RICARDO AUGUSTO TOMAZ NOSCHANG

PHYSICAL METHODS OF DENTAL CARIES DETECTION

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Trabalho apresentado à Universidade Fernando Pessoa como parte dos requisitos para obtenção do grau de Mestre em Medicina Dentária.

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RESUMO

A cárie dentária é a doença oral mais prevalente e seu diagnóstico envolve avaliação visual-tátil (AVT) e a radiografia dentária (Rx) como exame complementar. Contudo, o Rx expõe o paciente a radiação ionizante. A fluorescência induzida por luz (FL) e a transiluminação por infravermelho próximo (TLIP) são novas ferramentas para ajudar na obtenção de um diagnóstico mais preciso. Esta revisão da literatura tenta explicar as diferenças nestas tecnologias e compara-as aos métodos de diagnóstico tradicionais. A análise dos estudos mostrou que ambos os métodos foram validados para o diagnóstico de cárie e no caso da FL, a sensibilidade varia de 0,69 a 0,73 e a especificidade de 0,73 a 0,82. Para o TLIP, a faixa de sensibilidade foi de 0,66 a 0,92 e a especificidade de 0,76 a 0,98. FL e TLIP apresentaram resultado superior ao Rx, excepto em lesão profunda na dentina. Concluímos que as tecnologias FL e NILT são excelentes como ferramentas de diagnóstico de cárie dentária.

Palavras-chave: cáries dentárias; métodos de diagnóstico; fluorescência por laser; transiluminação por infravermelho próximo.

ABSTRACT

Dental caries is the most prevalent oral disease and it's diagnostic involve visual-tactile evaluation (VTE) and usually the Dental radiography (Rx) as an adjunct exam. However, Rx exposes patients to ionising radiation. Light-induced fluorescence (LF) and Near-infrared light transillumination (NILT) are new tools to help the achievement of an accurate diagnosis. This literature review explains the differences between these technologies and compare them to traditional diagnosis methods. The evaluation of the studies showed that both were validated to caries diagnosis and for the LF, sensitivity range from 0.69 to 0.73 and specificity from 0.73 to 0.82. For the NILT, sensitivity range was 0.66 to 0.92 and the specificity 0.76 to 0.98. There is a better result for LF and NILT than Rx in all sites, except deep dentin lesion. We concluded that the LF and NILT technologies are excellent tools in caries diagnosis.

Keywords: dental caries; diagnostic method; quantitative light-induced fluorescence; near-infrared light transillumination.

DEDICATORY

To my dear wife Vanessa and my beloved daughter Olivia. You are my pillars.

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I. INTRODUCTION

Dental caries is a multifactorial disease based on the nocuous interaction between bacteria's and the dental tissue. The sugar metabolisation by some oral bacteria's present in the dental plaque produce acids that progressively demineralise the hard dental structure. As is the most prevalent disease in oral cavity (Salas *et al*., 2015), still is a concern in oral health despite the major effort in control it with preventive procedures in clinical field and oral health promotion in public scale (Frencken, 2017). However, as the caries process is deeply understood, the interventive treatment plan has been modified. Preventive and no-invasive interventions are the focus of the new protocols, avoiding unnecessary surgical procedures (Lee *et al*., 2016). In the case of non-cavitated enamel lesion, there are interceptive methods that can reverse the demineralisation thus favouring the re-mineralization process (González-Cabezas and Fernández, 2018). In order to accomplish these goals, is necessary the early diagnosis of the caries process in dental tissue.

The clinical diagnosis of dental caries is based mainly on visual-tactile evaluation. As this exam is prone to subjectivity and there are a lot of protocols to interpreted the several stages of the caries continuum, the *International Caries Detection and Assessment System* (ICDAS) was developed (Ismail *et al*., 2007). The ICDAS is based in a sequential classification score that intend to be strongly related to the histological status of the affected tissue. Although the ICDAS is a very simple and clinical based method for dental caries diagnose, there are some limitations of the method that demand complementary tools to assess effectively the tissue status.

