Ability of 5th year Students to Detect Early Interproximal Caries

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A thesis submitted in fulfillment of the requirement for the degree of Masters of Science in Dental Science (MSc Dent)

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Keywords:

5th year students

Bitewing radiography

Digital radiography

Early Interproximal caries

Radiographic devices

Scoping Review

Student's diagnostic skills/abilities

Abstract:

Objective: The objectives of this study were to evaluate the diagnostic capability of 5th year students using digital imaging, conventional bitewing radiographs (BW), printed film on paper and to compare the results with the observers' experience level to detect early interproximal caries lesions on radiographs. To map the literature in regards to different diagnostic methods that students use globally in dental clinics by conducting a scoping review.

Methods: A cross-sectional study was conducted with senior dental students (Reg No: BM 19/9/8). Three digital radiographs were shown individually to the students on a screen, 3 bitewing radiographs and 3 printed films on paper were passed on individually to all students with a questionnaire; with a viewing time of 2 mins per radiograph; thus 9 radiographs in total were viewed. A control group consisting of specialists from both the Restorative and Radiology Departments had finalized the answers prior to conducting the study regarding the presence/absence of caries and its depth on all 3 different radiographic images. The answers recorded by students were divided into 5 categories, R0: Intact surface, R1: Radiolucency in outer half of enamel, R2: Radiolucency in inner half of enamel, R3: Radiolucency in outer half of dentin, and R4: Radiolucency in inner half of dentin.

A protocol specific for the objectives of this study was developed according to the criteria for a scoping reviews. Relevant databases (Pubmed, Scopus, Ebscohost, Science Direct, Wiley Online Library and Cochrane Library) were searched to identify evidence which was restricted to the English language for the period 2015–2021.

Results: Comparison using an Anova test on the 3 different diagnostic methods showed that the type of method used affects the presence detection and size measuring accuracy, where the P-value confirms a significant difference. The Prisma flow diagram showed a result of the most common methods for diagnosing interproximal caries happen to be visual examination and bitewing radiography.

Conclusions: Senior dental students have shown good accuracy in detecting the presence of interproximal caries. Although the accuracy in detecting the size of carious lesions was poor. The studies concluded that clinical examination and bitewing radiography are the most convenient and

popular methods for detecting interproximal caries.

DECLARATION

I, Muzan Abdalla, hereby declare that "*Ability of 5th Year Students to Detect Early Interproximal Caries"* is my own work, that it has not been submitted for any degree or examination in any other university, and that all the sources I have used or quoted have been indicated and acknowledged by complete references.

Muzan Abdalla July 2021

ACKNOWLEDGEMENTS

First and foremost, I would like to thank Allah for his endless mercy, blessings, and gifts. I thank Allah for His grace that enabled me to successfully complete this thesis.

I wish to express my sincere gratitude to **Professor Saadika Khan**, *for her encouragement and guidance in this study and for sharing with me her knowledge and wisdom whenever I needed it. It is of great honor to have her as my supervisor.*

A special thanks goes to ***Dr. Shoayeb Shaik*** *and* ***Dr. Khaled Beshtawi*** *for their endless guidance and time.*

Many thanks go to **Mr. Ahmed Eldud** *for his invaluable input and assistance in the statistical analysis.*

I wish to thank ***Dr. Ladin Elamin, Dr. Ro'aa Jafar***, ***Dr. Reem Musa*** *and last but not least,* **Mr. Mohamed Kamil** *for helping me in editing and finalizing this thesis. Your efforts are highly appreciated.*

DEDICATION

I dedicate this thesis first and foremost to Allah.

To mom and dad who always pick me up on time and encourage me to go on every adventure, especially this one. Thank you for your endless love, trust and support.

To my siblings for bearing with me and for lifting me up when times get hard. I will forever be grateful for your support.

To my friends all over the world and to my colleagues who have supported me and encouraged me throughout my academic journey. Thank you for the motivational talks when they were needed the most.

To the soul of my best friend's brother, Mohanad Elamin. May Allah grant you the highest levels of jannah and may your beautiful soul rest in peace.

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LIST OF ABBREVIATIONS

BMREC: Biomedical Science Research Ethics Committee

BW: Bitewing Radiography

CBCT: Cone-beam Computed Tomography

CCD: Charge Coupled Device

CP-OCT: Cross-Polarized Optical Coherence Tomography

DDS: Direct Digital Sensors

DEJ: Dento-Enamel Junction

DIFOTI: Digital Fiber Optic Transillumination

DMFS: Decayed, Missing, Filled teeth

DPBR: Digital Phosphor plate Bitewing Radiograph

DPI: Dots Per Inch

DR: Digital Radiography

EICL: Early Interproximal Carious Lesion

FOTI: Fiberoptic Transillumination

GIC: Glass Ionomer Cement

ICCMS: International Caries Classification and Management System

ICDAS: International Caries and Detection System

IOC: Intra Oral camera

IPD: Individual Participating Data

JBI: Joanna Briggs Institute

LED: Light Emitting Diode

LF: Laser Fluorescence

MMAT: Mixed Methods Appraisal Tool

NILT: Near Infrared Light Transillumination

PA: Periapical

PACS: Picture Archiving and Communication System

PP: Printed film on Paper

PRISMA: Preferred Reporting Items for Systematic reviews and Meta- Analysis

PSP: Photostimulable Phosphor Plates

QLF: Quantitative Light-Induced Fluorescence

QUOROM: *QU*ality *O*f *R*eporting *O*f *M*eta- analyses

RL: Radiolucency

ScR: Scoping Review

SDF: Silver Diamine Fluoride

SPSS: Statistical Package for Social Science

SS-OCT: Swept-source Optical Coherence Tomography

WHO: World Health Organization

CHAPTER 1: INTRODUCTION

1.1 Problem Statement:

Detecting caries before they proceed to irreversible lesions is one of the most important roles of dental professionals. As difficult as it may seem, detecting interproximal caries at an early stage is important. This detection plays an important role in avoiding irrelevant restoration treatment of non-carious teeth (Takahashi *et al.*, 2019).

Dental caries is reported as the most infectious disease that spread across the world (Ozdemir, 2013). Tooth caries can be caused by a variety of factors, including food habits, personal oral hygiene practices, and tooth morphology (Ozdemir, 2013). Caries tends to affect adults and children of all ages globally. Previous studies stated around 75 percent of proximal caries were identified on the approximal surface, and 25% on the lower proximal surface; both are typically discovered when the weaker marginal ridge is destroyed or a big cavity forms (Yoon, Yoo and Park, 2017).

From the earliest stages of caries until cavitation, the optimal caries detection system should capture the entire caries process and lesion activity. It should be precise, easy to use, and effective on all surfaces of teeth, as well as cavities near restorations (Zandoná and Zero, 2006).

In the past, these lesions were easily diagnosed by clinical examination due to their rapid progress of caries and visible cavitation (Featherstone, 2009). But today, progress of caries is slow and these lesions extend to dentin but without any evidence of clinical changes. This means that today, dentists mostly face patients with hidden carious lesions, making it difficult to diagnose and treat the caries appropriately (Featherstone, 2009).

The importance of radiographic examination has been brought to the attention of dentists due to the discovery of the hidden carious lesions (Tavakoli *et al.*, 2015). It gives the dental profession the opportunity to appropriately and timeously include procedures that will re-mineralize early carious lesions (Featherstone, 2009).

1.2 Introduction:

One of the most common bacterial infections affecting tooth hard tissues is dental caries, and this is caused by an imbalance in the oral microbial community known as dental biofilm (Du *et al.*, 2020). It is a highly organized poly-microbial structure on tooth surfaces (Du *et al.*, 2020).

Traditionally, relying on visual examination for caries detection with or without tactile sensation is very common. It is usually supported by radiography (Zandoná and Zero, 2006). Normally, to evaluate the carious state of a patient, we make a decision either the caries is absent or present, based on obvious signs such as color, hardness and translucency using explorers and radiographs (Zandoná and Zero, 2006).

Over the years, the concept of dental caries has evolved in many aspects for dental practitioners (Ozdemir, 2013). A National Institutes of Health consensus statement approved that tooth restoration is incapable of stopping the caries process (Domenick, 2009). The latter argued that the focus should rather be on enhancing diagnostic processes. In that way, one can prevent the formation and progression of caries, and manage them when in the early stages if detected. Therefore, the clinician's attention and accuracy is needed for improved diagnosis, prevention and management of caries in its early stages (Ozdemir, 2013).

Given the importance of early diagnosis of caries, it is necessary that dental students during their education obtain an acceptable level of competence in the detection of caries, prevention and their treatment. Our study targeted a group of final-year dental students aiming to assess their ability in detecting both, presence and depth of proximal caries. The test was based on 3 different radiographic diagnostic tools; bitewing radiography, digital radiography and printed film on paper.

A concise review of the literature about the different types of caries detection methods and the ability of 5th year dental students to detect early interproximal caries will be followed in the next chapter. A scoping review is also conducted related to different caries diagnostic methods used by students globally.

The third chapter highlights the research objectives which are conducting a scoping review of the literature in regards to different diagnostic methods that students use globally in dental clinics, determining the diagnostic ability using bitewing films, digital radiography and printed film on paper.

Materials and methods used to answer the aim and objectives related to this study will be explained in the 4th chapter.

The 5th chapter will interpret the results obtained from the study in regards to the students' ability in detecting early interproximal caries and the analysis of extracted data and how it was interpreted to address the objectives of the review and how the findings are synthesized narratively.

Chapter six includes a discussion of the results obtained from the questionnaire and the data extracted from the scoping review. These findings will be engaged with the literature to view the similarities and differences, controversies and new emerging research.

Finally, the seventh chapter includes a conclusion of the main objectives of this research and some recommendations and limitations regarding the study for future research and clinical practices.

CHAPTER 2: LITERATURE REVIEW

In this section I provided a group of local and universal formulations relevant to the aim of this study.

The World Health Organization (WHO) published a detailed report in 1997 that defined and assessed the oral health condition of children and adults in a number of nations. The primary goal of the WHO's International Collaborative Studies (ICS-I or ICS-II) was to compare oral health care systems and their effects on oral health (Petersen, 2005). The low-income group consisted of a small number of countries. All of the countries studied have a high prevalence of cavitated dentine carious lesions. In comparison to the upper-middle and lower-middle income groups, the severity of cavitated dentine carious lesions (median dmft count) 3.9 and 4.1 respectively was low in the high-income group, 2.0 (Frencken *et al.*, 2017).

2.1 Introduction to Dental Caries:

Dental caries is considered to be one of the most common oral infectious diseases that is characterized by demineralization and destruction of the hard tissues of the teeth often leading to cavitation (Gomez, 2015; Nagarajan and Anjaneyulu, 2019). Dental caries affect most of the teenagers and adults, both males and females globally (Gomez, 2015). Detection of dental caries could be done through the integration between clinical examination and radiographic findings (Hekimliğinde, Çürük and Yöntemleri, 2017).

2.2 Mechanism and Formation of Dental Caries:

Dental caries is caused by the accumulation of acid-producing endogenous bacteria *(Figure 1)* (Chen and Wang, 2011). It includes the following gram-positive species; *Streptococcus mutans*, *Streptococcus sobrinus* and *Lactobacillus spp*. in the biofilm (dental plaque) (Chen and Wang, 2011). As metabolic by-products of fermentable carbohydrates, these microorganisms release weak organic acids (Chen and Wang, 2011). Recent evidence supports the role of *Candida albicans* in the etiology of carious lesions (Ozdemir, 2013).

