineralization in the outer half of enamel	1 Visual change seen after air drying	1	8-15	D_1
	Score 2 demineralisation extending to the inner half of enamel	2 White or brown discoloration of enamel seen without air drying	2		
	Score 3 demineralisation in the outer one third of dentine		3	≥16	D_3
	Score 4 demineralisation extending to the middle third of dentine	3 Micro cavitation of enamel surface 4 intact surface with underlying shadow	4		ERK_3
	Score 5 demineralisation extending to the inner third of dentine	5, 6 Cavitation	5		

LF pen = laser fluorescenxe pen; RE = radiographic examination, D_1: D_0 = health, D_1-D_5 = disease; D_3: D_0-D_2 = health; D_3-D_5= disease; ERK_3: D_0-D_3 = health; D_4-D_5 = disease

FIGURE 2 | Relation between histological scores and codes, and criteria of clinical examination, radiographic examination and the LF pen at each level of diagnosis.[44]

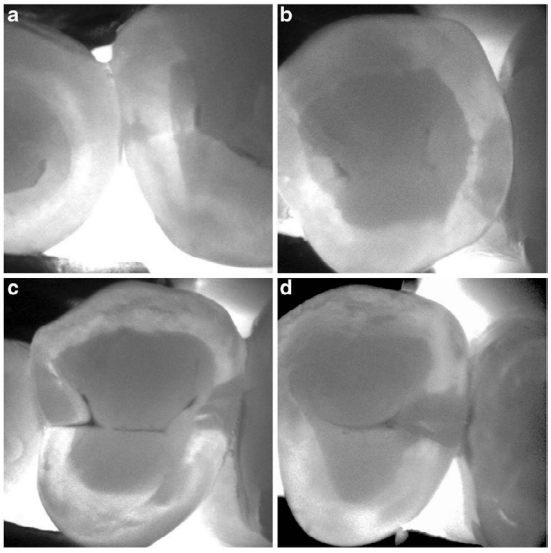

FIGURE 3 | NILT images of enamel and dentin interproximal caries lesions. Images a and b present enamel caries lesions, c shows a lesion associated with complete demineralization of the enamel and no dentin caries lesion, d shows an interproximal caries lesion with a less translucent dentin, which could be detected as a dark area.[45]

In this review, we found other authors developing new features with fluorescence methods for early caries detection. Singh et al.[47] researched multispectral fluorescence imaging (MSFI), which is considered a synergistic combination of imaging and spectroscopy that has been used for methods of drug response monitoring, tumor margin identification and *in vivo* imaging of animals and can provide information about exact spread of the infection, possibly aiding in long term dental monitoring and showing promising findings for dental abnormality detection. With the same lines of thought, Abdel Gawad et al.[48] and El-Sharkawy et al.[49] are proposing a novel approach with hyperspectral imaging that still deserve further investigation.

CONCLUSION

This literature review concludes that digital methods for diagnosing caries are efficient, but do not replace visual / tactile methods and bitewing radiographs. Therefore, they should be used as a complementary diagnostic method to those already known that are widely used and studied.

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