To overcome the limitations of the visual-tactile examination (VTE), especially in the suspicious of deep caries in areas of limited visual range or to study the relationship between the caries tissue and the pulp tissue, the complementary exam of dental radiography (Rx) is indicated (Schwendicke, Tzschoppe and Paris, 2015). This exam uses ionising radiation to penetrate dental tissue and the alterations produce by the shock between the radiation and the tissue are recorded in a film. The dental Rx is important to check the relationship between the affected lesion and the pulp tissue as this information can alter the intervention plan. It is also very sensitive for deep dentine caries but there are limitations in enamel caries diagnosis, especially due to the excess of interposition of the anatomical structures that produce interference around the enamel image (Erkstrand *et al*. 2011). The other concern is related to the individual exposure to ionising radiation that is accumulated thought life span and can produce a number of cellular alterations (Ribeiro, 2012).

The caries detection in approximal surface is challenging, especially in early stages. Around 75% of the of the approximal lesions are located in the contact area between the molars (Arnold, Gaengler and Kalkutschke, 1998), and this location make the direct visualisation more difficult. Therefore, in cases of proximal lesions the VTE usually have a lack of visibility and the lesions can be underestimated (Lederer *et al*., 2018). The bitewing radiograph offers very low sensitivity for enamel caries and repeating the exam is restricted because of the ionisation radiation (Schwendicke, Tzschoppe and Paris, 2015). New caries diagnosis methods were develop in the attempt of decrease subjectivity and increase accuracy. Light-induced fluorescence (LF) based instruments detect the variation of the autofluorescence in dental structure. Using a light or laser beam emitting wavelength radiation around 400nm-700nm (visible region of the electromagnetic spectrum), the teeth is irradiated and that energy excites the fluorescent molecules on it, and the backscattered fluorescence is captured and processed by a specific software that transforms into a numerical code or an image is captured (Ozcan and Guzel, 2017). Fluorescence methods can be used for caries detection, including approximal caries (Ko *et al*., 2015) because if there is an area of demineralisation, there are optical loss in the fluorescence signal and the LF systems can detect and quantify the difference in the fluorescence based in a predetermined scale. The products of the bacterial metabolism, especially the phosphoryns, also interact with visible light wavelengths and can be read by the LF as red fluorescence in contrast with the normal green aspect of the normal dental tissue. This reading can predict caries risk of the tooth and the amount of caries affected (Lee *et al*., 2013).

The fibre-optic transillumination (FOTI) is a light-based caries detection method which uses narrow white light beam to transilluminate the tooth structures. It can be applied for both occlusal and approximal caries lesions. After it’s moderate applicability and simple use, there was an upgrade of the equipment with the digitised version of FOTI (Digital Imaging Fibre-optic Transillumination - DIFOTI) which can be used for initial and advanced caries lesions diagnose with more accuracy (Ozcan and Guzel, 2017). In the natural sequence of investigation of an robust optical device, it was confirmed that near-infrared light wavelengths (NIR), that are longer than the visible light, would scatter less and therefore penetrate the tooth structure more deeply (Lussi *et al*., 2004). New near-infrared light transillumination (NILT) instruments as the DIAGNOcam (Kavo, Biberach, Germany), uses laser wavelengths between 700 nm and 1500 nm to produce an image of the dental structure. The caries affected tissue scatter NIR different from the health structure and allow a clear differentiation between sound and demineralised structure.

Based on the diversity of complementary instruments to caries diagnosis, the purpose of this work was to describe the LF instruments and the NILT instruments, their structure, physics mechanism and the accuracy in detecting occlusal or approximal caries lesion in dental tissue compared with the most used methods named visual-tactile examination (VTE) and dental Rx.

Materials and methods

To elaborate this work, we performed a bibliographic search in electronically databases available: Pubmed Database, ScienceDirect and Scielo. This search was performed in May, 2019 using the following keywords: caries diagnosis methods, quantitative light-induced fluorescence, near-infrared light transillumination. The database search used the following research protocols:

1. ((caries diagnostic methods) AND (quantitative light-induced fluorescence)) Presented 98 results including 34 in the last 5 years.
2. ((caries diagnostic methods) AND (near-infrared light transillumination)) – Presented 18 results including 14 in the last 5 years.

The bibliographic survey with the keywords above, revealed a total number of 116 scientific publications, of which we mainly selected *in-vitro* and *in-vivo* studies and publications referring to the last five years. This choice was made based on the recent equipment technologies that have evolved during the last years. An option was also made for articles exclusively in the English language, the predominant one in the journals of high scientific impact factor.