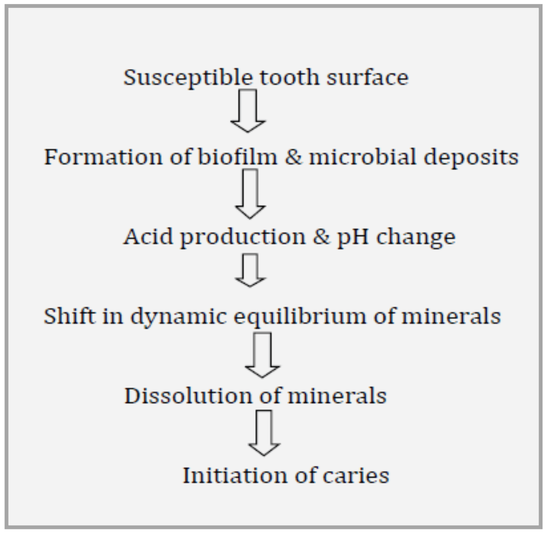


Figure 1: Mechanism of dental caries (Yadav and Prakash, 2017)

Dental caries is a disease that is caused by bacteria and host factors such as saliva and teeth (Simón-Soro and Mira, 2015). Keyes used the host-agent-environment model *(Figure 2)* to describe the occurrence of dental caries therefore, dental caries only occurs when the three factors are present; diet, saliva and tooth (Aoba, 2004).

Hence, in order to prevent the formation of dental caries, it is important to maintain the control over these three causative factors (Chen and Wang, 2011). Dental caries and demineralization of tooth enamel are caused mostly by the acids produced by acidogenic bacteria, rather than by pathogenic bacteria themselves (Chen and Wang, 2011).

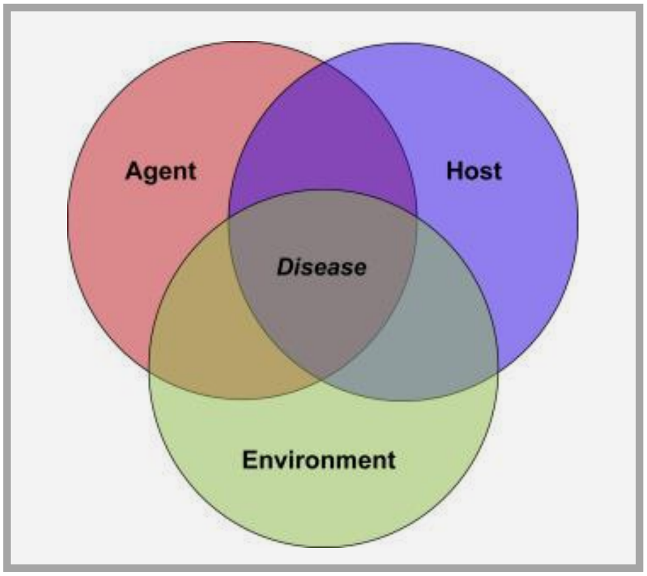


Figure 2: Host-Agent-Environment (Seventer and Health, 2020)

Saliva's consistency varies depending on its composition: it might be watery, viscous, gluey, or foamy. The percentage of proteins in saliva mostly will determine its thickness or frothiness (Cunha-Cruz *et al.*, 2013). It is fair to say the pH of saliva is neutral or close to neutral where the buffering agents aid in maintaining the pH (Cunha-Cruz *et al.*, 2013). Inorganic phosphate found in resting saliva and the carbonic acid-bicarbonate system in stimulated saliva are examples of buffering agents (Cunha-Cruz *et al.*, 2013). Sjögren syndrome is an autoimmune disease characterized by a significantly reduced salivary flow rate, and patients with this condition s have greater incidence of caries compared to other diseases included in this category (Cunha-Cruz *et al.*, 2013; Ou-Yang *et al.*, 2010). Other variations could be related to the anatomical morphology of the teeth such as the depth of fissures and grooves (Sánchez-Pérez *et al.*, 2019).

These bacteria may metabolize any fermentable carbohydrate, such as glucose, sucrose, fructose, or cooked starch, by producing organic acids. Every time a carbohydrate is taken into the mouth and digested by bacteria; the process of demineralization continues (Featherstone, 1999).

According to Cortes *et al.*, (2018), occurrence of interproximal caries was strongly associated with surface morphology due to their concavity and convexity of the mesial and distal surfaces. Occlusal surfaces are associated with deep fissures and grooves making it a suitable environment for bacterial acid production. Both occlusal morphology and enamel abnormalities are known to follow a hereditary and family pattern, which is modified by hygiene and sugar intake (Sánchez-Pérez *et al.*, 2019).

2.3 Classification of Dental Caries Lesions:

There are several classifications of dental caries reported in the literature *(Figure 3 and Figure 4)* (Nagarajan and Anjaneyulu, 2019). The old classification by G.V. Black categorizes the caries with regards to the topography of the tooth surface into pits and fissure and smooth surface caries (Nagarajan and Anjaneyulu, 2019). However, a recent classification by Mount and Hume (2009) categorizes caries according to the position and extension of the caries into dentine or not.

2.3.1 G. V Black Classification

According to G.V Black, dental caries is classified into 5 different classifications based on the principle "extension for prevention." A sixth classification was later added to the system (Nagarajan and Anjaneyulu, 2019). Details of each type of lesion or class is described below:

- **Class I:** Cavity can be found in the pits or fissures on the occlusal surfaces of molars and premolars; facial and lingual surfaces of molars; and lingual surfaces of maxillary incisors
- **Class II:** Cavity is seen on the proximal surfaces of premolars and molars
- **Class III:** Cavity seen on the proximal surfaces of incisors and canines that do not involve the incisal angle/ edge are grouped here
- **Class IV:** Cavity on proximal surfaces of incisors or canines that involve the incisal angle
- **Class V:** Cavity on the cervical third of the facial or lingual surfaces of any tooth
- **Class VI:** Cavity on the incisal edges of anterior teeth and posterior teeth. (Nagarajan and Anjaneyulu, 2019).

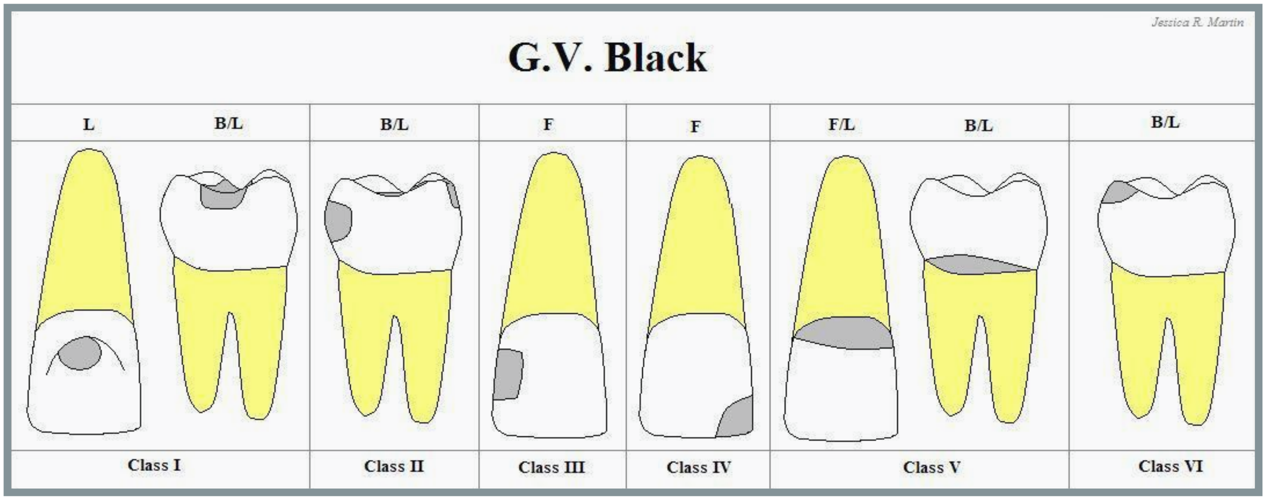


Figure 3: G.V. Black Caries Classification (https://dentodontics.com/2015/02/26/g-v-blacks-classification-of-carious-lesions/)

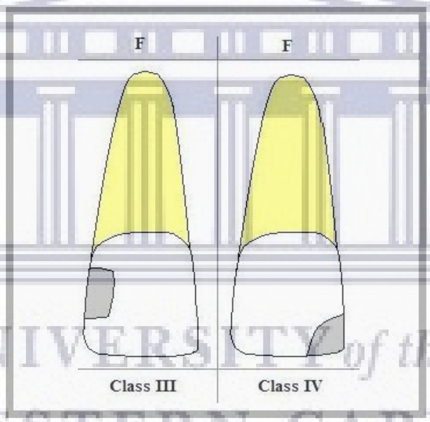


Figure 4: Interproximal Caries (Class III and Class IV) (https://dentodontics.com/2015/02/26/g-v-blacks-classification-of-carious-lesions/)

2.3.2 G. J. Mount classification

G. J. Mount's classification identified both the position and extent (progression) of dental caries.

Lesion Site:

- **Site 1:** Occlusal pits and fissures caries found posteriorly. Another location may be on the smooth surface of the enamel confined to defects.
- **Site 2:** Presence of the lesion interproximally in adjacent teeth whether anterior or posterior.

- **Site 3:** The cervical areas including visible root surfaces (Nagarajan and Anjaneyulu, 2019; Mount, 2005).

Lesion Size:

The size of the lesion is recorded as follows:

- **Size 0** – Initial lesion without cavitation found in any site, meaning no restoration is needed.
- **Size 1** – Minimal lesion requiring operative intervention. It can reach the remineralization stage with the help of a restoration.
- **Size 2** – Moderate size caries that reaches the dentin.
- **Size 3** – The cavity is enlarged causing weakness on the incisal edge or cusp of the tooth.
- **Size 4** – A cusp or incisal edge is broken due to extensive cavitation (Nagarajan and Anjaneyulu, 2019; Mount, 2005).

2.3.3. The International Caries Classification and Management System (ICCMS™)

The International Caries Classification and Management System (ICCMS™) *(Figure 5)* has also classified dental caries according to the surfaces of teeth (Ismail *et al.*, 2015; Pitts *et al.*, 2014). Interproximal caries, proximal caries and approximal caries are all different terms used to describe and define the same lesion which is caries lesions develop between the contacting proximal surfaces of two adjacent teeth. Proximal surface is the surface between 2 neighboring teeth (mesial and distal surface).

Categories for Interproximal surfaces of the tooth:

- **Sound surfaces:** Absence of caries when the tooth is clean and dry (ICDAS™ code 0).
- **Initial stage caries**: Changes in enamel are seen visually after drying the tooth (ICDAS™ code 1).
- **Moderate stage caries:** Localized breakdown of the enamel is visible with no exposure of the dentin (ICDAS™ code 3). When a dark shadow below the dentin is visible it is referred to as (ICDAS™ code 4).
- **Extensive stage caries:** When less than half of the tooth is involved during dentin exposure is referred to as (ICDAS™ code 5). Involvement of at least half of the tooth

surface is known as (ICDAS™ code 6).

ICDAS II

Score 0	Score 1	Score 2	Score 3	Score 4	Score 5	Score 6
No visual signs of carious lesions or any enamel defect	First visible changes in the enamel. Visible only after drying with air. Changes in coloration confined to areas of pits	Change in visible enamel even in the presence of moisture. More extensive and not restricted to pits.	Destruction located in enamel without visible dentin, discontinuities of enamel surface	Dark shadow on the underl-ying dentin, with or without locali-zed destruc-tion of enamel	Clear cavity with visible dentin; cavity that involves less than half the dental surface	Extensive cavity evident in dentin; cavity deep and wide, involves more than half of the tooth

Figure 5: ICDAS System (https://www.redalyc.org/jatsRepo/3786/378661089007/html/index.html)

After the classification has been outlined, diagnosing caries and using different detection methods will be discussed in the next section.

2.4 Diagnosing Dental Caries

Diagnosing dental caries takes place at the dental clinic using visual with or without tactile inspection aided by radiographs. Usually, practitioner's diagnosis of caries is influenced by signs such as color, hardness and translucency. Diagnosis is done with the aid of simple instruments such as explorers and radiographs to assess a patient's carious condition (Zandoná and Zero, 2006).

