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A review of detection of early interproximal caries in posterior teeth.

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Dissertação conducente ao Grau de Mestre em Medicina Dentária (Ciclo Integrado)

Trabalho realizado sob a Orientação da Mestre Lígia Rocha (MSc)

Gandra, 29 de setembro de 2021

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RESUMO

Objetivo: O objetivo deste trabalho foi realizar uma revisão sistemática para comparar e determinar as formas mais eficazes de diagnosticar lesões de cárie inicial interproximal, no sector posterior, em dentes permanentes.

Método: Efetuou-se uma pesquisa bibliográfica na plataforma PUBMED utilizando as palavras-chave: (((((((caries) OR (carious lesion)) AND (interdental)) OR (interproximal)) AND (diagnosis)) OR (diagnostic)) AND (detection)) AND (approximal caries). Critérios de inclusão envolveram trabalhos *in vitro* e *in vivo,* com disponibilidade de texto integral gratuito, disponível entre Maio de 2011 e Maio de 2021.

Resultados: Resultados mostraram que o método visual – tátil não permite uma precisa avaliação das lesões. As radiografias convencionais não mostram diferenças significativas entre as modalidades digitais e convencionais. O método NILT mostrou melhor fiabilidade, sensibilidade e especificidade em comparação com a radiografia convencional e PSP, mas sensibilidade semelhante à do DDR para a imagiologia das lesões interproximais do esmalte. O método DIFOTI mostrou ter uma precisão superior à radiografia relativamente ao diagnóstico da profundidade da lesão e à detecção de cáries interproximais não cavitadas e é comparável à radiografia nos casos de lesões interproximais avançadas.

Finalmente, LFpen mostrou uma maior precisão e sensibilidade para lesões de esmalte e uma excelente reprodutibilidade em comparação com métodos radiográficos.

Conclusões: Atualmente, o método visual-tátil apenas é reconhecido como meio auxiliar de diagnóstico adjuvante. Os métodos radiográficos ainda são os mais utilizados devido à suas polivalências, contudo, hoje em dia, outros métodos como o NILT, DIFOTI e, LFpen, são especificamente mais eficazes no diagnóstico precoce de lesões de cárie inicial interproximal.

KEY TERMS: caries; interproximal; approximal; diagnosis; detection

ABSTRACT

Objective: This study aimed to perform a systematic review to compare and determine the most effective ways to diagnose early interproximal caries in the posterior region of permanent teeth.

Method: A bibliographic search was performed on the PUBMED platform using the keywords: (((((((caries) OR (carious lesion)) AND (interdental)) OR (interproximal)) AND (diagnosis)) OR (diagnostic)) AND (detection)) AND (approximal caries). Inclusion criteria involved *in vitro* and *in vivo* papers, with free full text available between May 2011 and May 2021.

Results: Results show that the visual-tactile method does not allow complete confidence in the accuracy of lesion assessment. Conventional radiographs show no significant differences between digital and conventional modalities. The NILT method showed better reliability, sensitivity, and specificity compared to conventional and PSP, but similar sensitivity to DDR for imaging interproximal enamel lesions. The DIFOTI method showed the best inter-examiner agreement and its accuracy is superior to radiography regarding the diagnosis of lesion depth and detection of non-cavitated interproximal caries and comparable to radiography regarding advanced interproximal lesions.

Finally, LFpen showed higher accuracy and sensitivity for enamel lesions and excellent reproducibility compared to radiographic methods.

Conclusions: Nowadays, the visual-tactile method is still not recognized, but finds an interest, alone or with other methods. Radiographic methods are still the most widely used due to their polyvalence, however, today other methods such as NILT, DIFOTI and, LFpen, are specifically more competent in the early diagnosis of interproximal lesions.

KEY TERMS: *"caries"; "interproximal"; "Approximal"; "Diagnosis"; "detection"*

TABLE OF CONTENTS :

LIST OF FIGURES:

LIST OF TABLES:

LIST OF ABBREVIATIONS:

V.I: Visual Inspection / Visual-tactile examination

T.I: Transillumination

NIR/ near-IR: Near-Infrared Light system

NILT / NIR TI: Near-Infrared Light Transillumination

PSP: Photostimulable Phosphor / Photo Stimulable Plates

D.R. / DDR: Digital Radiography / Direct Digital RadiographyB.W.: Bitewing radiography

CCD: Charge-coupled device

LED: Light Emitting Diode

LF pen / LF : Laser Fluorescence Pen-type device / Laser Fluorescence

DIFOTI: Digital Imaging Fiber-Optic Transillumination

P.A : Periapical radiograph

InGaAs camera: Indium Gallium Arsenide Camera

ORCA: European Organisation for Caries Research

IADR: International Association for the Dental Research

FDA: Food and Drug Administration

NIH: National Institutes of Health

1. INTRODUCTION

Dental caries is one of the oldest and most common chronic infectious diseases in humans which results from specific bacteria as *Streptococci*, *Lactobacilli*, and *Actinomyces* adhering to teeth that metabolize sugars to produce acid, demineralizing the dental structure. (1) Dental caries is a multifactorial disease whose main factors are diet, dental plaque or microbial load, the host behavior or retention factors, and the "time" as the duration of the interaction of the factors above. (2) There are many theories to explain the fundamental basis of the etiology of caries, which the most accepted was from W.D Miller (3) in 1881: the "chemo-parasitic theory." This theory explains the combined effect of acid and acid-producing bacteria in the oral cavity. Based on this theory, several models are added to support the possible etiology of dental caries, such as the J.L Williams (1) concept of dental plaque-causing dental caries and the Keyes and Fitzgerald (1) model to explain the potential causal relationship of the presence of specific microorganisms such as *streptococci*, *lactobacilli* in dental plaque and their impact on dental caries. (1)(4)(5)

