Technologies for Dentin Caries Detection

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To enable conservative caries management, it is imperative that caries are detected at a non-cavitated stage. Non-cavitated caries lesions (NCCLs) have the surface of enamel still intact but in depth they can reach the enamel or dentin level. The shortcomings of traditional visual and radiographic methods to detect NCCLs highlight the need for further investigation of alternative methods for caries detection.

dental caries non-cavitated dentin caries diagnosis

1. Introduction

Dental caries are acknowledged as the most prevalent disease of the oral cavity and affect the vast majority of the population worldwide [1][2]. It is a multifactorial disease characterized by demineralization and loss of tooth structure over time as a result of the interaction between fermentable dietary carbohydrates and acid-producing bacteria [3][4]. Proper detection of dental caries enables clinicians to classify the severity of the lesion and provide optimal therapies that eliminate or reverse decay and preserve healthy tooth structure [5][6]. If identified and treated, dental caries can be prevented from progressing to advanced stages that may lead to tooth loss [7].

Visual and tactile examinations are traditional methods used by dental practitioners to detect caries lesions [8][9]. However, these examination approaches have limitations in their ability to ascertain caries due to their subjective and qualitative nature [10][11].

Dental radiographs are the most common technique for imaging dental caries and dental hard tissue [12]. Despite being a more objective method than the visual examination, radiographic examination may underestimate the caries lesions' depth [11][13][14]. An emerging technology that has shown potential for dental imaging applications is optical coherence tomography (OCT) [12][15][16][17]. Moreover, it has applications in imaging caries at all stages of progression, and dentin structures, as well [18][19][20][21]. OCT is a non-invasive, non-ionizing, and non-destructive imaging technique that has the potential to facilitate detection of caries and become a valuable tool in clinical practice [22].

Due to the declining caries trends worldwide as a result of fluoride introduction and emphasis on oral hygiene maintenance [23], there is an increased demand for effective methods of detecting caries lesions at an early stage. Caries lesions can be cavitated or non-cavitated. To enable conservative caries management, it is imperative that caries are detected at a non-cavitated stage [5]. Non-cavitated caries lesions (NCCLs) have the surface of enamel still intact but in depth they can reach the enamel or dentin level [8][9]. Throughout the past decades, various new and innovative tools for caries detection have been developed, steadily progressing towards contemporary clinical practice [5]. The shortcomings of traditional visual and radiographic methods to detect NCCLs highlight the need for further investigation of alternative methods for caries detection [8][9][10][24]. Such methods include non-ionizing technologies based on fluorescence, light transillumination, light-emitting diode devices, fiber-optic transillumination, optical coherence tomography, alternating current impedance spectroscopy, optical coherence tomography and photo-thermal radiometry, and modulated luminescence [24].

Previous have evaluated the performance of emerging technologies in detecting and quantifying carious lesions [25][26][27][28][29][30], but results from in vivo and in vitro studies have been heterogeneous and there is ambiguity regarding their overall effectiveness as diagnostic methods in clinical practice. Recent systematic studies have investigated the most commonly used caries detection methods for occlusal and proximal studies, but they either overlooked less studied or reported methods [29][30], such as near-infrared light transillumination and alternating current impedance spectroscopy, or included only in vivo studies [28].

2. Laser Fluorescence Technology

DIAGNOdent (DD) groups, utilizing the LF technology, comprised the largest number of studies included in this meta-analysis. There are two DD devices: DIAGNOdent 2095 (DD 2095) and DIAGNOdent pen 2190 (DD pen) [28][31]. DD 2095 works only on occlusal surfaces, whereas the DD pen works on both occlusal and proximal surfaces [32][33][34].

DD 2095 was assessed in five reports. Under experimental in vitro conditions, the DD 2095 had moderate to low pooled sensitivity associated with rather high specificity (i.e., low FPR). However, the few identified studies made it difficult to conclude on the actual performance of the device.

DD pen was assessed in 19 reports. Most studies were carried out under in vitro conditions and evaluated occlusal surfaces. The pooled sensitivity was high and the FPR was low, implying high specificity. The publication bias of in vitro DD pen occlusal studies was low, with most studies fitting into the funnel and only one outlier. There was moderate heterogeneity among the 11 in vitro occlusal studies, with high area under the sROC curve, thus proving good discriminative capacity. The overall good performance of the DD pen and meta-analysis was in accordance with previous studies concerning experimental in vitro conditions [26][27][28].

Fewer in vivo DD pen studies evaluating occlusal surfaces met the inclusion criteria and indicated the more difficult nature of in vivo studies designs, due to limitations in the ability to accurately validate all types of caries and teeth [35]. The included in vivo studies of occlusal surfaces using a DD pen exhibited higher heterogeneity, probably generated by the variations in sample size and difficulties in obtaining a true representative sample. This effect was also apparent in the qualitative RoB assessment, particularly in domains 1 and 3 (concerned with selection and spectrum bias, and reference test bias, respectively).