2.4.1. Visual Tactile Examination:

The training of dental practitioners include developing skills that will enable them to detect caries before they progress to irreversible lesions (Lino *et al.*, 2015). According to previous studies, clinical examination may not show 25-42% of proximal caries without radiographic screening (Safi *et al.*, 2015). Visual inspection is the most basic and widely used method in dental clinics for detecting caries, however it has limitations in separating the different caries phases because it can only detect changes reflected on the surface (Kim *et al.*, 2017; Bader, Shugars and Bonito, 2002). The use of an explorer to identify caries using tactile sensation has been extensively researched *(Figure 6)* (Ou-Yang *et al.*, 2010). Using an explorer to firmly probe suspected carious pits and fissures does not aid the diagnosis and may even be harmful (Zandoná and Zero, 2006).

Figure 6: Visual tactile examination (https://www.dreamstime.com/royalty-free-stock-image-dental-examination-image18912096)

Most proximal dental caries lesions, for example, begin below the proximal contact point, making them difficult to identify visually. Therefore, the use of radiographs will further enhance the diagnosis (Gimenez *et al.*, 2015). According to a recent systematic review, visual inspection has a high specificity (0.908–0.992) which means the ability of a test to correctly classify an individual as *disease- free*. On the other hand, it reported relatively low sensitivity which is the ability of a test to correctly classify an individual as ′diseased′ (0.274–0.543) when it comes to detecting interproximal caries in both dentitions (Gimenez *et al.*, 2015).

2.4.2. Radiography:

Bitewing radiography, another frequently used diagnostic tool, performed better than visual inspection in detecting dentine caries on proximal surfaces (Kim *et al.*, 2017). Because of the presence of neighboring teeth and gingival tissue in cervical area, bitewing radiographs are designed to examine interproximal surfaces (Shah, Bansal and Logani, 2014). They are being used for decades as the main method for the diagnosis of proximal dentin decay due to its high sensitivity when detecting caries compared to clinical inspection (Allan G. Farman, 2007; Bozdemir *et al.*, 2016). Bitewing radiography is mainly indicated when there is destruction larger than 2-3 mm of the dentin (Bozdemir *et al.*, 2016).

Other diagnostic methods used for caries detection are Caries Detecting Dyes, Fiber Optic Transillumination, Laser Fluorescence (DIAGNOdent or DIAGNOcam), Quantitative Light Induced Fluorescence, and Cone Beam Computed Tomography (CBCT) (Hekimliğinde, Çürük and Yöntemleri, 2017). Improvement in the different ways of detecting carious lesions has developed successfully in the past few decades (Gomez, 2015). During the past years, quantitative methods have been introduced which means methods that deal more with numbers and closed ended questionnaire questions. Some of the development reasons are quantitative methods for example, fluorescence light (QLF), can detect non carious cavities at early stages better than conventional methods such as bitewing radiography (Takahashi *et al.*, 2019). In terms of detection, conventional methods can be more reliable and can monitor the course and progression of the disease (Gomez, 2015). During clinical examination, general dental practitioners and students tend to overlook interproximal caries because their surfaces cannot be displayed directly and they are often challenged because they cannot be visualized directly (Bozdemir *et al.*, 2016).

The term used for caries detection and diagnosis is frequently misunderstood in the literature. Three concepts have been agreed upon in terms of direct relevance to preventative caries care in the recent decade and these are:
Lesion detection: implies an objective method of determining whether or not disease is present.
Lesion assessment: aims to characterize or monitor a lesion, once it has been detected.
Caries diagnosis: should imply a human, professional, summation of all available data (Gomez, 2015; Pitts and Ekstrand, 2013).

On the other hand, Ozdemir (2013) had mentioned that the diagnostic methods for detecting dental caries have not improved significantly in recent years. This could be related to several reasons such as anatomical morphology of the teeth and the shape of restorations. It is particularly difficult to diagnose early-stage disease when, tight interproximal contacts deep fissures and secondary lesions are present, and many lesions are eventually detected in the advanced or late stage (Ozdemir, 2013)**.**

Zandoná a & Zero (2006) reported that recording of the carious lesion is no longer acceptable to merely have lesions at the cavitation level, based on the International Consensus Workshop on Caries Clinical Trials that was conducted in Loch Lomond, Scotland, 2004.

Our understanding of caries has evolved significantly over the last century, with a focus on improved diagnosis, prevention, and control of caries in its early phases (non-cavitated) and a recognition that tooth restoration does not stop the caries process (Ozdemir, 2013).

Nevertheless, one of the main limitations of bitewing is that radiographically detected marginal gaps may result in incorrect positive or negative treatment decisions, such as underestimation of caries lesion size (Mjör and Toffenetti, 2000). In addition to that, misreading may occur due to the difficulty in distinguishing between the tooth itself and the radio-opacity of the restorative material (Mjör and Toffenetti, 2000).

2.5 Prevention, Management and Treatment of Dental Caries:

There are many different ways how the formation of caries may be prevented, stopped and/ or reversed. In the following section, in-office treatment and oral habits are discussed.

2.5.1 Prevention of carious lesions

Application of certain materials such as fluoride plays a huge role in caries prevention and can be found as supplements for example gel, varnish, toothpaste and mouthwashes (Featherstone, 1999; Nicholson, Hill and Sidhu, 2021). It is even found in dental materials used for restoration such as glass ionomer cement (GIC) and fluoridated composite resins (Nicholson, Hill and Sidhu, 2021). Low quantities of fluoride in solution among enamel crystals can significantly reduce acid dissolution of tooth mineral. Fluoride prevents demineralization, enhances remineralization, as well as inhibition of bacterial activity in the plaque-tooth interface (Featherstone, 1999).

Sugar substitutes, for example, sucralose and xylitol can also help prevent formation of caries in addition to chewing sugar free gum after meals (Ozdemir, 2013; Gris, 2013). Brushing the teeth at least 2 times per day helps in getting rid of food debris and accumulation of plaque (Carvalho *et al.*, 2016). Reduction of the cariogenic bacteria takes place through mechanical and chemical plaque control. Mechanical tooth brushing using toothpaste containing fluoride especially at night and using dental floss can also work as preventive factors (Ozdemir, 2013). In addition to daily tooth brushing, the use of chlorohexidine mouthwash would ensure chemical control of the cariogenic bacteria (Gris, 2013). However, there is lack of evidence of the chlorohexidine effect in inhibiting dental caries but can be considered as a short term caries control (Gris, 2013). The use of fissure sealants in the dental clinic helps in the prevention of caries as well (Sánchez-Pérez *et al.*, 2019). Pit-and-fissure sealants, for example, can effectively penetrate and seal these surfaces with a dental substance, preventing lesions and becoming part of a comprehensive caries control strategy (Manual, 2016).

2.5.2 Management of different carious lesions:

Deciding on which management approach to use should be based on a reasonable, approach as stated below, with the most critical issue being, "When does a practitioner need to interfere using minimally invasive treatment?" For the following cases, minimally invasive intervention is recommended: (Banerjee *et al.*, 2017)

- Primary dentition and permanent dentition (according to the state, site and size of the lesion)
- Reversible pulpitis or asymptomatic teeth
- Decayed teeth extending into the dentine
- Undetectable irreversible pulpitis

Non-cavitated carious lesions:

The management of non-cavitated, incipient lesions is considered to be non-operative, meaning, eliminating the biofilm, which can be done with fluoride containing toothpaste and the use of additional topical remineralization treatments if needed, or by therapeutic fissure sealants mainly used on deep occlusal pits and fissures (Banerjee *et al.*, 2017).

Cavitated carious lesions:

Cavitated dentinal lesions that may be evaluated using visual-tactile examination are possibly cleanable lesions. As their recurrence is relatively uncommon, they can be maintained, that is not needing any additional operational treatments. As a result, they can be treated non-invasively by removing the biofilm. This can be done by using a toothbrush, dental floss, fluoride containing toothpaste or remineralization treatments. and fluoridated toothpaste or remineralization therapies (Banerjee *et al.*, 2017).

Soft Dentine:

The soft dentin can be distinguished by its sticky texture. It can be removed using a manual excavator with light force applied. This dentine consistency is moist and frequently referred to as caries-infected dentine (Banerjee *et al.*, 2017).

Hard dentine:

To pass through the dentin with a dental explorer, pressure is applied. The use of a handpiece with a diamond bur or a manual sharp instrument can help in the removal of the infected dentin. When a straight probe is run across the dentine, a scratchy high-pitched sound may be heard. This consistency has traditionally been associated with healthy dentine. (Banerjee *et al.*, 2017)

Cavity restoration:

The following factors guide the choice of restorative material:

- the lesion site and size
- the dental caries risks
- activity of the carious lesion
- specific environmental conditions (Banerjee *et al.*, 2017; Mount, 2005).

Definitive evidence is yet to be found in order to support specific dental materials for restoration of teeth after removing the caries from both soft and hard dentin (Banerjee *et al.*, 2017).

Silver diamine fluoride (SDF) has been recently used in young children and special needs patient (Crystal and Niederman, 2019). It is a clear fluid containing a therapeutic agent used for the management of dental caries in deciduous teeth (Crystal and Niederman, 2019). SDF is a combination of antibacterial effects and re-mineralization, silver and fluoride respectively (Crystal and Niederman, 2019). It works in reducing the effect of the cariogenic bacteria and re-mineralizes the enamel and dentin (Crystal and Niederman, 2019). Re-mineralization and strengthening takes place with the fluoride. One of the disadvantages of SDF is its interference with the biofilm (Crystal and Niederman, 2019).

2.5.3 Treatment of Dental Caries

Ozdemir (2013) has also stated that the conventional approach to treat dental caries is by removing the decayed part and replacing it with a restoration of the right choice none the less, this has not shown any sign of preventing caries formation. Non-cavitated carious lesions can be treated by means of remineralization without restorative intervention (Rechmann *et al.*, 2016). According to the research, close monitoring of topical fluoride administration with pit and fissure sealants is the best practice and should be the standard treatment technique for non-cavitated carious lesions (Rechmann *et al.*, 2016).

Early interproximal caries is defined when the lesion is seen radiographically and the radiolucency developing below the contact areas appear like horizontal V-shaped notches in enamel-only lesions *(Figure 7)* (Kamburoğlu *et al.*, 2012; Young *et al.*, 2015). As the lesion progresses into dentin, a mushroom formation occurs as the enamel appears to be undermined along the dentino-enamel junction, this is defined as the advanced stage of interproximal caries (Young *et al.*, 2015).

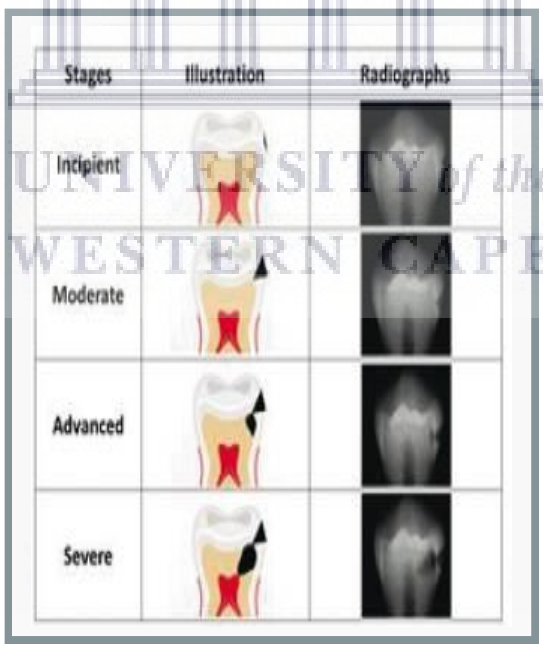


Figure 7: Stages of tooth decay (Londoño-Lemos and Bustamante, 2019)

Interproximal caries occurs in the contact area between two neighboring teeth (Şenel *et al.*, 2010). They are caused by the enamel loss translucency and they appear as opaque regions clinically

(Kamburoğlu *et al.*, 2012). Interproximal caries on the posterior teeth are difficult to detect due to the large proximal surface (Kamburoğlu *et al.*, 2012).

Whether they are occlusal caries or interproximal caries, detecting them on an early stage is beneficial for both the patient and the dentist (Gomez, 2015). Several detection methods have been used lately which include direct digital radiography, optic property imaging such as laser fluorescence (LF) and transillumination light emitting diode (LED) and CBCT (Zandoná and Zero, 2006). Dental practitioners have access to all these methods and assist in the right choice of treatment (Zandoná and Zero, 2006).