The term «dental caries» from Latin origin was mentioned for the first time in scientific writings in 1634. (6) Even today, there is confusion about the terminology of initial caries: "Initial lesions", "early lesions", "White Spot", "pre-cavitated lesions", "non-cavitated lesions", "hidden caries lesions", are all terms that can be defined differently according to different interpretations and classifications. Does the term "initial" or "early" caries necessarily imply a limitation to the superficial layer of the tooth (enamel)? Or can dentin be considered? Since the lesion is confined to the internal third of the enamel non-invasive treatment options are usually the same. (7) According to Beauchamp *et al.* (8) "The tooth surface should have no evidence of a shadow indicating dentinal caries, and, if radiographs are available, they should be evaluated to determine that neither the occlusal nor proximal surfaces have signs of dentinal caries".(8)

It seems more relevant to distinguish between cavitated and non-cavitated lesions rather than simply refer to "initial" lesions. The clinical terms cavitated and non cavitated lesions effectively include all stages of the progression of a carie lesion from the first signs of demineralization (early lesions, initial lesions) to the presence of a dentine lesion without cavitation. (7)

The American Dental Association (ADA) and their Caries Classification System (CCS) for Clinical Practice depict caries lesion as "The clinical manifestation of caries disease". (9) A patient diagnosed with caries disease may have few or many caries (clinical manifestation) lesions, varying numbers, and extensions. Each caries lesion can be classified as non cavitated or cavitated. (9) A non cavitated lesion refers to initial caries lesion development before cavitation occurs. Noncavitated lesions are characterized by a change in color, glossiness, or surface structure because of demineralization before a macroscopic breakdown in surface tooth structure. These lesions represent areas with net mineral loss due to an imbalance between demineralization and remineralization. (9)

This review will focus on these types of lesions, which are the most difficult to diagnose. We are mainly interested in the interproximal regions of the posterior teeth, which are difficult-to-access areas, and with reduced visibility. With the evolution of technologies, the diagnosis of dental caries also progresses; it now includes various techniques. Therefore, this review will compare and determine the most effective way to diagnose the non cavitated interproximal caries in the posterior region.

2. METHOD

A literature search was carried out on PUBMED (via National Library of Medicine), using the following combination of search terms: (((((((caries) OR (carious lesion)) AND (interdental)) OR (interproximal)) AND (diagnosis)) OR (diagnostic)) AND (detection)) AND (approximal caries). The inclusion criteria involved articles published in the English language, between May 2011 and May 2021, regarding *in vitro* and *in vivo* studies on detecting early interproximal caries in posterior teeth. The exclusion criteria were the following: articles without abstract. The total of articles was compiled for each combination of key terms, and therefore the duplicates were removed using Mendeley citation manager (Elsevier B.V.). Two authors (N.B.; L.R.) independently evaluated the titles and abstracts of potentially pertinent articles. Selected articles were individually read and analyzed concerning the main aim of this study. The following factors were considered for the present study: titles, author's names; publication year; type of study; the purpose of the study; equipment used, and conclusions.

3. RESULTS

The literature search on PUBMED identified a total of 260 articles, as seen in Figure 1. After preliminary filtering, 224 studies were excluded because they did not assemble to the research inclusion criteria. Based on the title and abstract, a further 10 articles were excluded. The remnant 26 potentially relevant studies were selected for a full reading. However, 3 studies were excluded because they did not match the eligibility criteria of this study. At last, 23 articles were included in the present scoping review.

Of the 23 selected studies, publication years ranged from 2011 to 2021, several 14 studies were conducted *in vitro*, 9 *in vivo*. The objective of 16 of these studies was to compare different evaluation methods; for 6 studies of this selection, the goal was to assess changes in influential factors of the diagnostic method concerned. Finally, in one study, the aim was to develop an automatic diagnostic method.

A summary detailing the characteristics of each included study and the references related to these included studies is provided in Table 1 & Table 2.

Later on, to complete the work done, 34 articles were added to support our remarks. Nine of them, in the introduction, explain the origin of caries and the nomenclature in use to qualify initial caries. Five of them explain what interproximal caries are. Nine of them tell us the chronology of the appearance of diagnostic methods. Finally, 11 of them explain the advantages and disadvantages of each diagnostic method.