II. DEVELOPMENT

Clinical diagnosis of dental caries is one of the major concerns in preventive dentistry. Dental professional uses visual detection methods based on colour (white or brown), lesion reflectance (shiny or opaque) and texture to determinate the presence or absence of an active lesion (Veen and Jong, 2000). The development of the ICDAS system for clinical diagnoses in 2002 could provide more consistency in dental evaluation in caries diagnosis as standardisation in data collection and promoting the possibility of direct comparability among scientific studies. The ICDAS system classifies dental sites using a code: (0) sound tooth, (1) first visual change in enamel visible after air drying, (2) distinct visual change in enamel visible with no drying, (3) localised enamel breakdown, (4) underlying dark shadow from dentine, (5) distinct cavity involving less than 50% of dentine surface, and (6) extensive distinct cavity involving more than 50% of dentine surface. The code is linked with the histological status and can also be used for treatment planning (Ismail *et al*., 2007). But there are limitations in visual-tactile examinations that require complementary exams especially in occlusal an approximal superficies with no enamel breakdown what make the diagnostic more subjective.

The most common complementary exam to detect the presence of caries lesions is the dental Rx (Bozdemir *et al*., 2016). It is most important in approximal lesions detection as they are not normally directly visualise by the VTE. For that specific type of lesion search, the interproximal radiography or "*bite wing"* technique is indicated. The 90 degree beam incidence with the patient "biting" a wing of the guide pellicle promote extra separation of the teeth and diminish the interference of the dental structures. The dental radiography is also well indicate in cases of doubt or suspicious of a dentine lesion or when the evaluation of the relationship between the carious process and the underlying pulp tissue is required (Park *et al*., 2018). Although is largely used, the technique has two main limitations: the first is related to the ionising radiation that is needed to interact with the dental structure and sensitise the radiography pellicle. The radiation exposure of the patient though life increases the risk for cellular damage and must be avoided. The second is related with the limitations of the technique in respect to its poor general sensitivity (range from 0.21 to 0.34) (Schwendicke, Tzschoppe and Paris, 2015). The dental radiography have a good sensitivity in dentin lesions especially in deep ones (0.54) (Erkstrand *et al*., 2011) but the sensitivity is low for enamel tissue and especially for non cavitated caries lesion (0.29) (Silva Neto *et al*., 2008).

The Light-induced fluorescence (LF) is a validated method for caries detection. That includes early and deep caries detection, occlusal and approximal caries detection and it enables the comparison of different reading in a long term evaluation (Bozdemir *et al*. 2016, Rosa *et al*., 2016) . The first dental work highlighting its dental use was from Bjelkhagen and Sundström in 1981, that used an Argon laser emitting at 488 nm central wavelength to observe a white spot in dental enamel and showed that was clearly distinguish from sound enamel. The instrument is based in detect the alteration of the natural fluorescence of the tooth. The sound tooth presents green fluorescence when illuminated by a specific spectrum of violet-blue light. When a demineralisation lesion is present in the enamel or dentine, the altered tissue blocks part of the light reflection and produces a modification in the dentine backscattered fluorescence. The scattering coefficient of a demineralised lesion is 5 to 10 times the sound enamel scattering coefficient (Spitzer and Bosch, 1977). As the dentine is the major source of backscattered fluorescence in the tooth, if the light doesn't reach properly the dentin, the fluorophore will not be activated and the fluorescence characteristic will not be seem, that is why the demineralised area is seen as a dark spot. The LF device is a fluorescence based instrument able to detect this decreasing in the normal dental fluorescence and the contrast of the lesion point to the normal area (van der Veen and Jong, 2000). It uses a laser light source, usually an Argon laser, because the laser can produce a more distinctive difference between the demineralised area than the rest of the tooth, compared with white light illumination (Bjelkhagen and Sundström, 1982).