In this thesis, a literature review of specific diagnostic aids related to the current investigation: Bitewing Radiography, Digital Radiography specifically and Near Infrared Light Transillumination (NILT), Fiber Optic Transillumination (FOTI), laser fluorescence (LF) , Light Emitting Diode (LED) and CBCT generally, will be discussed in details.

2.6 Interproximal Caries Detection and Diagnostic Methods

Dental caries can be detected and diagnosed using various methods ranging from the visual tactile inspection up to the use of CBCT as a diagnostic aid. In the following section, the different methods of detecting interproximal caries will be further explained.

2.6.1 Bitewing Radiography

The original technique, which required the patient to bite on a small wing attached to an intraoral film packet, is known as bitewing radiography (García Reyes, 2013). Bitewing radiographs are the main diagnostic tool used for early interproximal caries detection (Allan G. Farman, 2007). It does, however, underestimate the depth of the lesion and is more suited to detecting dentin caries rather than enamel caries (Bozdemir *et al.*, 2016).

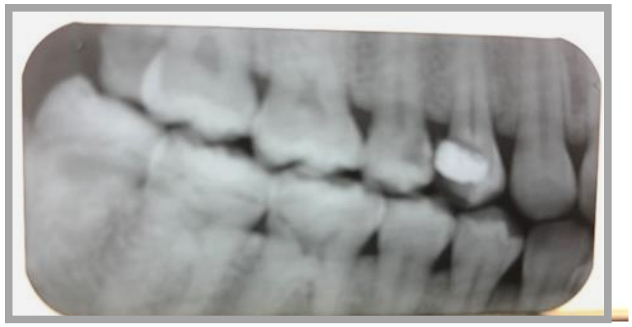


Figure 8: Bitewing radiography with interproximal caries (https://dentagama.com/news/bitewing-dental-x-rays)

Bitewings are used to examine interproximal surfaces due to the presence of neighboring teeth and gingival tissue in cervical areas *(Figure 8)* (Shah, Bansal and Logani, 2014). Proximal caries progress rapidly and they are difficult to diagnose due to its site (Yoon, Yoo and Park, 2017). Visual inspection, tactile examination, and radiography are currently used in dental clinics to diagnose proximal caries (Yoon, Yoo and Park, 2017; Kühnisch *et al*., 2016a).

Detecting carious and non-carious lesions on an early stage is of high importance (Takahashi *et al.*, 2019). Depending on the size, smaller lesions respond better to either preventive or re-mineralization as a choice of treatment (Gris, 2013). But there is also a cause for concern, because failure in diagnosing caries, may lead to irrelevant restorative treatment of sound teeth (Takahashi *et al.*, 2019). Some of those failures may include presence of a cervical burnout which can be misleading and appears like dental caries. It is defined as a radiolucent band around the necks of teeth and is more pronounced at the proximal edges or the mach bands effect on the X-ray. This is referred to as a false positive diagnosis of dental caries (Hekimliğinde, Çürük and Yöntemleri, 2017; Secgin, Gulsahi and Arhun, 2016).

The mach band effect is named after Ernest Mach 1865 (Secgin, Gulsahi and Arhun, 2016). Mach bands effects or optical illusion means production of radiolucent areas due to illusion (Secgin, Gulsahi and Arhun, 2016). The contrast between dark and light areas increases causing a dark demarcation band *(Figure 9)* (Secgin, Gulsahi and Arhun, 2016). Another diagnostic artifact is the cervical burnout (Secgin, Gulsahi and Arhun, 2016). This phenomenon usually presents as apparent radiolucency with ill-defined borders that may be confused with root caries (Rechmann *et al*., 2016).

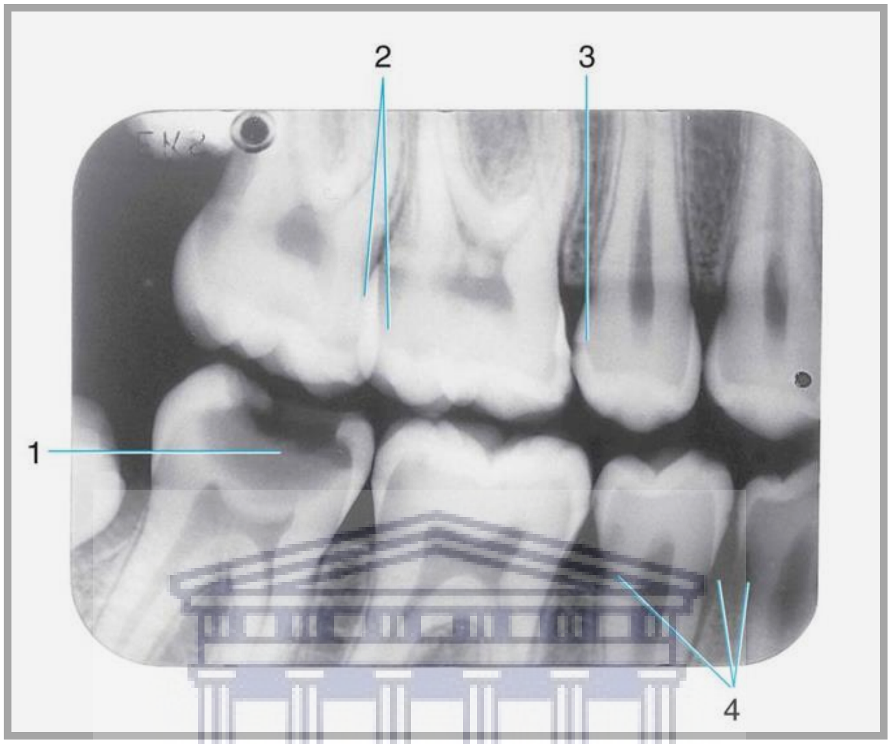


Figure 9: 1) Severe occlusal caries. 2)Radiolucent lines creating a mach band effect caused by over lapped enamel. 3)Incipient distal surface caries. 4)Cervical burnout. (https://slideplayer.com/slide/3897910/)

Gomez, (2015) mentioned a few of the advantages of bitewing radiography which are bitewing radiography offers access to surfaces that may not be visible during a clinical visual–tactile examination, as well as determining the depth of lesions. Other benefits include the fact that it is non-invasive and does not damage tooth structure as a poorly handled dental probe might. (García Reyes, 2013). Relatively simple to use and straightforward. The image receptor is firmly fixed in place and cannot be moved by the tongue, which can result in blurred images (García Reyes, 2013). The beam-aiming device determines the position of the X-ray tube-head *(Figure 10),* assisting the operator in ensuring that the X-ray beam is always at right angles to the image receptor (García Reyes, 2013). Radiographs can also be saved and compared to a more recent image to see if a lesion is progressing or not in the case of digital radiographs (Gomez, 2015).

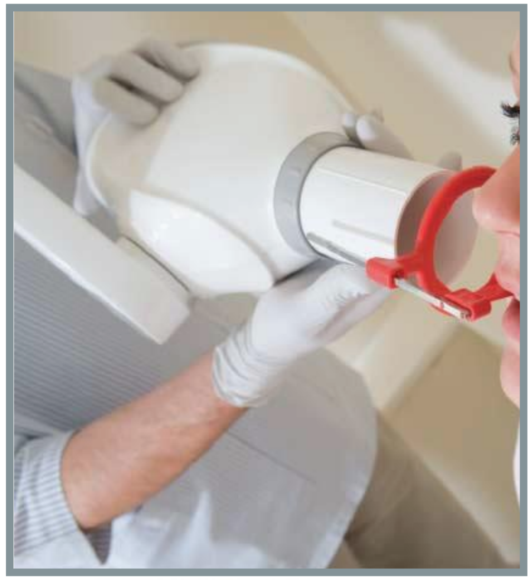


Figure 10 X-Ray machine with BW RINN apparatus (https://www.deardoctor.com/inside-the-magazine/issue-30/bitewing-x-rays/)

However, (Clifton, Tyndall and Ludlow, 1998;Terry *et al.*, 2016; García Reyes, 2013) discussed the disadvantages of bitewing and concluded the following, it is painful and causes discomfort to the patient, cross contamination possibility, parotid glands may be affected by radiation and skill level of the assistant may lead to the need of retaking the x-rays which causes excess radiation dose on the patient. Bitewings cannot be ideal for monitoring the progression of dental caries because the position of the holder in the mouth is hand operated and does not give 100% accuracy. The film holders are not suitable for pediatric patients due to their mouth being smaller in size compared to adults (Pierro, V., Barcelos, R., Souza, I.P., & Raymundo, 2008). Not only do they have smaller mouths making it more difficult to position the film, but there is also less tolerance, anxiety, and lack of understanding in some circumstances (Pierro, V., Barcelos, R., Souza, I.P., & Raymundo, 2008). Currently, the most commonly used film holders include commercial the KWIK-BITE film holder Sticky tape, and the Snap-a-ray film holder (Ashkenazi M, 2013).

2.6.2 Digital Radiography

When radiographic images are in digital form and can be shown on a computer monitor, the phrase "digital imaging" is used to describe general radiography *(Figure 11)*. It can be viewed with computed radiography or digital radiography, respectively (Nyathi, 2010).

Figure 11: Digital radiography (https://pauljangdentistry.com/2016/07/09/digital-x-rays/)

Over time, radiography has progressed from using screen-film technology to digital imaging, sometimes known as filmless radiography (Nyathi, 2010). Nowadays, digital X-ray units are frequently used in most radiology departments (Nyathi, 2010). Public hospitals in South Africa, such as Tygerberg Oral Health Center, have started purchasing digital machines for their radiology departments in recent years. This is consistent with global changes from screen-film radiography to digital radiography (Nyathi, 2010). It has gained the greater critique in comparison with conventional film images. When compared to conventional plain film radiography, one of the most frequently reported advantages of digital radiography is that the radiation dose is lowered by up to 80% (Shah, Bansal and Logani, 2014). Studies have reported that the level of accuracy provided by digital radiography in detecting caries is more substantial than film radiography, while some reports have stated that digitalized films have the same accuracy as charge coupled device (CCD) (Katib and Alfuraih, 2018) (Abesi *et al.*, 2012).

The data for an image is stored and shown in such a way that each pixel (picture element) in the image is turned into an electrical charge, the intensity of which is associated to a color in the color spectrum. This is known as CCD (Katib and Alfuraih, 2018). On the other hand, paper-print images of the CCD system are less accurate than film images (Katib and Alfuraih, 2018). Many manufacturers have created image analysis software that can indicate areas of image density disparity, which is consistent with interproximal caries, alerting practitioners to areas that require further investigation (Rochlen and Wolff, 2011).

Nyathi, (2010) mentioned some of the advantages and disadvantages related to the digital radiography. The most common advantages are: reduction of the radiation dose, increased dynamic range, time saving, image enhancement and ease of image storage, retrieval and transmission (Nyathi, 2010). On the other hand, the reported disadvantages in relation to digital radiography are: poorer spatial resolution, non-availability of post-processing functions, increased sensitivity to scattered radiation and high cost in relation to the screen-film radiography (Nyathi, 2010).

Several studies have assessed intra observer (Intra-observer is the amount of variation one observer experiences when observing the same material more than once) and interobserver (occurring between or involving two or more observers) agreement according to diagnostic accuracy of carious lesions (Hellén-Halme and Petersson, 2010; Stoppler, Melissa Conrad; Medical Dictionary. MedicineNet.com). Gröndahl and Hauge-Jorden found variations in inter-observer agreement for carious lesions and found that the number and size of carious lesions are the main influences on agreement (Hellén-Halme and Petersson, 2010). Carious lesion detection in digital radiographs is a matter of finding an abnormality, recognizing it, and establishing it as a carious lesion (Hellén-Halme and Petersson, 2010). Both, educational level and experience years of the examiner may influence detection of caries (Hellén-Halme and Petersson, 2010).