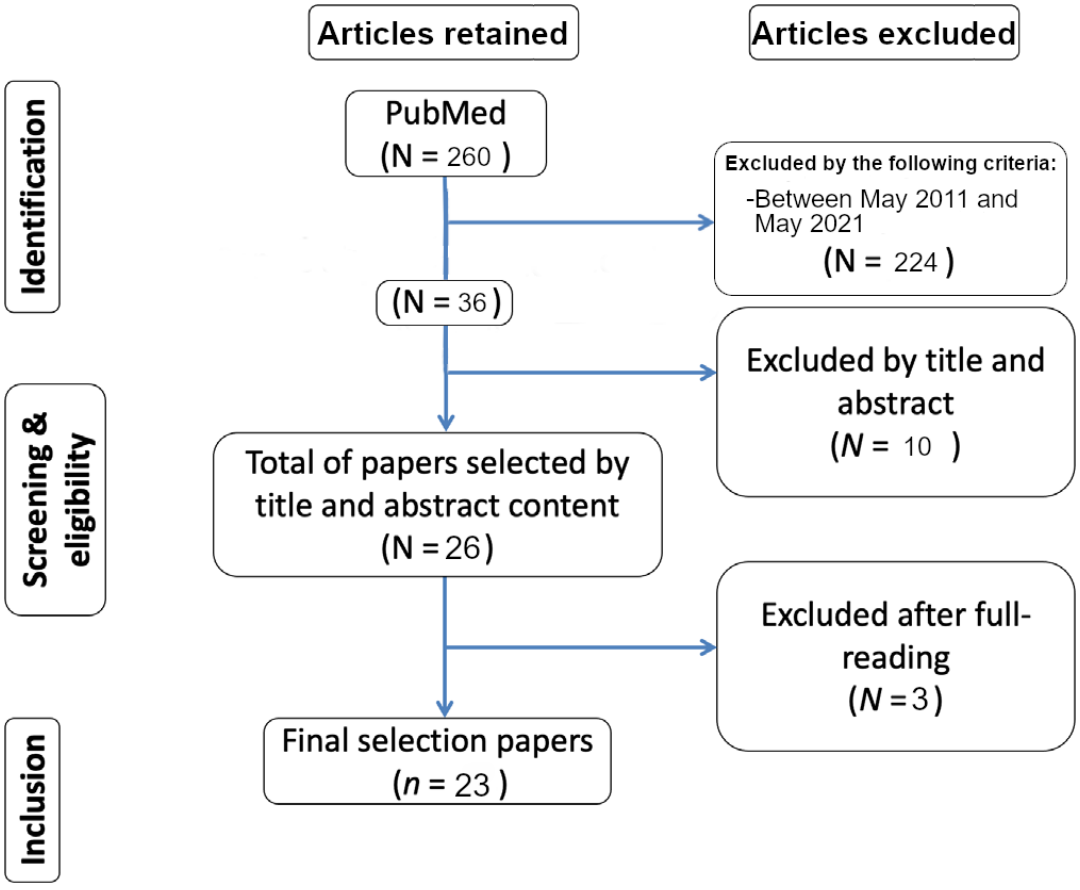

Figure 1: Flow diagram of the search strategy used in this study.

Table 1: Relevant data of the *In Vitro* studies selected.

Author (year)	Type of study	Purpose of the study	Equipment used	Conclusions
Madalli et al. (2014)	*In Vitro*	Accuracy between Kodak Ultraspeed, Ektaspeed and, Agfa Dentus M2	- 100 extracted in groups of 5 teeth/plaster model. -fresh & aged processing solution.	-All films had equal diagnostic accuracy in fresh solution. -Ektaspeed film should be the film of choice (significant reduction in patient radiation) -Processing solutions should not be used longer than 3 weeks.
Pakkala et al. (2012)	*In Vitro*	- 3 different types of displays - 3 different room illuminance settings ranging from low illumination to higher illumination levels	- 100 extracted human premolars and molars. - phosphor plate system Digora FMX - sunlight from windows -fluorescent lights - **Dell 2007FP** an off-the-shelf colour display, might be found at a dental practice - **Eizo Flexscan MX210**, DICOM-calibrated colour LCD clinical viewing station - **Barco MDCG2121CB**, DICOM-calibrated grayscale LCD display designed for medical diagnostic work.	-Different displays and room illuminance levels did not affect the overall accuracy of radiographic caries detection.

Krzyżostaniak et al. (2015)	*In Vitro*	-Cone beam computed tomography (CBCT) - intraoral radiographic systems	- 135 extracted human posterior teeth - Conventional film (Kodak Insight) - Digital system (PSP plates Digora Optime, Soredex) - CBCT system (NewTom 3G, Quantitative Radiology)	-The diagnostic accuracy of all three tested radiographic systems is low, and it is necessary to use other methods to improve early caries detection.
Kajan et al. (2015)	*In Vitro*	-Photostimulable phosphor (PSP)	- 48 extracted human posterior teeth -PSP sensor Digora - Miniray intraoral X-ray unit Soredex - bitewing film holder (Kerr Hawe) - Scanora version 0.8 software -Evaluated histologically as the gold standard	-The application of "Sharpening U.M." (highest sharpening function in the Scanora 0.8 software) along with the "Magnification 1:3" processing option improved the diagnostic accuracy and the observer agreement more effectively than the other processing procedures.
Abesi et al. (2012)	*In Vitro*	-Charge-coupled devices (CCD) - Photo Stimulable Phosphor (PSP) -Film radiography	-72 non-cavitated approximal surfaces of extracted human posterior teeth - CCD Dixi3 (Planmeca) - PSP Digora PCT (Soredex) - E-speed film (Kodak) - hard- tissue sectioning apparatus (Acuatum 50) for histological analysis, which served as the gold standard	-The results demonstrated that the diagnostic accuracy of digital images is similar to that of conventional film radiography in the detection of non-cavitated approximal caries

Ghoncheh et al. (2017)	*In Vitro*	-Photostimulable phosphor plates (PSPs)	- 52 posterior extracted teeth - Mounted into wax blocks - DIGORA PSP - MINRAY® device - IsoMet saw CNC - stereomicroscope (Olympus, SZX10)	-To detect approximal caries more accurately, DIGORA PSPs should be scanned within 30 min after exposure.
Shokri et al. (2018)	*In Vitro*	-Digital radiographs -Enhancement filters -Denoising filters	-120 proximal and occlusal surfaces of posterior human extracted permanent teeth. -MinRay intraoral radiography unit Soredex - Photostimulable phosphor plates (Optime soredex) -LCD display monitor (L40 Satellite 15, Toshiba) - diamond disc parallel on CNC machine - stereomicroscope Olympus (gold standard)	-Application of enhancement filters, particularly enhancement filter 2 with/without denoising, increases the accuracy of caries detection on digital radiographs.
Schneider et al. (2020)	*In Vitro*	Optical coherence tomography	20 extracted human teeth OCT. x-ray microtomography Skyscan light microscopy Stemi 2000-C dental unit TENEO Nupro Sensodyne Stain Removal and polish Nikon D7000 FOTI-DIA-STICK Heliodent DS Dental X-ray unit VistaScan Mini Plus DBSWin software	- The hand-held OCT probe maybe a valuable non-invasive supplement for intraoral caries diagnosis and the evaluation of non-metallic adhesively luted restorations.