The LF is suitable to clinical and laboratory dental caries diagnostic, but it can also be used to evaluate the de-remineralisation process longitudinally, after preventive or interceptive treatment or when monitoring dental lesions. According to Amaechi, Owosho and Fried (2018), some of the advantages of the LF are: the low intensity light that is no harmful for the patient or the dentist; offer high contrast between the caries and the sound enamel; some devices allow the quantification of the demineralised area; the images are clear and can be used for educational purpose with the patient. For their point of view, the drawbacks are: the instrument cannot differentiate the stain from de caries lesion; the instrument cannot differentiate early caries lesion from hypomineralisation; the contrast between the lesion and the sound area can be masked by moisture in tooth surface thus the need for drying the tooth before the readings; the instrument cannot differentiate between active or inactive caries lesion and cannot indicate the deep of the lesion.

Some commercial devices were developed using the fluorescence method for imaging caries and its detection. With illumination between 460 nm and 655 nm light wavelength they activate de dental fluorescence and capture an image of the tooth. With adequate software, it is possible to demarcate the size of the lesion. It is also possible to measure the difference in lesion severity by calculating the ΔQ (expressed in $\%.mm^2$), which is defined as the lesion area (mm^2) multiplied by the mean change in fluorescence radiance (%). These parameters are useful for clinical longitudinal evaluation using the LF (van der Veen and Jong, 2000). Commercial examples are the SoproLife (ACTEON Group, La Ciotat, France), Inspektor ™ Pro (Inspektor Dental Care, Amsterdam, Netherlands) and Vista Cam iX Proof (Dürr Dental, Bietigheim-Bissingen, Germany). These products also offer a colour scale that can differentiate the colour nuance of the different fluorescence areas based on the fluorescence loss. This shade scale make diagnosis easier and longitudinal photographs of the tooth can be used for control purpose. The Inspektor ™ Pro is also know as *Quantitative Light-Induced Fluorescence*™ (QLF ™) instrument. Other brands also offer quantitative (numerical) products based on laser light emission. Examples are the Diagnodent™ (Kavo, Biberach, Germany) that convert the fluorescence loss in a numerical scale. The instrument gives a reading number between 0 and 99 according with the intensity of the fluorescence signal. Readings above 16 are considered positive for dental caries (Huth *et al*., 2010). As higher the number larger the carious lesion. To minimize the difficulty in reading the approximal surface adequately, the same manufacturer also developed a pen hold Laser Fluorescent based probe on the previous instrument, the Diagnodent™ Pen LF (Kavo, Biberach, Germany). The product includes an interproximal tip that can reach easier the approximal surface and perform better readings of this area that might be limited by a ~3mm laser beam penetration (Amaechi, 2009). It detects approximal lesion by angling and moving the probe along the marginal ridge and in the proximal surface. By sending and capturing the signal in a direct line it is possible to reduce the interference in the signal (Bozdemir *et al*., 2016). Also it is also easier to handle and carry, but works with 655 nm wavelength radiation.

Near-infrared light transillumination (NILT) is an upgrade of the *Digital Fiber-Optic Transillumination technology* (DiFOTI) as a caries detection method that uses transillumination light for detection and diagnosis. Dental studies using near-infrared wavelengths were first published by Fried and collaborators in 1995 (Fried *et al*., 1995) and the first approximal image of the tooth was published in 2003 by Jones, Huynh and Fried were they generate a very clear caries lesion image with an 1300 nm wavelength instrument. The difference comparing NILT with other transillumination instruments is that instead of using visible light the NILT uses near-infrared light to penetrate the object, in range variating from 700 nm to 1500 nm. The use of a longer wavelength is beneficial especially because it provides a deeper penetration in the object with less scattering and a better contrast than the visible spectrum light source (Jones *et al*., 2003). The principle of the instrument is based on that the light intensity can be reduced by absorption or scattering. The first is related with the absorption of photons (by the healthy tissue , by the lesion or by the amount of water content) and the second is related to the differences in scattering of the photons by the differences of the structures permeability and reflection properties that change the direction without the loss of energy (Amaechi, Owosho and Fried, 2018). It is know that light scattering increases 2 to 3 times in demineralised dental tissue when using 1300 nm wavelength illumination, allowing good visual contrast (Darling, Huynh and Fried, 2006) and probably this wavelength is the best to observe approximal caries lesions (Chung *et al*., 2011). This fact is explained because in the 1300 nm wavelength range the dental structure manifest its higher transparency and the scattering coefficient of enamel is 20 to 30 times lower than in visible light wavelengths (Fried *et al*., 1995). As the scattering coefficient in the demineralised tissue increases 1 to 2 orders of magnitude, this fact yield high contrast between the sound and the affected enamel (Darling *et al*., 2006). The role of the water absorption is interesting in the NILT energy and as higher the wavelength, higher the penetration of the energy and the water absorption. Longer wavelengths as 1450 nm (where there is a water band absorption) can provide better contrast between dentine and demineralised tissue, probably because of the huge difference in water present in the structure of each one (Amaechi, Owosho and Fried, 2018).