2.6.3 Near Infra-red Light Transillumination (NILT)

Near-infrared light transillumination (NILT) is a method used for detection of caries which is a radiological technique for medical imaging. It was first introduced in 1995 (Baltacioglu and Orhan, 2017a; Kühnisch *et al.*, 2016b). Later on, this optical technique was modified to Digital Imaging Fiber-optic Transillumination system *(Figure12)* (N. Abogazalah, Eckert and Ando, 2017; Baltacioglu and Orhan, 2017b; Kühnisch *et al.*, 2016a). It is observed to be more non-irradiative adjunctive and sensitive method for early caries detection (N. Abogazalah, Eckert and Ando, 2017). The increased focus on the use of less ionizing radiation and treating early caries in a minimally invasive manner has driven research into the possibilities of light-based caries detection method (Abdelaziz *et al.*, 2018).

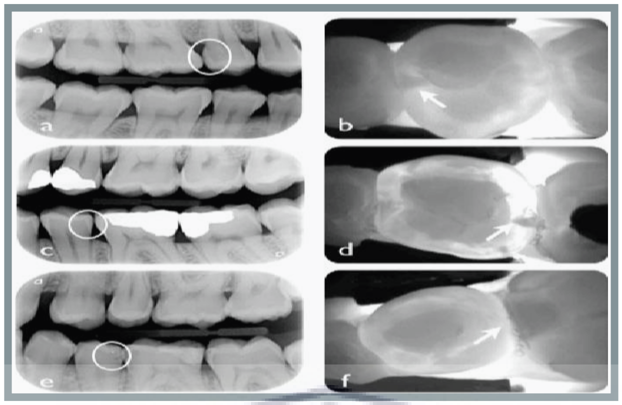


Figure 12: Near Infra-red Light Transillumination ((F et al., 2016)

Several studies have used digital intra oral methods for carious lesion detection, although for caries detection, only a few studies have used digital radiography techniques and photo-optical methods (Baltacioglu and Orhan, 2017a).

One of the main advantages is the elimination of radiation hazards (N. Abogazalah, Eckert and Ando, 2017). Some of the other advantages of NILT is its accuracy to locate the lesion, images can be saved and used multiple times according to their need (Kühnisch *et al.*, 2016b). It can detect proximal and caries on the occlusal surface from one view saving time and effort (N Abogazalah, Eckert and Ando, 2017). In addition to that, it is able to determine lesion extension. However, the disadvantages are incapability of determining the depth of the lesion. Therefore, the detection of proximal cavitation based on depth cannot be estimated with the same accuracy as in radiography (N. Abogazalah, Eckert and Ando, 2017; Kühnisch *et al.*, 2016b).

The bitewing and NILT assessment methods were also reviewed in a recent study by (Kühnisch *et al.*, 2016). The authors demonstrated that NILT examination can perform similarly to bitewing radiography in terms of independently inspecting the proximal and occlusal surfaces. However, another clinical study showed that one of the devices that used NILT, particularly DIAGNOcam could detect the enamel lesion of proximal permanent teeth more accurate than the BW (Neuhaus *et al.*, 2015;Abdelaziz *et al.*, 2018). The reason could be related to underestimation of the size of the carious lesion during the use of BW. Likewise, Söchtig *et al.* (Kühnisch *et al.*, 2016b) compared bitewing and NILT examination methods and discovered that NILT examination can perform similarly to bitewing radiography in terms of examining both proximal and occlusal surfaces at once (Baltacioglu and Orhan, 2017a).

NILT devices usually used very high wave length; between 700 nm and 1500 nm NILT (Marmaneu-Menero *et al.*, 2020). This high wavelengths help in reduction of scattering, therefore, enhance the depth of penetration of the objects by this light (N. Abogazalah, Eckert and Ando, 2017). As a result, near-infrared light might easily pass through solid dental enamel and provide a good contrast between a caries lesion and the surrounding healthy hard tissue (Kühnisch *et al.*, 2016a). The emitted light is focused on the alveolar process rather than straight into the interproximal region, which is another significant change in the NILT. From an occlusal view, both changes have significantly enhanced the imaging quality of interproximal sites (Kühnisch *et al.*, 2016a). Non-ionizing radiation is performed to visualize the interproximal caries process, which appears to have a significant effect (Kühnisch *et al.*, 2016a).

2.6.4 Fiber Optic Transillumination (FOTI)

Transillumination is a technique that uses optic fiber technology to target a tooth with high-intensity white light from a hand-held device (Marmaneu-Menero *et al.*, 2020). Because carious teeth absorb considerably more light, we can see that the surrounding tissue is whiter and opaquer, whereas the lesion appears darker because it scatters visible light *(Figure 13)* (Marmaneu-Menero *et al.*, 2020). This procedure can be utilized on all of the patient's dental surfaces, but it's especially useful in interproximal lesions of anterior teeth, where the buccolingual enamel thickness is lower than that of posterior teeth (Marmaneu-Menero *et al.*, 2020). Radiography was found to be superior to fiber-optic transillumination of teeth (FOTI), which works well for thin front teeth (Marmaneu-Menero *et al.*, 2020).

Digital fiber optic transillumination (DIFOTI) is a digital variant of the technique in which the device saves the images on a computer (Braga, Mendes and Ekstrand, 2010). Instead of white light, DIFOTI uses near infrared radiation with a wavelength of 780 nm (Kühnisch *et al.*, 2016b De Zutter *et al.*, 2020). This new detection method seems capable of identifying caries and capturing different stages of interproximal enamel and dentin caries lesions (Kühnisch *et al.*, 2016b). As per the research, this method is noninvasive that is, does not involve ionizing radiation and it is more accurate compared to x-rays in detecting early tooth demineralization (Hekimliğinde, Çürük and Yöntemleri, 2017).

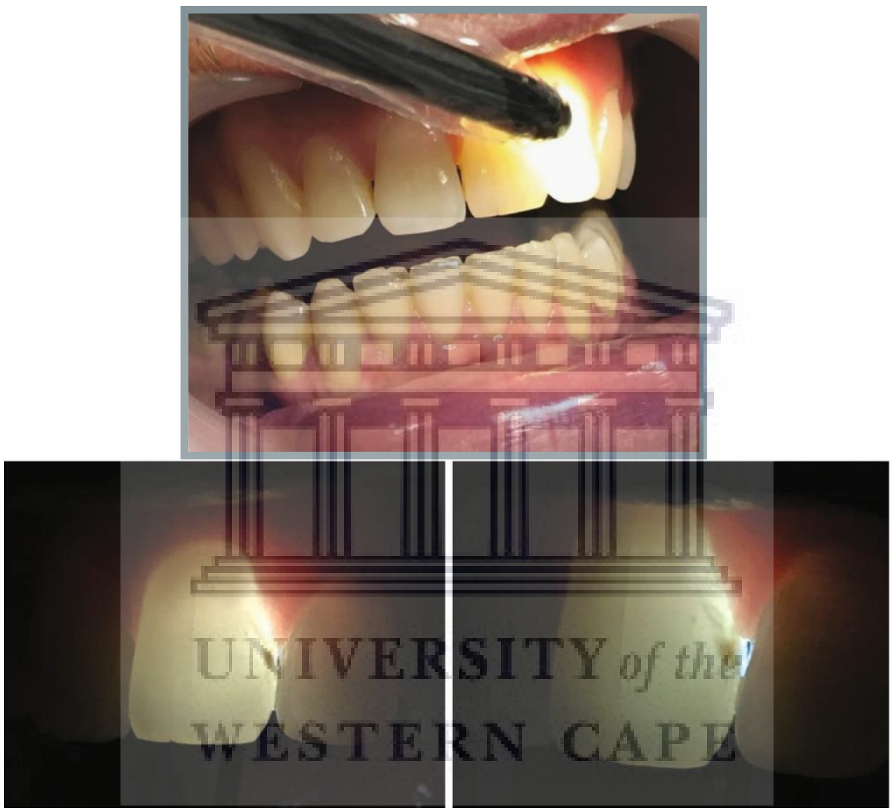


Figure 13: Fiber Optic Transillumination (FOTI) (https://link.springer.com/chapter/10.1007/978-3-030-16967-1_14)

Several studies have concluded the FOTI system has high specificities but low sensitivities for both proximal and occlusal surfaces when it comes to detecting caries lesions (Braga, Mendes and Ekstrand, 2010). It was concluded that bitewing radiography can't be replaced by FOTI (Neuhaus *et al.*, 2015; Rochlen and Wolff, 2011).

2.6.5 Laser Fluorescence (LF)

Quantitative light-induced fluorescence (QLF), which involves an arc lamp with a wavelength of 290-450 nm, was the first fluorescence-based technology to enter the market (Hekimliğinde, Çürük and Yöntemleri, 2017; Braga, Mendes and Ekstrand, 2010). The speed of light travels faster in a carious tooth than in healthy tooth. The light pathway is shortened in the carious lesion therefore the absorption and fluorescence are decreased *(Figure 14)*. In this way the scattered light is used to evaluate demineralization of the tooth (Hekimliğinde, Çürük and Yöntemleri, 2017). The QLF approach has been proposed as a useful tool not only for detecting caries on their early stage but to observe the progression of the lesion or the process of remineralization (Hekimliğinde, Çürük and Yöntemleri, 2017).

Figure 14: Example of FOTI images. A: No shadow; B: Thin-grey shadow into enamel; C: Wide-grey shadow into enamel; D: Microcavitated lesion shadow <2 mm in dentine; E: Shadow >2 mm in dentine (Gomez, 2015).

In recent years, new adjunct devices like as the laser fluorescence pen (LF), Biberach, KaVo, DIAGNOdent 2095, Germany, have been proposed to improve caries diagnosis accuracy and improve assessments (Bozdemir *et al.*, 2016). The LF pen can detect occlusal and interproximal caries by measuring the fluorescence released when laser light with a wavelength of 655 nm is used (Yoon, Yoo and Park, 2017). It has demonstrated high accuracy and reliability in determining proximal demineralization (Yoon, Yoo and Park, 2017; Bozdemir *et al.*, 2016). Radiography and the LF pen have both showed promise in terms of enhancing the sensitivity of interproximal caries detection. According to Lussi et al. (2006), the LF pen performed better than radiography in identifying interproximal caries in permanent teeth and performed well in detecting both early and advanced enamel interproximal caries (Bozdemir *et al.*, 2016).

According to a recent controlled clinical trial study, the ability to identify dentine lesions is equivalent to bitewing radiography. The LF pen's minimal dimension of 0.4 mm is large in order to assess all interproximal regions and accurately measure the dental caries below the contact area (Neuhaus *et al.*, 2015). There has been no clinical investigation to validate quantitative light-induced fluorescence (QLF) in interproximal caries lesions (Neuhaus *et al.*, 2015).

2.6.6 Light Emitting Diode (LED)

Recently a new device has been invented to detect occlusal and interproximal caries (Ozsevik *et al.*, 2015). Only a few studies in the literature are reported on the application of LED compared to studies made on its efficiency in detecting occlusal surface caries (Bozdemir *et al.,* 2016). The manufacturers aim regarding the LED device is to detect any kind of lesions from the occlusal surface (Neuhaus *et al.*, 2015).

When projecting the LED beam, a sound tooth appears to be have a translucent incical edge (anterior teeth) compared to demineralized tooth (Bozdemir *et al.*, 2016). Because of the changes in translucency, there is a difference in the optical appearance of a sound tooth and a demineralized tooth (Bozdemir *et al.*, 2016). Caries are detected using 2 signals: sound and light (the green light changes to red) (Hekimliğinde, Çürük and Yöntemleri, 2017). It has shown effectiveness in wet teeth but removal of plaques is a must before the examination (Hekimliğinde, Çürük and Yöntemleri, 2017). The diodes produce light at 450 nm and capture vast regions of the tooth in a single picture, isolating areas of changed fluorescence. (Rochlen and Wolff, 2011). Organic deposits such as stains, porosities, and crystalline de-structuring causes interruptions for the autofluorescence signal and may lead to incorrect valuation of the tooth surface ending with false-positive readings (Rochlen and Wolff, 2011).