Maia et al. (2011)	*In Vitro*	- Transillumination (T.I.) system using near-infrared light (NIR) VS - bitewing radiographs	- 14 mesiodistal sections of teeth -stereomicroscope images as a gold standard.	-NIR TI images showed reliability, and the enamel caries surfaces were better identified than on dental radiographs.
Abogazalah et al. (2017)	*In Vitro*	- Near Infrared Light Transillumination (NILT) VS - Digital Radiography (D.R.)	-30 extracted premolars - micro-computed tomography (μ-CT) - CariVu™ (NILT) - Schick 33 CDR sensor (D.R.)	-NILT and D.R. performed the same regarding the accuracy for non-cavitated approximal caries detection -NILT was superior to D.R. in terms of repeatability, agreement and correlation with μ-CT.
Ástvaldsdóttir et al. (2012)	*In Vitro*	- Digital imaging fiber-optic transillumination (DIFOTI) VS - Film and digital radiography	- 112approximal surfaces were scored for caries - DIFOTI instrument (Electro-Optical Sciences Inc) - Microsoft PowerPoint 2002 - Hewlett Packard (L1520) monitor - 22mm Plexiglas to simulate soft tissue - darkroom - Planmeca intraoral radiographic equipment - Sigma direct digital sensor and Cliniview software (Instrumentarium) -Buehler IsoMet low-speed precision saw	- The results show that under in vitro conditions, the diagnostic accuracy of DIFOTI in detecting early approximal enamel lesions is greater than that of film and digital radiography. In contrast, the potential for detecting lesions in dentin is similar for all three methods.
De Souza et al. (2014)	*In Vitro*	- Pen-type laser fluorescence device (LFpen) VS -Bitewing radiographs (B.W.)	-102 permanent and 144 primaries anterior approximal surfaces -DIAGNOdent -X-ray machine Spectro 60X -Kodak insight films -X-ray film developer (Dent-X 9000) -sectioning machine (ISOMET 1000)	-LFpen presented better reproducibility for primary and permanent teeth and higher accuracy in detecting caries lesions at D1 threshold than B.W. for permanent teeth. LFpen should be used as an adjunct method for approximal caries detection.

Bozdemir et al. (2016)	*In Vitro*	- Light-emitting diode (LED) VS -Laser fluorescence (L.F.) VS -Radiographic VS -Visual examination	- 156 approximal regions were evaluated -PSP (Vista Scan Mini) - Air drier, aid probe and a light reflector for the VI (Visual inspection) - LED device Midwest Caries I.D.	- The ability of bitewing radiography to identify sound surfaces was better than that of the other methods. The L.F. device was the most sensitive tool for detecting approximal surfaces with caries, followed by the LED device. VI was least sensitive in detecting caries lesions.
Valizadeh et al. (2015)	*In Vitro*	- computer software	-183 proximal surfaces as a database for designing the software -Dixi® digital radiographic system -Gendex intraoral X-ray system -stereomicroscope Olympus, SZX9 -diamond disc (0.15 mm diameter)	-The designed software could detect a significant number of dentin caries and properly measure the depth of carious lesions in enamel and dentin. However, the software had limited ability in detecting enamel lesions.

Radiographic Studies NILT Studies DIFOTI Studies LFpen Studies

Table 2: Relevant data of the *In Vivo* studies selected.

Author (year)	Type of study	Purpose of the study	Equipment used	Conclusions
Simon et al. (2016)	*In Vivo*	- Imaging at 1,300 nm and 1,500–1,700nm **VS** - Digital radiographs	- 109 teeth on 40 test subjects - 3 intra-oral NIR imaging probes (Using InGaAs camera and NIR broadband light sources) - Polarised light microscopy and microradiography as a gold standard - Digital radiographs (CareStream 2200 System, Kodak)	-The sensitivity of the combined near-IR imaging probes was significantly higher than radiographs for both occlusal and proximal lesions. - The sensitivity of each near-IR probe was either individually equal to or higher than radiography.
Lara-Capi et al. (2017)	*In Vivo*	- near-infrared light transillumination **VS** - clinical and radiographic examinations	- 52 randomly selected subjects -1664 approximal surfaces - DIAGNOcam - Bitewing radiographs (Planmeca intraoral & Kodak® UltraSpeed DF42)	-The transillumination method showed a high concordance compared with traditional methods -Transillumination showed to be a reliable method and as effective as traditional methods in caries detection.

Baltacioglu et al. (2017)	*In Vivo*	-Near-infrared light transillumination (NILT) **VS** -PSP-Bitewing	- 52 untreated, posterior teeth - Clinical examination - Bitewing (Digore Optime) - KID software (KaVo Integrated Desktop/version)	- NILT examination has an appropriate sensitivity and diagnostic accuracy for detecting early interproximal caries lesions and can be considered as a method of choice for detecting caries without the use of ionising radiation.
Melo et al. (2019)	*In Vivo*	- Near-infrared Light-transillumination (NILT) **VS** - Direct digital-radiography (DDR)	- 138 posterior teeth - DIAGNOcam - Gendex Oralix - 0.5 mm-in-diameter diamond-bar was used as a gold standard	- NILT showed sensitivity similar to that of DDR and higher correlation than DDR for approximal dentinal caries detection - it may be used to monitor the progression of caries without exposing the patient to ionising radiation, this being of particular interest in growing patients and pregnant women.
Antipoviene et al. (2019)	*In Vivo*	- Digital imaging fiber-optic transillumination (DIFOTI) **VS** - Periapical radiographs (P.A.)	- 10 Patients; 31 approximal caries lesions - intraoral X-ray system C.S. 2200® - DIAGNOcam™	- Both produce evaluations of the depth of approximal caries lesions that do not match
Ribeiro et al. (2015)	*In Vivo*	- DIAGNOdent (LFpen) **VS** - visual-tactile examination	- 33 children were selected, and 209 approximal surfaces - bitewing radiography (B.W.).	-Visual-tactile examination showed better results in detecting sound surfaces and approximal caries lesions without tooth separation.