Studies carried out on occlusal surfaces using a DD pen, in both in vivo and in vitro conditions, exhibited lower heterogeneity than studies carried out on proximal surfaces. A low number of reports were identified for proximal NC dentin caries under in vitro conditions and they reported a high pooled specificity (i.e., low FPR) but inconclusive sensitivity. Proximal caries are more difficult to diagnose [36][37], therefore the high heterogeneity in proximal surface sub-groups may be due to the variations in reference standards and their (in)ability to detect proximal caries. Although the DD pen is able to detect proximal caries, it is more challenging to conduct such an investigation under in vivo conditions when proximal tooth contacts are tight; it is difficult to accurately simulate this in vitro, as well [32]. DD pen tips have a minimal thickness of 0.4 mm and tooth separation is necessary to increase accessibility for the DD pen tip, especially in tight contact areas [32]. Due to these additional challenges of proximal caries detection with the DD pen, fewer studies were identified.

Differences in the experimental designs (i.e., simulating proximal caries in vitro) and in separating tight proximal contacts between teeth in clinical in vivo set-ups may have introduced additional heterogeneity. For example, in case of DD pen for proximal NC dentin caries, in vivo studies used operative validation as the reference standard [38][39], and one study in the in vitro sub-group used visual examination and bitewing radiographs as the reference standard [40]. This less rigorous validation may also bring limitations and introduce heterogeneity [35].

Summing up, the DD pen proved to have good diagnostic performance in experimental in vitro studies for occlusal NC dentin caries, but there is inconclusive evidence regarding the NC dentin caries detection on proximal surfaces.

3. Fluorescence Camera Technology

There were 12 reports that assessed the FC VistaProof and VistaCam iX instruments, all on occlusal NC dentin caries detection. Considerably higher sensitivity was observed when optimal cut-off was used (maintaining reasonably moderate specificity), compared to the manufacturer cut-off values. Low-sensitivity results in low negative predictive values, which might be an issue when manufacturer cut-off values are used in clinical practice. Therefore, these results strongly suggest a reconsideration of the manufacturer’s cut-off values.

In addition, the small (i.e., tight) 95% confidence interval of the pooled sensitivity for in vitro VistaProof instruments indicates good stability and reliable estimation of performance when optimal cut-offs are employed. The sROC curve also showed excellent sensitivity in case of optimal cut-off values.

On the other hand, the low number of in vivo studies that met the inclusion criteria restrains the conclusions on this technology’s efficacy under clinical conditions.

4. Optical Coherence Tomography

OCT appears to be a promising tool as high sensitivity and specificity were observed in three out of four individual datasets. Since OCT is an imaging technology that can provide accurate 2D and 3D visualization of caries lesions for both occlusal and proximal surfaces, by using the same technical principles [41][42][43], the datasets of the four identified OCT studies that met the inclusion criteria were combined for an overall meta-analysis. The aggregated results confirmed high sensitivity and specificity. Even though the comprehensive meta-analysis included results on different surfaces and design settings, only moderate to high heterogeneity was observed. The sROC curve clearly showed this outstanding discriminative capacity, in spite of the large 95% confidence area on the ROC space.

These findings suggest OCT as a promising emerging technology, although more studies are needed to confirm these results and further assessment of this technology should be carried out.

5. Newly Emerging Technologies

The remaining emerging technologies had few identified studies that met the inclusion criteria. Although recent systematic studies and meta-analyses overlooked these technologies probably due to the low number of available studies [29][30], their diagnostic potential should be acknowledged. Researchers systematically identified these studies, collected the performance data, synthesized them and then put them in context, irrespective of the reports' number; this contribution might help future investigators to build up on existing body of evidence. For example, previous research considered the QLF as a good diagnostic instrument [44] and the results found consistency in the NC dentin caries detection performance, suggested by the overlap in the confidence intervals on the ROC ellipse plot; it was further confirmed by the high AUC value, and high pooled sensitivity and specificity.

Nevertheless, additional assessment of FOTI, QLF, LIF, ACIS, and PTR-LUM technologies is needed to determine their diagnostic performance in occlusal and proximal NC caries detection using the RoB criteria set out by Kuhnisch et al. [35]. The RoB assessment tool was useful in the identification and synthesis of potential sources of bias. Many in vivo and in vitro studies exhibited high RoB in items from domain 1, concerned with selection and spectrum bias. Bias and heterogeneity may be due to the challenges associated to enrolling a population-based, randomized sample of patients, teeth, and NC dentin caries. In addition, it is important to note the difference in the potential sources of bias between in vitro and in vivo studies in terms of the reference tests. Higher RoB was found in the in vivo studies across the domain 3 items, generated by the inability to apply rigorous validation methods under clinical conditions (due to the destructive nature of such gold standards). Furthermore, RoB was noted for the calibration of index and reference tests, as many studies did not specify the extent of their investigators' training and calibration.

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