2.6.7 Cone Beam Computed Tomography (CBCT)

Radiography is well acknowledged to be an important tool in the diagnosis of caries. The fast advancement of technology has resulted in the production of numerous digital dental imaging modalities, such as digital intraoral radiography and cone beam computerized tomography (CBCT) scanners (Cheng *et al.*, 2012). CBCT, a new 3D radiographic modality is used in dental clinics. It is a volumetric- based image where the tomographic sections are obtained in given resolutions which then are joined together to form a cubic pixel (Valizadeh *et al.*, 2012; Katib and Alfuraih, 2018). CBCT is a novel technique that produces images with sub-millimeter resolution in the axial, coronal, and sagittal planes *(Figure 15)* (Qu *et al.*, 2011).

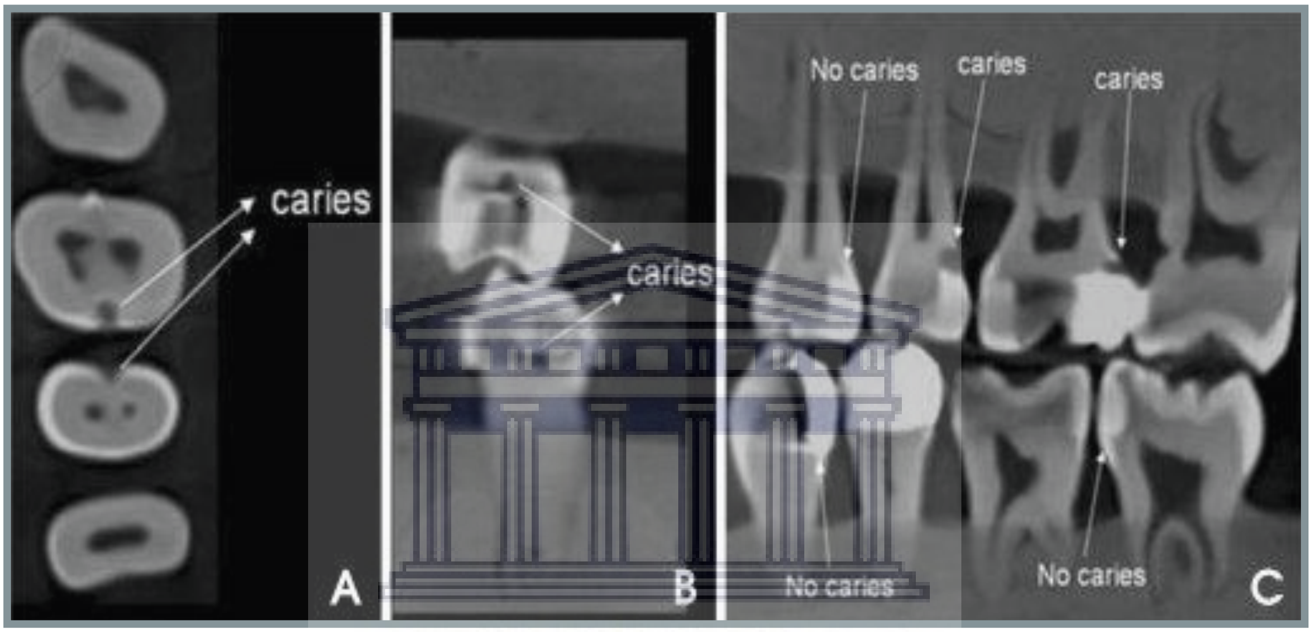


Figure 15: CBCT image (https://www.researchgate.net/publication/221736175_Diagnostic_performance_of_cone-beam_computed_tomography_on_detection_of_mechanically-created_artificial_secondary_caries/figures?lo=1)

The formation of images is divided into two stages: image acquisition and reconstruction, followed by image presentation. During the acquisition stage, cone beam collection procedures typically involve a single 180-degree rotation or more in which the x-ray source and a reciprocating x-ray detector are attached by an arm and rotate around the patient's head. (Nasseh and Al-Rawi, 2018). Some machines demand that data be captured by a separate acquisition computer and transmitted to another processing computer for reconstruction in order to ease data handling (Nasseh and Al-Rawi, 2018).

Studies regarding the effectiveness of CBCT have found that there is no difference between CBCT and traditional methods in identifying interproximal caries without cavitation (Isman, Aktan and Ertas, 2020).

A few studies investigated the effects of amalgam restorations on the diagnosis of interproximal caries using CBCT and found that diagnosis was insufficient due to low specificity (Isman, Aktan and Ertas, 2020).

Some of the advantages of CBCT mentioned are as follows: X-ray beam limitation, image accuracy, good bony tissue visualization, rapid scan time (4.5-30 seconds), maxillofacial imaging has its own set of display options, artifacts of images are reduced , adjustable images, avoidance of chemical processing, less working time and convenient transferable software reconstruction (Işınlı *et al.*, 2017; Cheng *et al.*, 2012; Drage, 2018).

“Cone-beam" projection geometry, detector sensitivity, and contrast resolution are all linked to the limitations of CBCT (Nasseh and Al-Rawi, 2018; Işınlı *et al.*, 2017). The CBCT images have disadvantages which are as follows: radiation dose is high compared to plain film, artifacts (metal and movement), noise, and poor soft tissue contrast, structure edges lose their definition and costly (Nasseh and Al-Rawi, 2018; Drage, 2018).

With all the different types of diagnostic methods being introduced, used and compared to each other, the final diagnosis for treating a case depends on the student. In order for the students to diagnose caries, some skills need to be mastered so they can decide on a correct treatment plan. Some of the differences the students should know are arrested caries and soft caries, non cavitated carious lesions and cavitated carious lesions, soft dentine and hard dentine (Banerjee *et al.*, 2017).

2.7 Literature related to research methods

2.7.1. Scoping Review

Scoping review commonly refers to ‘mapping,’ a process of summarizing a range of evidence in order to convey the breadth and depth of a field and have been used to answer a range of research questions (Hacking, 2012). It has a broad scope and an extensive inclusion criterion (Munn *et al*.,2018). Scoping reviews include a wide range of methodologies and study designs; however, some researchers indicate that a critical appraisal of individual studies is not necessary to produce evidence from studies (Pham *et al.*, 2014). Others have completed an appraisal of studies included for a scoping review using the Mixed methods appraisal tool (MMAT) version 2011 (Pluye P, Robert E, Cargo M, Bartlett G, O'Cathain A, Griffiths F, *et al*).

Background of Arksey & O'Malley's Framework

The method that was used by Arksey and O'Malley for scoping review studies relied on the definition formulated by Mays *et al*: "to map rapidly the key concepts underpinning a research area and the main sources and types of evidence available (Daudt, Van Mossel and Scott, 2013). It can be undertaken as separate projects in their own right, especially where an area is complex or has not been reviewed comprehensively before" (Mays et al. 2001: 194; emphasis in original;Daudt, Van Mossel and Scott, 2013; Colquhoun *et al.*, 2014). They came up with the first framework for scoping reviews. The framework they created expands on this description by outlining 4 primary reasons for undertaking a scoping review study and these are:

1. To examine the extent, range and nature of research activity.
2. To determine the value of undertaking a full systematic review.
3. To summarize and disseminate research findings.
4. To identify research gaps in the existing literature.

They later on expanded their first framework to provide a more precise and sequenced guidance to authors undertaking scoping studies and the 6th step being an optional step (Hacking, 2012 ; Pham *et al.*, 2014).

Arksey and O'Malley's framework consists of 6 steps which are:

1. Identifying the research question
2. Identifying relevant studies
3. Study selection
4. Charting the data

5. Collating, summarizing, reporting the results and

6. Consultation exercise, in some cases it is optional

They also encouraged other researchers to build on their framework to improve the methodology. One such example are the recommendations made by Levac *et al* (2010) (Daudt, Van Mossel and Scott, 2013). They made recommendations to every step in Arksey and O'Malley's framework and it included the following:

Stage 1: Linking the research question and the purpose of the research.

Stage 2: Balancing comprehensiveness with the feasibility of conducting scoping reviews.

Stage 3: Systematic multidisciplinary team approach to selecting studies.

Stage 4: Means to aid data extraction.

Stage 5: Using number summaries and qualitative theme analysis, reporting of the results and considering the results of the findings in a wider context in relation to policy, practice and research.

Stage 6: Determining clearly why consultation with experts are required (Levac *et al.*, 2010).

Arksey and O'Malley framework stage	Description of scoping review stage	Levac et al. enhancements
#1 Identifying the research question	The scoping review question must be clearly defined as it plays a role in all subsequent stages including search strategy. In order to examine and summarize breadth, scoping review questions are broad.	1. Despite the broad nature of the question, ensure adequate clarity to guide the scope of inquiry including concept, target population, and health outcomes of interest. 2. Determine the research question in conjunction with the purpose for conducting the scoping review. Use the rationale for the scoping review to help define the purpose. 3. Stipulate the outputs (eg, framework, list of recommendations) that will be the result of the review.
#2 Identifying relevant studies	This stage involves identifying the relevant studies and developing a plan for where to search, which terms to use, which sources to search, time span, and language. Sources include electronic databases, reference lists, hand searching of key journals, and organizations and conferences. Comprehensiveness and breadth is important; however, so too are the practicalities of time, budget and personnel resources. Decisions need to be made upfront about how feasibility issues will impact the search.	1. Use the research question and purpose to guide decision-making around the scope of the review. 2. Justify all decisions for limiting the scope of the review and acknowledge any potential limitations as a result. 3. Ensure the team has the content and methodological expertise necessary for the review.
#3 Study selection	Study selection involves post-hoc inclusion and exclusion criteria. These criteria are based on the specifics of the research question and on new familiarity with the subject matter through reading the studies.	1. Study selection is not linear, but rather an iterative process that involves searching the literature, refining the search strategy, and reviewing articles for study inclusion. 2. Improved clarity in decision-making for study selection can be achieved using the following steps: • Conduct an initial team meeting to discuss inclusion and exclusion criteria. • Use two reviewers to independently review abstracts and full text articles • Incorporate a third reviewer in situations of disagreement to determine final inclusion. • Hold reviewer meetings at the beginning, midpoint and final stages of the abstract review process to discuss challenges and uncertainties related to study selection and to go back and refine the search strategy if needed.
#4 Charting the data	A data charting form is developed and used to extract data from each study. A "narrative review" or "descriptive analytical" method is used to extract contextual or process-oriented information from each study.	1. The research team should collectively determine which variables to extract in order to answer the research question. 2. Charting should be considered an iterative process in which reviewers continually extract data and update the data charting form. 3. Reviewers should pilot the charting form on five to ten studies to determine whether their approach to data extraction is consistent with the research question and purpose. 4. Contextual or process-oriented data may require a qualitative content analysis approach.
#5 Collating, summarizing, and reporting the results	An analytic framework or thematic construction is used to provide an overview of the breadth of the literature. A numerical analysis of the nature and extent of studies using tables and charts is presented. A thematic analysis is then presented. Clarity and consistency are required when reporting results.	1. Researchers should undertake the following three steps: • Analyze (including descriptive numerical summary analysis and qualitative thematic analysis) • Report the results (including the outputs as defined in the first stage) • Discuss the findings as they relate to the study purpose and implications for future research, practice and policy

(*Continued*)

Arksey and O'Malley framework stage	Description of scoping review stage	Levac et al. enhancements
#6 Consultation	This optional stage provides opportunities for consumer and stakeholder involvement to suggest additional references and provide insights beyond those in the literature.	1. The value of consultation should be considered for every scoping review. 2. The process for consultation should include the following steps: • Establish a clear purpose for the consultation • Use preliminary findings to inform the consultation • Clearly articulate the type of stakeholders to consult and how stakeholder data will be collected, analyzed, reported and integrated within the study • Incorporate opportunities for knowledge transfer and exchange with stakeholders in the field

Adapted from Levac et al., 2010.