			- examined by computed microtomography as a reference standard.	
Mendes et al. (2012)	*In Vivo*	- visual inspection **VS** - visual inspection with radiographic and laser fluorescence pen (LFpen)	- 126 children, 1,213 surfaces - plane buccal mirror and ballpoint probe - Kodak Insight radiographic films - DIAGNOdent pen - orthodontic rubber rings	-Adjunct radiographic and laser fluorescence methods offer no benefits to the detection of caries in primary teeth in comparison to visual inspection alone
Bizhang et al. (2016)	*In Vivo*	- Pen-type laser fluorescence device (L.F. pen) **VS** - Bitewing radiographs (B.W.).	- 141 surfaces utilised for the study - Radiographs used as the gold standard	-Dentin caries on approximal surfaces could be detected equally well by the L.F. pen as by the bitewing radiographs.
Menem et al. (2017)	*In Vivo*	- Pen-type laser fluorescence (LFpen) **VS** - Digital bitewing radiography	- 90 approximal surfaces of permanent posterior teeth - DIAGNOdent pen - Intraoral sensor Sopix USB - reference standard was the visual-tactile inspection	- The LFpen's diagnostic performance was accurate and significantly better than digital bitewing radiography in detecting approximal caries lesions in permanent posterior teeth

Radiographic Studies NILT Studies DIFOTI Studies LFpen Studies

4. DISCUSSION

4.1. The Interproximal caries

In individuals (even with diastema), the approximal surfaces form contact points between adjacent teeth (Figure 2).

The main factor in carious lesions is caused by the biofilm-tooth interface and the acid production of the biofilm on the tooth surface. By metabolizing carbohydrate substrates, the bacteria form lactic acids, which cause changes in pH, and these fluctuations can result in a greater demineralization potential of the tooth than remineralization potential. As a result, a mineral deficit is observed, resulting in a carious lesion which can progress to cavitation and destruction of the tooth. (10)

Therefore, it is essential to pay particular attention to the biofilm's so-called "Stagnation zones" (Figure 2). Their surfaces areas are approximal and occlusal surfaces and surfaces along the gingival margin. These are the areas less prone to mechanical wear, such as tongue, cheeks, abrasive foods, and toothbrushing, and limited in saliva and fluor access favoring respectively, a more acidogenic environment and an impossibility of remineralization, which makes this ground even more fertile for the development of carious lesions. (11)(12)

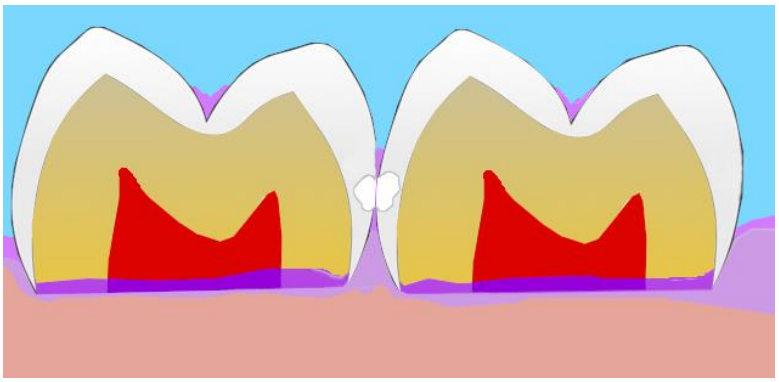

Figure 2: Schematic drawing of a posterior region with biofilm and contact point affected by white spot lesion.

On the approximal surfaces, these lesions developed between the contact point and the gingival margin, resulting in "white spot lesion" (Figure 2), which are according to the ORCA and the IADR consensus on terminology: "A popular term for non-cavitated lesions in the past. Which refers solely to the color of the lesion, has no bearing on the activity of the lesion, and may be confused with other types of pathology such as dental fluorosis or MIH.".(13)

There is a real urgency to diagnose interproximal caries as soon as possible and in the most effective ways. Once the lesion extends to the dentine, it is generally impossible to remove the cavitated lesions by removing the biofilm (ex: flossing). Since dentin is composed of about 50% mineral structure, and most of it is located in the intertubular spaces, the demineralization process tends to follow the direction of dentine tubules, and caries progression tends to be faster than in enamel. (14)

Fortunately, various methods have emerged to diagnose interproximal caries with more or less sensitivity over the years and technological developments.
(Figure 3 in Appendix).