The wavelength used in NILT depend on the manufacturer specifications but commercially available instruments range from 780 nm in the DIAGNOcam (2012, Kavo, Biberach, Germany) and DEXIS CariVu™ (DEXIS, Biberach, Germany) to 850 nm Vista Cam iX Proxi (Dürr, Bietigheim-Bissingen, Germany). The system works with an elastic arm of the instrument which contain optical fibres that transmit NIR light that pass through the tooth. The NIR light is scattered from the tooth surface and an optoelectronic sensor (usually a CCD-type) captures the data. An image is generated by a software and displayed in the computer screen (Ozcan and Guzel, 2017). The normal tissue is more translucent in the image and the caries lesion is presented as dark areas. The enamel imaged by the NIL appears highly transparent (Lederer *et al*., 2018) and enables the image of the underlying tissue. The property reflex that occurs even in early demineralisation process, results in a high scattering coefficient in the lesion thus reducing the intensity of the light that goes back to the sensor (Amaechi, Owosho and Fried, 2018).

In clinical use, the NILT equipment can present images that have areas of under- or overexposure generated by the intense reflection of light. This fact can also be originated by hypomineralization areas or metallic restorations (Lederer *et al*., 2018). There is also a difficulty in evaluate very deep caries lesions in the approximal area because of the decrease visibility in commercial instruments with shorter wavelengths. That effect is not present in deep occlusal caries (Lederer *et al*., 2018) which indicate 788 nm laser beam for more precise occlusal diagnoses than approximal. Differently of the LF, common stains in dental structure are not seen in the NIRT imaging because the organic chromophores molecules absorbed poorly the NIR photonics energy (Bühler, Ngaotheppitak and Fried, 2003). Therefore, they do not generate confusion with demineralised areas as happen in visible wavelengths (Simon *et al*., 2016).

Accordingly to Amaechi, Owosho and Fried (2018) the advantages of the NILT are the sensitivity to detect early caries lesion including the approximal surfaces; no interference of the stain or pigmentation in the images; able to provide images that can be recorded and used as educational purposes and can relatively indicate the deep of the lesion in approximal caries. They also highlighted the instrument limitations as the NILT is not efficient to detect caries underneath restorations; stain can interfere in wavelengths lower than 1200 nm and that the system cannot differentiate arrested from active lesion.

As the technology and approach is far from different, is difficult to compare photonics instruments in caries diagnosis. To overcome this limitation, the most common effect used to compare different diagnose instruments in medical field is to evaluate tree basic parameters: sensitivity, specificity and accuracy. The formula address the validity of the instruments and is related with true-positive (TP), true-negative (TN), false-positive (FP), and false-negative (FN) rates of a diagnostic test. The formulas that reflect this are: Sensitivity (positivity in disease) = (TP/(TP + FN)); specificity (negativity in health) = (TN/(FP + TN)); accuracy = ((TP + TN)/(TP + TN + FP + FN)) express in numbers between 0 - 1 (100%) (Ozcan, Guzel, 2017). In the caries research studies, sensitivity measure the ability to correctly diagnose caries lesion and specificity the correctly identify the sound area (Karlston, 2010). As higher the percentage, the best is the instrument evaluation.

III. DISCUSSION

Caries diagnosis, specially early non-cavitated lesions, are the daily challenges of the preventive dentist. Accordingly to Tonkaboni *et al*. (2018), the adequate caries detection system should be able to not only detect all caries lesions, including initial caries, but also enhance decision making and treatment plan.