Figure 16: Arksey and O'Malley framework stage with Levac's enhancements (Colquhoun et al., *2014)*

Once the Arksey and O'Malley framework was published, numerous academics took up the challenge in modifying it and enhancing its steps (Daudt, Van Mossel and Scott, 2013). In 2010, one of the most commonly used modification was published by Levac *et al.* This framework targeted the strengths and limitations in order to maintain a steady method for different scoping reviews studies *(Figure 16).* Arksey & O'Malley and Levac's framework was later improved in 2015 by the Joanna Briggs Institute (JBI) (Tricco *et al.*, 2016). JBI is a recognized global leader in evidence-based healthcare with a methodological guidance for the conduct of scoping review (The Joanna Briggs Institute, 2016). The improvements mentioned previously by these researchers led to the following steps for conducting scoping reviews as shared by the JBI.

Stage 1: Aligning and defining the questions and objectives.

Stage 2: Aligning and developing the inclusion criteria with the questions and objectives.

Stage 3: Explaining a planned approach to searching and selecting the evidence.

Stage 4: Evidence search.

Stage 5: Evidence selection.

Stage 6: Evidence extraction.

Stage 7: Evidence charting.

Stage 8: Evidence summary in relation to the questions and objectives (stage 8); consultation of information throughout the process (Peters *et al.*, 2015).

2.7.2 Explanation and elaboration of the 4 stages of the Prisma Flow Diagram

1. Identification

Following the database searches that must be done for this scoping review, this entails finding relevant papers linked to final year dental students and diagnostic methods. A number of documents will be identified once all search words have been merged, and all appropriate constraints have been applied. This includes any articles that were discovered in other databases including other sources such as reference lists, trial registries, conference proceedings, or information collected from research authors who have conducted. As a result, these records will be included as well. After they have been added, an online system like Mendeley is used to delete any duplicates.

2. Screening

An abstract that provides important information about the review's major aims or questions, methodology, conclusions, and implications should enable readers decide whether to access the entire report. The abstract may be all that some readers have access to. As a result, regardless of statistical significance, size, or direction of effect, results for all key outcomes for the main review goal or question must be given. As a result, it is important to submit terms that correctly define the review topic (such as population, interventions, and outcomes) (Matthew J. Page *et al.*, 2021).

3. Eligibility Criteria

Specifying the criteria used to determine whether evidence was acceptable or ineligible in sufficient detail should allow readers to comprehend the breadth of the review and verify inclusion choices. The Population, Intervention, Comparator, Outcome The (PICO) framework is frequently used to organize the reporting of eligibility criteria for intervention evaluations. In addition to identifying and defining the review PICO, the intervention, outcome, and demographic groups utilized in the synthesis must be identified and specified.

Specify all research criteria used to determine if a study was suitable for inclusion in the review, including components stated in the PICO framework or one of its variations, as well as other factors such as appropriate study design and setting, and minimal period of follow-up (Matthew J. Page *et al.*, 2021).

• Specify eligibility criteria for report features such as publication year, language, and report status for example, if unpublished manuscripts and conference abstracts were eligible for inclusion (Matthew J. Page *et al.*, 2021).

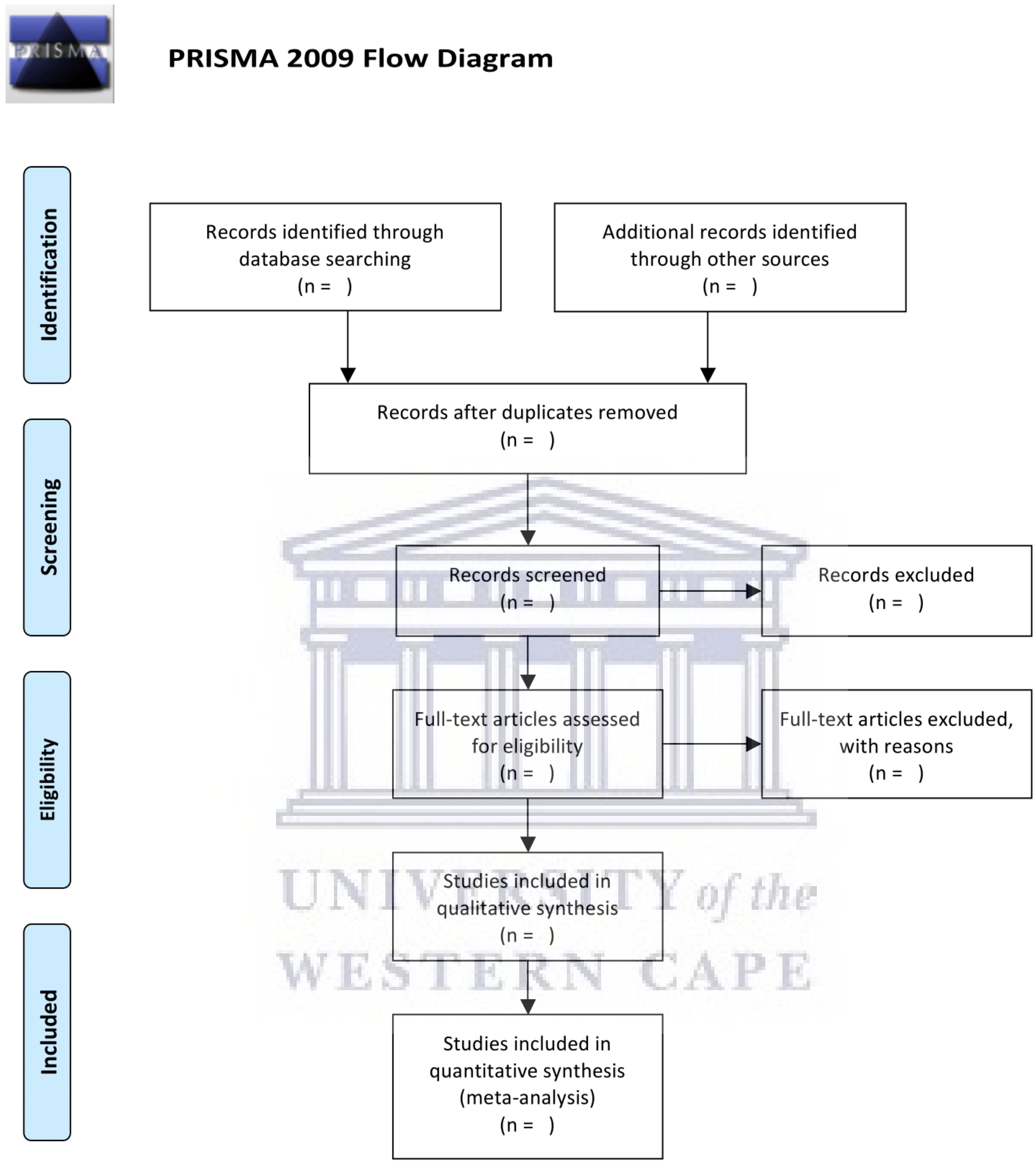
• Indicate clearly if studies were excluded because the outcomes of interest were not assessed or because the results for the outcomes of interest were not published. It is unclear and should be avoided to report that studies were eliminated because they lacked "relevant outcome data" (Matthew J. Page *et al.*, 2021).,

• Specify any groups included in the synthesis (such as intervention, outcome, and demographic groups) and connect them to the objectives for comparisons (Matthew J. Page *et al.*, 2021).

Rationales should be considered for any significant restrictions on study eligibility (Matthew J. Page *et al.*, 2021).

4. Included Studies

Details of the included studies should be reported as it enables readers to understand the features of studies that addressed the review questions. This is significant for understanding the review's relevance. Interest factors might include research design elements, participant characteristics, how results were determined, funding source, and the competition of conflict of interests between study authors. Tables and figures are used to present the important details in studies and are used for comparison. Referencing or citing all the studies will allow for the retrieval of the reports if needed (Matthew J. Page *et al.*, 2021).



From: Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). *P*referred *R*eporting *I*tems for *S*ystematic Reviews and *M*eta-*A*nalyses: The PRISMA Statement. PLoS Med 6(7): e1000097. doi:10.1371/journal.pmed1000097

For more information, visit www.prisma-statement.org.

Figure 17: Prisma Flow Diagram

2.7.3 Mixed Methods Appraisal Tool (MMAT):

In the year 2006, the development of the MMAT took place and revised in 2011 (Nha *et al.*, 2018). It is a critical appraisal tool that is designed for the appraisal stage of systematic mixed studies reviews, meaning, reviews that include mixed methods studies in addition to both quantitative and qualitative studies (Nha *et al.*, 2018; Pace *et al.*, 2012). The combination of quantitative and qualitative techniques has been practiced for a long time in assessment and research, only lately that it was defined as mixed methods research (Pluye, Grad, *et al.*, 2009; Pluye, Gagnon, *et al.*, 2009). It appraises the methodological quality of studies in 5 categories: mixed methods studies, qualitative research, quantitative descriptive studies, randomized controlled trials and non-randomized studies (Nha *et al.*, 2018; Pace *et al.*, 2012).

2.7.4 Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA)

QUOROM (*QU*ality *O*f *R*eporting *O*f *M*eta- analyses) Statement was first introduced in 1999 and was later updated into Preferred Reporting Items for Systematic reviews and Meta-Analysis (PRISMA) (Liberati *et al.*, 2009; Sohrabi *et al.*, 2021).

Moher and colleagues published the (PRISMA) guideline in 2009 (Mcgowan *et al.*, 2020). PRISMA is defined as an evidence-based minimum set of items for systematic review and meta-analysis reporting. It focuses mainly on the reporting of reviews assessing the effects of interventions, but it may also be used to record systematic reviews with purposes other than evaluating interventions, such as evaluation of diagnosis, prognosis, etiology and prevalence of a disease (Page *et al.*, 2021; Sohrabi *et al.*, 2021). PRISMA 2009 was criticized for lack of exploring details relating to individual participation data (IPD) widely used in both systematic reviews and meta-analyses prompting the 2015 publication of the PRISMA-IPD (Sohrabi *et al.*, 2021).

Since the publication of PRISMA, numerous extensions were issued to address some of the different aspects for example:

a) PRISMA-ScR (Scoping Review)

b) PRISMA-E 2012 (systematic reviews with a focus on health equity),

c) PRISMA-Abstracts (systematic reviews in journal and conference abstracts),

d) PRISMA-P (systematic review and meta-analysis protocols),

e) PRISMA-IPD (systematic review and meta-analysis of individual participant data),

f) PRISMA extension (network meta-analyses),

g) PRISMA-harms (improving harms reporting),

h) PRISMA-CI (AHRQ series on complex interventions) and

i) PRISMA-DTA (systematic review and meta- analysis of diagnostic test accuracy studies) (Mcgowan *et al.*, 2020).

The PRISMA-ScR extension for scoping reviews was created to improve the quality and conduct of scoping review reporting (Mcgowan *et al.*, 2020). There is a difference between a scoping review and a systematic review. A scoping review answers a non-specific research questions and identify ideas and knowledge gaps in a new topic instead of evaluating the intervention's safeness and effectiveness (Sohrabi *et al.*, 2021). Scoping reviews are flexible in their conduct, allowing them to be customized to the needs of researchers (Mcgowan *et al.*, 2020).

It is recommended to use the PRISMA 2020 statement as an alternative of the out-of-date 2009 statement for any future original and revised systematic reviews. It is strongly advised to refer to the PRISMA 2020 statement to provide prospective consideration and inclusion of all specified elements. Authors should edit the PRISMA flow diagram, which is freely accessible online, to match the 27-item checklist (Sohrabi *et al.*, 2021; Page *et al.*, 2021).

CHAPTER 3: RESEARCH OBJECTIVES AND HYPOTHESIS

This chapter describes the research aim, the correctly formulated research questions and an outline of the research objectives to address the aim and answer the research questions. In addition, the null hypothesis for the cross-sectional study is also described.

3.1 Aim

To determine the capability of 5th year dental students in diagnosing early interproximal caries using conventional bitewing film, digital radiographs and printed film on paper.

3.2 Objectives

1. To conduct a scoping review literature in regards to the most common and different diagnostic methods used to detect early interproximal caries.
2. To determine the students' diagnostic ability using bitewing films.
3. To determine the students' diagnostic ability using digital radiographs.
4. To determine the students' diagnostic ability using printed film on paper.
5. To compare the results between the 3 different diagnostic methods.

3.3 Research Questions

Are 5th year dental students capable of detecting early interproximal caries using various radiographic diagnostic methods?