The technique used is the visual-tactile method, in which the examiner uses an oral mirror and a proper explorer probe to make a clinical judgment. (15) Then came the radiographs, which saw their days around the 1900s but did not democratize commercially in dentistry until the 1920s. (16) They were first developed using a dental film based on silver halide crystals; it will be necessary to wait until the 1980s to see the development of the first phosphorus plates and the 1990s to the first digital radiographs based on a charge-coupled device. (17)

Along with radiography, decade 90 will see the appearances of various methods of diagnosis like the near-infrared light transillumination (NILT) in 1995, which uses the optical properties of decayed enamel, modified by the increased porosity, which results in an augmented diffusion when light passes. (18) A few years later, in 1997, it will be coupled to a Charge-coupled device to increase the accuracy of its diagnosis; it is the appearance of the Digital Imaging Fiber-Optic Trans-Illumination (DIFOTI). (19)

Then, in 1998, the laser fluorescence device will appear based on the principle that when Diode laser is irradiated on the dental surface, it is absorbed by intraoral bacteria and emit fluorescence. (20)

4.2. The visual-tactile method

The visual-tactile method is the latest method still used now; in 1869, an anonymous dentist from Missouri, USA, already reported using a sharp instrument to detect caries lesions. (15)

However, since the late 19th century, it has been recognized that detecting and classifying dental caries are not easy tasks. The International Caries Classification

Management System (ICCMS™) made in 2014 a classification for approximal tooth surfaces that describes caries categories at different stages; according to them, the "Sound surfaces have no visible caries when viewed clean and dry. Non-carious white or brown marks on tooth surfaces must be differentiated from early caries lesions."

> "The **Initial stage of caries** is characterized by the first visual change in enamel (seen only after prolonged air drying). These lesions appear light or dark brown non-cavitated areas confined to the pits to fissures in occlusal surfaces. On smooth surfaces, these lesions appear as non-cavitated white demineralization bands that parallel the gingival margin." (21)

Many reviews show the consistency regarding the use of explorers, such as misdiagnosis of caries lesions and "hidden caries." For example, in 2001, the NIH Consensus Development Conference on Dental Caries Diagnosis and Management Throughout Life concluded that "...the use of sharp explorers in detecting primary occlusal caries appears to add little diagnostic information to other modalities and may be detrimental." (22)

That is why Macey R, Walsh T *et al.* (23) tried to determine the diagnostic accuracy of different visual classification systems to detect and diagnose non-cavitated dental caries. They found that the visual-tactile method does not allow complete confidence in the assessment accuracy because of the considerable heterogeneity present in the studies due to various biases such as oral cavities with dental plaque, tooth coloring, and restorations, which future studies will need to correct. Finally, even if a treatment is provided due to a "false positive," the latter would be non-invasive (e.g., fluoride varnish). Although unnecessary, it would only develop a low potential for undesirable events but actual costs on healthcare resources and finance costs. (23)

In conclusion, even if the visual-tactile method's effectiveness is not universally recognized, nowadays still finds an interest in our dental offices, alone or in combination with other auxiliary methods. Because it could allow earlier identification of a disease with less invasive treatment and less destruction of tooth tissue, reducing the need for treatment with aerosol and radiation generation procedures, potentially resulting in a reduced cost of care for patients and healthcare services.

4.3. Radiographic method

4.3.1 Conventional film radiographs

Analog radiography is one of the oldest and most fundamental methods of caries diagnosis, used since the beginning of the 20th century, particularly in detecting interproximal caries. It is known that the earliest evidence of this disease can remain hidden until there has been some surface damage and becomes visible to the naked eye. Then, as the disease progresses slowly in the early stages, it can be controlled or even eliminated before surface cavitation. (24)

Nowadays, researchers seek tools with sufficient sensitivity and specificity to accurately diagnose primary non-cavitated caries of the approximal region. Over the past, the diagnostic accuracy of digital radiography systems has been compared with conventional film systems. (25) Some studies consider the image quality of radiographic films comparable to that of the systems with charge-coupled devices (CCD) or the phosphor plates. Other studies reported their superiority; however, few studies have been implemented on non-cavitated interproximal caries detection. (26)(17)

Therefore, F. Abesi *et al.* (27) tried to determine the diagnostic accuracy of CCD and PSP plates versus film radiography in detecting non-cavitated approximal caries and demonstrated no significant differences between digital and conventional radiographic modalities in the detection of non-cavitated interproximal caries. (27)

However, the advent of digital imaging is transforming the practice of radiology. Computers are increasingly prominent in dental offices, and this role is growing as various functions, such as scheduling appointments, invoicing procedures, and creating patient records, are integrated into practice management software solutions. Thus, it is no longer a matter of "if" but rather "when" all dental offices will use digital imaging.

Although digital radiography has many advantages, which will be discussed below, it is essential to remember that the excellent image quality and the relatively low cost of a properly exposed and processed film maintain film-based radiography competitive with digital alternatives.

4.3.2 Photo Stimulable Phosphor plate (PSP)

There are many reasons for moving from film to digital systems. For example, digital imaging eliminates chemical processing or lead foil, thus preventing hazardous waste generation. In addition, images can be digitally transferred to other members of the medical profession without altering the original image quality. However, digital systems also have certain disadvantages compared to films: the initial costs are relatively high, some components are sensitive to handling and expensive to replace, and because digital systems technologies are in permanent evolution, there is a high probability that the systems will become obsolete or that manufacturers will cease operations. (28)

The Photo Stimulable Phosphor plate (PSP) is one of these digital imaging systems. Developed in the 80s, it will not be marketed until 1994. Its technology absorbs and stores X-ray energy and releases it as light when stimulated by another light of an appropriate wavelength. (17)(29)

Digital radiography is displayed on a computer screen, allowing new processing options that were not available with the films. Patient records are also used to being viewed on the same screen and visualization conditions, while the interpretation of a radiographic image does not necessarily need the exact requirements in terms of depth, resolution, luminance, contrast response, or room illuminance. All these new features make us wonder if these new digital benefits come at the detriment of diagnostic accuracy?