The visual-tactile inspection is the most common method in clinical practice to evaluate and diagnose dental caries but it has some limitations that must be fulfilled by complementary diagnosis tools. One of this limitations is reference to evaluate the progression of caries lesions longitudinally, especially because of the subjectivity involved in visual-tactile inspection (Novaes *et al*., 2012). The visual-tactile evaluation can be effective for all sizes of caries lesion, including initial non-cavitated lesions in enamel, as it presents high sensitivity (Novaes *et al*., 2012) however may not present the adequate specificity, fact that can possible lead to more false negatives than expected. The opposite occurs in dentine lesion evaluation, where the specificity is higher but the sensitivity is moderate (Tassoker *et al*., 2019) and so increases the chance of false positives that can indicate unnecessary intervention.

The visual-tactile exam using the ICDAS system can improve the clinical evaluation and can reach a good accuracy. In dentin approximal lesions the sensitivity of 0.93 and the specificity of 0.84, as shown in the study of Erkstrand *et al*. (2011), are really high for the method in this surface but in this specific study the group performed direct lesion visualisation. The fact is that the major clinical challenging lesions are not presented in direct visualisation but instead, in normal dentition they are hidden in the approximal area. The other point to take into consideration is that the evaluator's performance with ICDAS is direct related to his/her previous training (Kockanat and Unal, 2017). Erkstrand *et al*. (2011) also evaluated the dental radiography accuracy and reinforced its limitations in early caries detection (<10% sensitivity). In dentin lesions, the dental radiography had 0.54 of sensitivity and no false negatives. Their results might even be overestimated when compared with a recent systematic review that analysed 177 studies using dental intra-oral radiography for caries detection. The systematic review demonstrated a median sensitivity of 36% (0.24/0.49) for approximal to 56% (0.53/0.59) for occlusal lesions and specificities above 0.87 (Schwendicke, Tzschoppe and Paris, 2015). Bozdenir *et al*. (2016) suggests that only caries lesion bigger than 2 to 3 mm deep into dentin or one-third of the buccolingual area are clearly viewed by the Rx imaging. Even that the Rx examination do not accurately show the depth, activity or cavitation of these lesions, dental intraoral radiography is still the most used method for approximal caries detection (Simon *et al*., 2016).

Based on the necessity of adjunct instruments for caries diagnosis to complement clinical evaluation and reduce ionising the patient, the Light-induced fluorescence (LF) and Transillumination techniques were introduced. In the study of Novaes and collaborators (2012), they tested three fluorescence instruments for dental caries detection in primary molars and compare them to traditional diagnosis instruments with the histology analyses as standard. In enamel caries, the fluorescence methods demonstrate less sensitivity (0.70-0.72) than the visual inspection. It was in dentin lesions that they had the higher sensitivity (usually higher than 0.85) and an accuracy ranging from 0.81-0.85. There was a small difference between the operators with inter-examiner coefficient of 83%, indicating high inter-examination accordance. The Rx demonstrate in this study that is really not indicated for enamel lesions (sensitivity of 31%) but confirmed that is a good complementary method to detect deep dentin caries. For inicial enamel caries in primary teeth, the best method used in their study was the visual-tactile exam using the ICDAS classification.

The LF presented good results of sensitivity and specificity also for approximal dentin caries, with the overall efficiency superior to ICDAS and digital Rx (Ko *et al*., 2015). In dentin deep lesions, the study of Ko and collaborators (2015) showed higher sensitivity of LF (64%) than the digital Rx (50%) with high specificity (88%), but in their study was less than the digital Rx specificity (94%). In the study of Bozdemir *et al*. (2016), histology confirmed that LF with the LF Pen recorded even higher sensitivity rates for both enamel (0.94) and dentin (0.79) caries decay. The accuracy of LF Pen (0.81) was higher than Visual-tactile ICDAS examination and Digital intra-oral radiography. It is interesting to say that the potentiality of the LF reading for approximal caries is improved when the laser beam is positioned in the buccal or lingual site of the tooth instead of the occlusal (Ko *et al*., 2015). It is also recommended to perform 3 screening in the same zone and record the highest value (peak value) (Kockanat and Unal, 2017). In the study of Alammari *et al*. (2013), they developed a clinical index based in the loss of fluorescence readings of the QLF in the occlusal superficies of the teeth and suggested a different clinical management index for dental caries diagnosis and treatment indication based on the mineral loss: less than 12% - monitoring, 12-23% - fissure sealants or remineralizer agents and 24-32% - class I restorative treatment. Complementing the good examples above, two previously Systematic Reviews (Baders and Shugars, 2004; Gomez et al., 2012) had already concluded the LF methods for caries detection are excellent complementary diagnostic tools for all types of tooth areas and types of lesions. The systematic review of Rosa and collaborators (2016) evaluated LF for permanent teeth and concludes that based on the 39 studies and 2082 dental sites, sensitivity of LF was 0.71 (0.69, 0.73), and the specificity was 0.81 (0.73, 0.82). The fact is that the technology is still getting improved and also the accuracy of the instruments, so more studies are needed. The second fact is that neither of them suggest that the Visual-tactile examination be set aside, on the contrary, it is still the clinical “gold standard”.