T. Pakkala *et al.* (30) hypothesized that higher display luminance could compensate for high room illuminance and decided to test three types of displays in three different levels of ambient lighting. Finally, Z. Kajan *et al.* (31) have analyzed the effects of noise reduction, sharpening, enhancement, and image magnification on the diagnostic accuracy of the PSP. Results conclude that the quality of the display and room illuminance does not have a significant effect, but the application of sharpening and magnifications processing options could improve the diagnostic accuracy in the detection of non-cavitated approximal dental caries. (30)(31)

Another type of digital diagnostic method is just as commonly used in dental clinics, which is charge-coupled devices. These kinds of detectors can generate a digital image in the computer without any other external device.

4.3.3 Charge-coupled devices (CCD)

The charge-coupled device, also called intraoral solid-state detectors or sensors, is a digital image receptor whose main clinical advantage is the direct availability of the image after the exposure. However, although reduced by the continued miniaturization of electronic components, the sensor is quite bulky. In addition, most of them incorporate a cable which can cause discomfort to the dentist to place in the mouth and requires adaptation. (28)

Each digital system presents images through its software, which often differs in design, understanding, quality, and number of processing options. In larger institutions, e.g., dental schools and hospitals, universal software for displaying images from all systems are made on the assumption that the image quality and diagnostic accuracy are not affected. This procedure is used because it is too inconvenient for the observer to evaluate the various images in their respective software.

Therefore, H. Hintze *et al.* (32) compared the diagnostic accuracy for caries detection using the system's dedicated software with that obtained using the general software. There were no significant differences in diagnostic accuracy for the detection of approximal and occlusal caries lesions, which makes it reasonable to use general software for displaying and enhancing digital radiographs. Furthermore, from a clinical point of view, the daily use of general software for all digital radiographs also allows observers to become familiar with its enhancement features, reducing examination time compared to using software that is only occasionally used. It is a good result in a department where several different digital radiography systems are used, as universal software generally speeds up and facilitates the diagnostic procedure. (32)

After analyzing the different radiographic diagnostic methods, we can conclude that there is no method more accurate than another in diagnosing non-cavitated interproximal caries. However, each method has its advantages and disadvantages in its use. Moreover, the choice of one of the methods should only be made in response to the individual practitioner's needs.

4.4. Near-Infrared Light Transillumination (NILT)

Devices using transillumination were initially designed for the detection of proximal caries. By sending a beam of light towards the tooth surface, the light is then directed through the contact areas of the proximal surfaces. Since caries does not transmit the same amount of light as healthy enamel or dentin, a shadow area will appear on the illuminated tooth (Figure 4). (33)

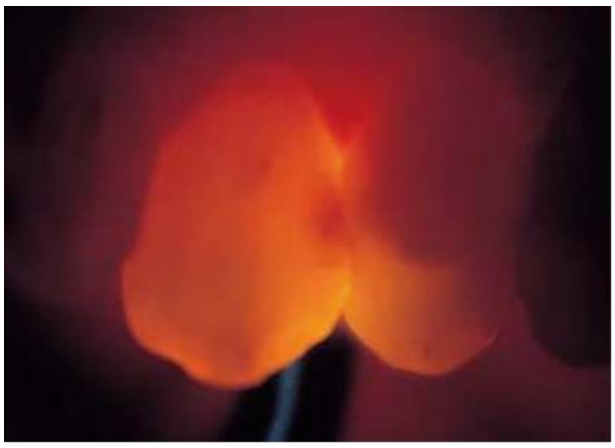

Figure 4: Examination of a distal canine caries seen by NILT. (Pictured provided and allowed by Dr. F.Madar)

Fiber-optic transillumination can be helpful as long as fillings do not compromise the examination. Restorations, such as composite resins will alter the transmission and dispersion of light. As a result, a shadow may appear even in the absence of a lesion. Furthermore, diagnosis by transillumination must be carried out, avoiding interference from ambient light, as there is a risk that a small lesion may not be detected. (34)

There are several studies comparing NILT with radiographic methods. A. Maia *et al.* (19) compared NIR TI with conventional film bitewing radiography. Baltacioglu *et al.* (27) compared it with PSP-Bitewing radiographs. Finally, M. Melo *et al.* (28) evaluated the NILT technique compared with direct digital radiography (DDR) to determine whether the combination of both techniques improved diagnostic capacity. The results showed better interexaminer reliability when evaluating NIR TI images; in addition, the sensitivity and specificity of NILT offer more significant potential for imaging early approximal enamel lesions. (19)(27) NILT has shown similar specificity to DDR but superior correlation and

sensitivity in detecting the extent of the lesions. Therefore, combining the two techniques would increase the diagnostic capability. (28)

Based on the above studies, we can conclude that NILT examination can therefore be an effective diagnostic tool alone or in addition to radiographs to diagnose early interproximal caries. NILT can also monitor caries progression without exposing the patient to ionizing radiation, which is of particular interest for growing patients and pregnant women. It should be noted that the NILT system also offers the possibility of introducing a third dimension in the diagnosis of carious lesions and that this aspect is crucial in cases where the opening of the cavity is necessary since it allows us to know the precise vestibulo-lingual location of the lesion and therefore to act in a more conservative way to treat it.

4.5. Digital Imaging Fiber-Optic Trans-illumination (DIFOTI)

DIFOTI is a dental imaging device developed by Electro-optical Sciences® and can be considered an evolution of the NILT system. DIFOTI aims to reduce the high inter-observer variability of NILT diagnosis. To achieve this, fiber optic transillumination has been combined with a CCD (charge-coupled device) camera. Thanks to the CCD, the acquired images are sent directly to the computer. The system allows for image magnification, repeatable acquisition with no waiting time, saving the images in the patient's file, and image transformations to allow for more accurate quantification of the carious lesion than conventional methods. (35)

The DIFOTI method has so far been applied as an aid to visual and radiographic examination. (36) However, Á. Ástvaldsdóttir *et al.* (37) conducted an in vitro study to compare the diagnostic accuracy of the DIFOTI method and conventional and digital radiography in detecting approximal caries DIFOTI method showed the best agreement. The diagnostic accuracy of the DIFOTI method is superior to radiography in detecting approximal non-cavitated caries and comparable to radiography in the detection of advanced approximal caries lesions. (37)

Based on the above study, we can conclude that DIFOTI is not only a self-sufficient diagnostic method, but it is just as competitive, If not more, than the radiographic methods in diagnosing different depths of lesions and its numerical capabilities.

4.6. Laser Fluorescence

Optical methods of detecting caries are based on the observation of the interaction of energy applied to the tooth or on the observation of the energy emitted by the tooth. This energy takes the form of a wave belonging to the electromagnetic spectrum (Figure5).

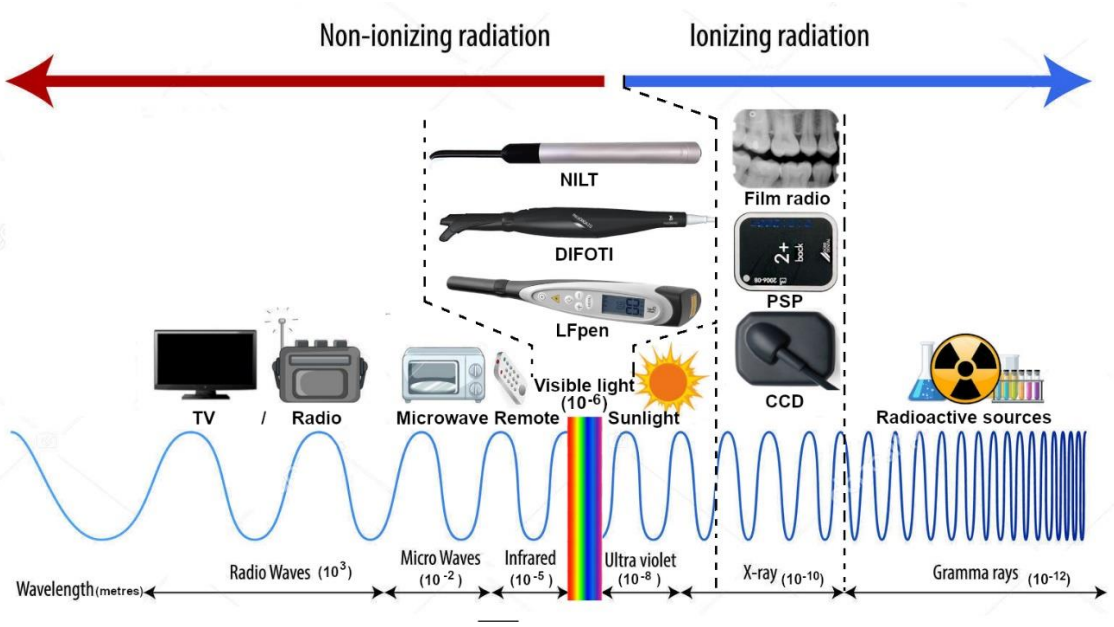

Figure 5: The Electromagnetic spectrum.

Fluorescence can be used to differentiate an organic-rich area such as dental caries from the surrounding healthy area. Enamel and dentin have low auto-fluorescence in the red spectrum emission; however, carious surfaces show a substantial increase in auto-fluorescence. Dental caries depletes mineral elements and enrich organic matter (bacteria, plasma, or salivary proteins), creating a significant fluorescence differential. Thus, the change in fluorescence can be used to determine the presence or absence of a structural alteration. (38)

Based on the different results in the literature regarding the performance of the LFpen, J. De Souza *et al.* (39) wanted to compare in an in vitro study the performance of the LFpen device and conventional radiography. Later, E. Bozdemir *et al.* (40) tried to compare the performance of the LFpen with PSP and visual inspection. Finally, R. Menem *et al.* (41) conducted an in vivo study to evaluate the LFpen device compared to CCD radiography. In conclusion, LFpen showed higher accuracy values for enamel lesions and excellent reproducibility. The radiographic method was more effective in detecting more advanced carious lesions, but the LFpen could be a suitable alternative method to conventional BW methods in detecting non-cavitated approximal lesions. (39)(41)(40)

To sum up, the Laser Fluorescence method has proven to be a powerful tool in diagnosing interproximal non-cavitated caries. It naturally outperforms the visual-tactile inspection method and has a high specificity in the detection of enamel lesions. However, it has a lower sensitivity to lesion depth, whereas the radiographic methods have a better sensitivity to detect more advanced carious lesions.

5. CONCLUSION

Nowadays, there are numerous more or less qualitative and reproducible methods to detect non-cavitated interproximal caries in posterior teeth.

According to the results of this dissertation, DIFOTI seems to be the method of choice for detecting non-cavitated approximal caries in posterior teeth because its diagnostic accuracy is superior to radiography concerning the detection of non-cavitated approximal caries and comparable to radiography concerning advanced approximal caries lesions. In addition, it offers good reliability and reproducibility, and with an integrated CCD, it offers the same computing advantages as digital radiography.

However, each method has its advantages and disadvantages in its use. Moreover, the choice of one of the methods should only be made in response to the individual practitioner's needs, his economic capacities, and the needs of his patients.

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APPENDIX

Figure 3: Timeline of the appearance of auxiliary diagnostic methods.