The Near-infrared light transillumination technique is very useful in dental diagnosis, as for occlusal or approximal sites, as for dentine or enamel tissues. In 2011, Staninec and collaborators used a 1300 nm NILT to demonstrate in a clinical study the applicability of the instrument in detecting non-cavitated occlusal caries and its possible application in caries diagnosis. The study of Tassoker *et al*. (2019) demonstrate that the modern NILT instruments have excellent accuracy *in vivo* (91.1%) and is even better than Visual-tactile examination in detecting early occlusal caries. The sensitivity of the instrument was 96.1% and was superior to LF in all sizes of lesions that were confirmed by histology.

The NILT is also a good instrument to evaluate deep dentin caries lesion. It has the same accuracy of the bitewing Rx, above 96.1% (Kühnisch *et al*., 2016), with the convenience of generate a real time image without exposing the patient to ionising radiation. Kühnisch and col. (2016) analysed *in vivo* the LF, NILT, Visual-tactile ICDAS system and digital dental bitewing Rx. Their evaluation with the LF resulted in several false negatives what pushed the sensitivity of the instrument to 66.7% of the real lesion diagnosticated. The NILT had excellent sensitivity, mostly in deep dentin lesions (99.2%), but was not able to detect many of the lesions involving the inner outer dentin and DEJ. This study also confirmed the limitation of the Visual-tactile examination in the diagnosis of approximal caries lesions in normal dentition. Even when affecting dentin, the sensitivity of the ICDAS system was less than 5% in this area. The study of Ozcan and Guzel (2017) also demonstrate that the NILT have great utility *in vivo* for approximal dentine caries diagnose. On their study, NILT and Rx presented more sensitivity (0.82-0.80) than Visual-tactile inspection and Laser Fluorescence. NILT also presented one of the highest accuracy (0.80).

Simon and collaborators (2016) tested NILT instruments *in vivo* in occlusal and approximal surfaces comparing to Digital Rx. Although their customised system did not presented good sensitivity (median of 0.53 ranging from 0.34 to 0.72) it presented excellent specificity (0.86 ranging from 0.76 to 0.93) and was superior than the Digital Rx in both areas tested. Tonkaboni and collaborators (2018) evaluated a commercial NILT system (Vista Cam iX Proxi, Dürr Dental, Germany) that uses 850 nm wavelength beam. They evaluated 3 distinct zones of the proximal surface: (1) the contact area (2) below the contact area to the cementoenamel junction (CEJ) and (3) below the Cement-Enamel Junction (CEJ). The results suggest that are differences in diagnose efficiency in the zones evaluated. For the (1) area NILT expressed more sensitivity (100%) than Visual-tactile evaluation and Rx. In the (2) area Visual-tactile evaluation and Rx obtained the best results for sensitivity although they were moderate (52%). For specificity the three methods were excellent (>98%). The (3) area was far from the NILT ability to reach and offer a good diagnose. Only the Rx could detect caries lesion below the CEJ. In this study of proximal surface, the overall sensitivity and specificity values were 0.49 and 0.99 for Visual-tactile, 0.53 and 1 Rx, and 0.63 and 0.96 for NILT.

The study of Lederer *et al*. (2018) tested two NILT systems with 780 nm laser wavelength and observed that both systems presented high sensitivity for sound (>0.94) and dentin caries (>0.76) as well good specificity of 79% and 98% respectively. As the results were compared with micro-CT, that can detect small differences in mineralization, the early enamel caries diagnosis was not very effective with NIRT (~59%) although presented no problem with false negatives (98% of specificity).

Some characteristics of the NILT instrument can interfere with the final image produced, as the beam energy source, the wavelength used and require especial details when taking the image as the appropriate angle for each site and during imaging acquisition an air spray must be employed to dry the tooth surface to remove saliva em bubbles thus increasing lesion contrast (Simon *et al*., 2016). Staninec *et al*. (2010) demonstrated that to improve diagnosis, the geometry used to capture the image with NILT should be variating and that for better approximal imaging the beam light should be applied near the gum-line following the occlusal imaging geometry capture. With that, the images of the NILT in approximal evaluations are very similar in appearance to that of convention Rx *bitewings* (Simon *et al*., 2016).

The digital radiography is still used in large scale in the dental clinic for caries diagnostic. It has the disadvantage of using ionising radiation but has the advantage of, complementary to the above methods mentioned, it is reliable for estimate the caries deep in dentin lesion and it is possible to determinate the relationship of the lesion with the pulp tissue (Kühnisch *et al*., 2016). Contrasting, both LF and NILT techniques allow many images production as they do not employ hazard radiation (Simon *et al*., 2016). Except for visual-tactile diagnosis, all instruments discussed can have their images stored in the patient file for later comparison. In this review, three basic examination indexes where taken into consideration: sensitivity, specificity and accuracy. The evaluation of the studies showed that both new methods were validated to caries diagnosis, including approximal caries and occlusal no-cavitated caries lesion. The LF median sensitivity between studies range from 0.69 to 0.73, and the specificity ranged from 0.73 to 0.82 for quantitative methods. For the NILT instrument, the sensitivity range was 0.66 to 0.92, the specificity range 0.76 to 0.98 and the accuracy over 0.91. There are differences in sensitivity depending of the surface evaluated but that is an overall better result of LF and NILT than dental radiography almost all sites. Only in deep dentin lesion that dental radiography is superior in sensitivity (>0.52) and attain 100% of specificity. The specificity of Dental radiography is also high in most of the sites evaluated.

Most of the studies testing these new methods are *in vitro* studies and in this format they cannot reflect directly the clinical outcomes. Laboratory results demonstrate higher sensitivity and specificity when compared to clinical studies (Tassoker *et al*., 2019) employing these technologies. Also, we must consider that the differences in the results can be related to the storage conditions, stain or plaque in the dental surface and must be seeing more carefully.

IV. CONCLUSIONS

Based on the evaluation of the literature, we can conclude that both Laser Fluoresce and Near-Infrared Light Transillumination are good complementary diagnostic tools for caries detection, both enamel and dentin caries. Visual-tactile examination is the base of caries diagnose but these photonics instruments can offer an improved capability, both in sensitivity and specificity than the Rx or, in some cases, even the visual-tactile examination. We must consider that each site of the tooth presents its personal challenges and the use of the best of each instrument can overcame this limitations. Dental radiography, especially the digital radiography, still have space in the dentist arsenal and is very indicated when under CEJ evaluations are needed, or when there is a suspicious communication with the pulp tissue. The other sites can be covered by LF, especially the occlusal area where imaging with the laser fluorescence can be very useful and with the NILT especially in the approximal areas. In those areas NILT provides high sensitivity and in the images the involvement of the dentine can be estimated.

The LF instruments, especially the quantitative ones can provide a numerical scale that make the interpretation less subjective and also can provide an estimation of the amount of de-mineralization. In the image production instruments, the images can also provide a longitudinal evaluation of the lesion process as long as many images are taken. It is also a characteristic that can be used with NILT systems. Digital Rx can also have their image storage but the re-exposure of the patient to longitudinal evaluation might not be recommended. The other fact is that is also not recommended take many frames in the same evaluation point to have several incidences and make future comparisons easier.

The Visual-tactile examination with the ICDAS system is excellent for direct visualisation but demand complementary information in approximal suspected lesions. Also, demand an intense training to diminish the subjectivity. A photograph is an important tool for longitudinal estimation of the characteristics of the evaluated lesion. All the instruments discussed have their limitations and new tolls are been developed and improved such as the Optical Coherence Tomography (OCT), making the future of the preventive diagnose more accurate and allowing the best management of dental caries.

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