What are the most common diagnostic methods used by students and practitioners (general and specialists) to detect interproximal caries?

3.4 Hypothesis

The 5th year dental students are incapable of detecting early interproximal caries using 3 different radiographic diagnostic techniques.

CHAPTER 4: METHODOLOGY

This chapter describes the methodology for the data collection for both, scoping review and the cross-sectional study that has been conducted.

4.1 Methodology of Scoping Review

Scoping reviews (ScR) are used to identify knowledge gaps, research objectives, and decision-making implications. In the literature, there is inconsistency in the conduct and reporting of scoping reviews (Tricco et al., 2016). The methodology for this scoping review was based on Arksey and O'Malley's (2005) framework and the recommendations provided by Levac et al (2010). The review consisted of the 5 major steps listed below:

Stage 1: Identifying the research question

This review was guided by the question:

'What are the most common and different diagnostic methods used to detect early interproximal caries?'

A scoping review is a type of research synthesis that aims to 'map the literature on a particular topic or research area and provide an opportunity to identify key concepts, gaps in the research, types and sources of evidence to inform practice, policymaking, and research (Daudt, Van Mossel and Scott, 2013).

Stage 2: Identifying relevant studies

For the scoping review (ScR), relevant studies were searched for using several electronic databases with scientific materials, including Cochrane library, PubMed, Wiley Online Library, Ebscohost, Science Direct and Scopus. Keywords and keyword combinations using Boolean operators were used to identify studies which were relevant to the research question. An example for this study is as follows: (dental students AND bitewing radiography), (diagnostic methods AND interproximal caries OR dental caries), (final year students AND digital radiography).

Search strategy:

(Undergraduate students OR senior dental students OR final year students) AND (bitewing radiography OR digital radiography OR diagnostic method) AND (interproximal caries

OR dental caries OR caries) AND (cross sectional OR randomized controlled trials OR clinical trials OR cohort studies OR prospective studies).

Other specifics such as the year, in this case was from 2015-2021, were limited to the search. Following these electronic searches, a hand-search of journals was undertaken, and the reference lists of related studies were examined to find additional publications that may not have been identified during the first search.

Stage 3: Study selection

The team (MA and SK) formulated the inclusion and exclusion criteria to apply to the studies, and these were applied to the relevant literature that were identified through searching different databases which included Cochrane library, PubMed, Wiley Online Library, Ebscohost, Science Direct and Scopus. The primary researcher and the research supervisor applied these criteria to the papers gathered, then the duplicates were removed which narrowed down the articles to title viewing and further exclusion took place. The papers' abstracts were then viewed, to allow us to rule out those articles that do not meet the inclusion criteria. Next, we review the full text of the articles to select out the papers that follows the inclusion criteria. Finally, studies with common findings on diagnostic methods used by students and practitioners (general and specialists) to detect interproximal caries were included in full text and the final data was extracted from these.

Stage 4: Charting the data

Arksey and O'Malley advise charting and categorizing data according to themes and issues to organize the data (Appendix 3). They recommend that the data extracted should have a combination of general research information and specialized data linked to the study topic. For a particular study, researchers are allowed to choose which categories to chart.

Stage 5: Collating, Summarizing and reporting the results

It was important to follow a consistent, straightforward method while reporting the data for this study. Data was plotted according to the extent, type, and distribution of the included articles, using Arksey and O'Malley's methodology. Tables are used to report the necessary information.

Stage 6: Consultation exercise (optional)

According to Arksey and O'Malley, a consultation step involving researchers and stakeholders is optional, but Levac *et al*. believe it should be mandatory.

4.1.1 Searching criteria for studies inclusion:

The scoping review has been conducted using computerized searches of various databases including Cochrane library, PubMed, Wiley Online Library, Ebscohost, Science Direct and Scopus.

The article search is reported using a PRISMA flow chart for data analysis. Characteristics were evaluated descriptively for all included studies, and data extraction criteria were followed, which had to be somewhat changed based on the kind of report (e.g., date of publication, location, study design, study characteristics and author details). The data is presented in a descriptive form based on the study's criteria.

4.2 Methodology of Cross-sectional Study:

The following objectives were covered using the method explained below:

1. To determine the students' diagnostic ability using bitewing films.
2. To determine the students' diagnostic ability using digital radiographs.
3. To determine the students' diagnostic ability using printed film on paper.
4. To compare the results between the 3 different diagnostic methods.

4.2.1 Study Design

- It is a cross-sectional study with the involvement of current 5th year dental students, the class of 2019 using retrospective data; different radiographs of previous patients were randomly selected to assess the students.

4.2.2 Study Area

- The study has been conducted at the Tygerberg Oral Health Centre, Faculty of Dentistry, University of the Western Cape. The area set for the study was in one of the dental cubicles in the Prosthodontics clinic, where there was a lightbox that was used to read the radiographs, the digital screens are placed in the clinical section as well, thus these or the digital radiographs and a desk lamp was used as well for the printed film on paper.

4.2.3 Study Duration

- The duration of this study was 1 year for collecting data only. The preparation after ethics registration took about 2 months to decide with the standardized subjects what these final X-rays should be that were used in the study.

4.2.4 Sampling Selection Process

- The selected radiographs were selected in systematic random sampling approach. The selection was based according to the inclusion and exclusion criteria listed below.

Inclusion of Radiographs:

- Radiographs included for this study are collected from those taken only at the Tygerberg Oral Health Center.
- Good quality radiographs showing early signs or no signs of interproximal caries with the neighboring tooth.

Exclusion of Radiographs:

- The poor-quality radiographs have been discarded (for example if they showed poor exposure, artifacts and movements).
- Radiographs showing any features of overlapping interproximal areas were also excluded as these would be difficult for students to view.

4.2.5 Target Population

- The class of 5th year dental students (2019) from the University of the Western Cape in Tygerberg Oral Health Center were targeted for this study.
- They were chosen for the study due to their clinical experience, as they have been exposed to numerous different radiographs and are much more familiar with them in comparison to the 3rd and 4th year dental students. Their familiarity with the ICDAS system will be of benefit for them while viewing the radiographs.
- The 3rd year students have not been selected for this study because in this year, they are only introduced to the radiographic techniques and devices and have not yet been taught how to read radiographs clinically. They are yet to have any clinical experience.
- The 4th year students have not been selected for this study due to the fact that they only start clinical sessions in 4th year and may have not been exposed to a numerous number of radiographs that involve interproximal caries.

4.2.6 Data Collection Method:

A questionnaire was given out to the students to complete. The questions have been derived from previous similar studies that involved students and diagnostic methods (Tavakoli *et al.*, 2015; Nemati *et al.*, 2017). It has been slightly altered to fit the aim and objectives of this current study.

The first part was general knowledge questions related to diagnostic methods and interproximal caries. The second part of the questionnaire involved the students examining radiographs and answering the questions accordingly.

The students were shown 3 conventional bitewing radiographs using a light box located in the dental cubicles. The light box had to be working with bright light in order to see the radio-opacity and radiolucency clearly. The students had 2 minutes for standardization to examine each radiograph.

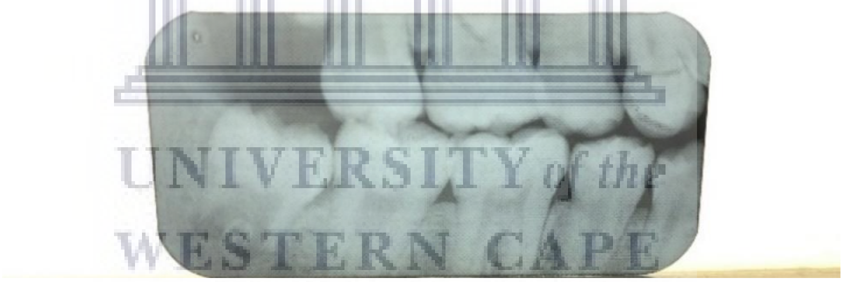


Figure 18: Conventional bitewing image with an intact surface (R0).

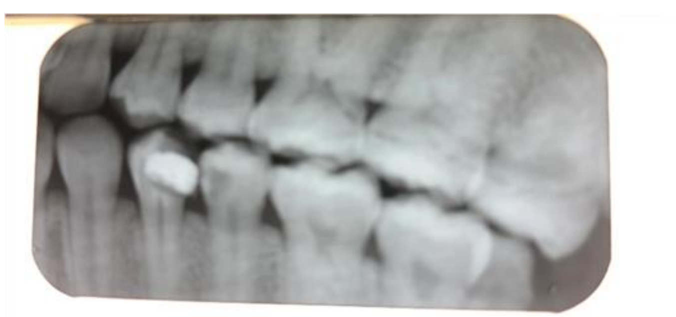


Figure 19: Conventional bitewing image with radiolucency in inner half of dentin (R4).

Figure20: Conventional bitewing image with radiolucency in inner half of dentin (R4).

The students were shown 3 radiographs on the digital screens using the Picture Archiving and Communication System (PACS) which helped them to zoom in (magnify) and zoom out in areas where they doubted if there is dental caries or not. The digital screens are located in the dental cubicles in Tygerberg Oral Health Center where the students have their clinical sessions. They were given 2 minutes for standardization of the study to examine each radiograph.

Figure 21: Digital bitewing radiograph with radiolucency in the outer half of enamel (R1).

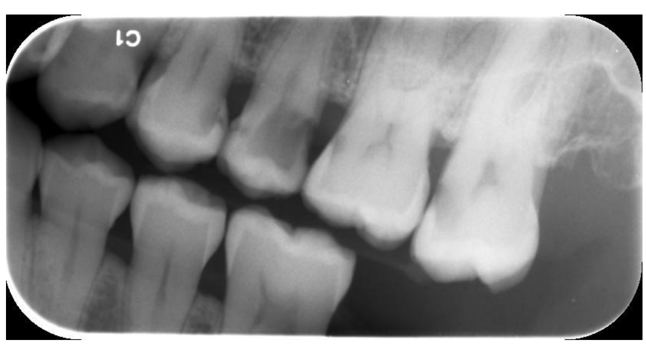


Figure 22: Digital bitewing radiograph with radiolucency in the outer half of dentin (R3).

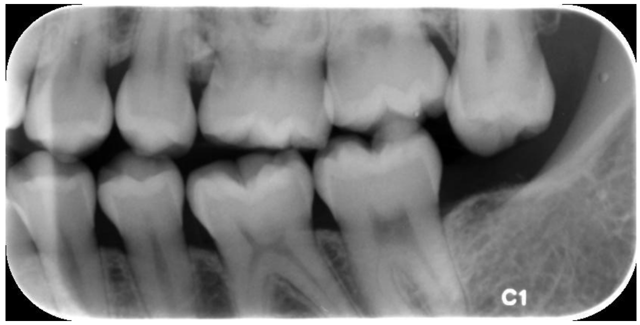


Figure 23: Digital bitewing radiograph with intact surface (R0).

The students were given 3 printed films on paper that they had to examine. The printed films on paper were viewed under a desk lamp for a more accurate diagnosis. The students were given a time of 2 minutes per radiograph for standardization.

Figure 24: Printed film on paper with radiolucency in the outer half of dentin (R3).

Figure25: Printed film on paper with radiolucency in inner half of dentin (R4).

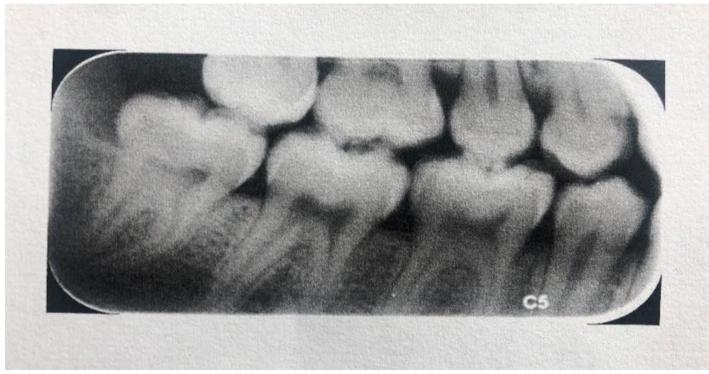
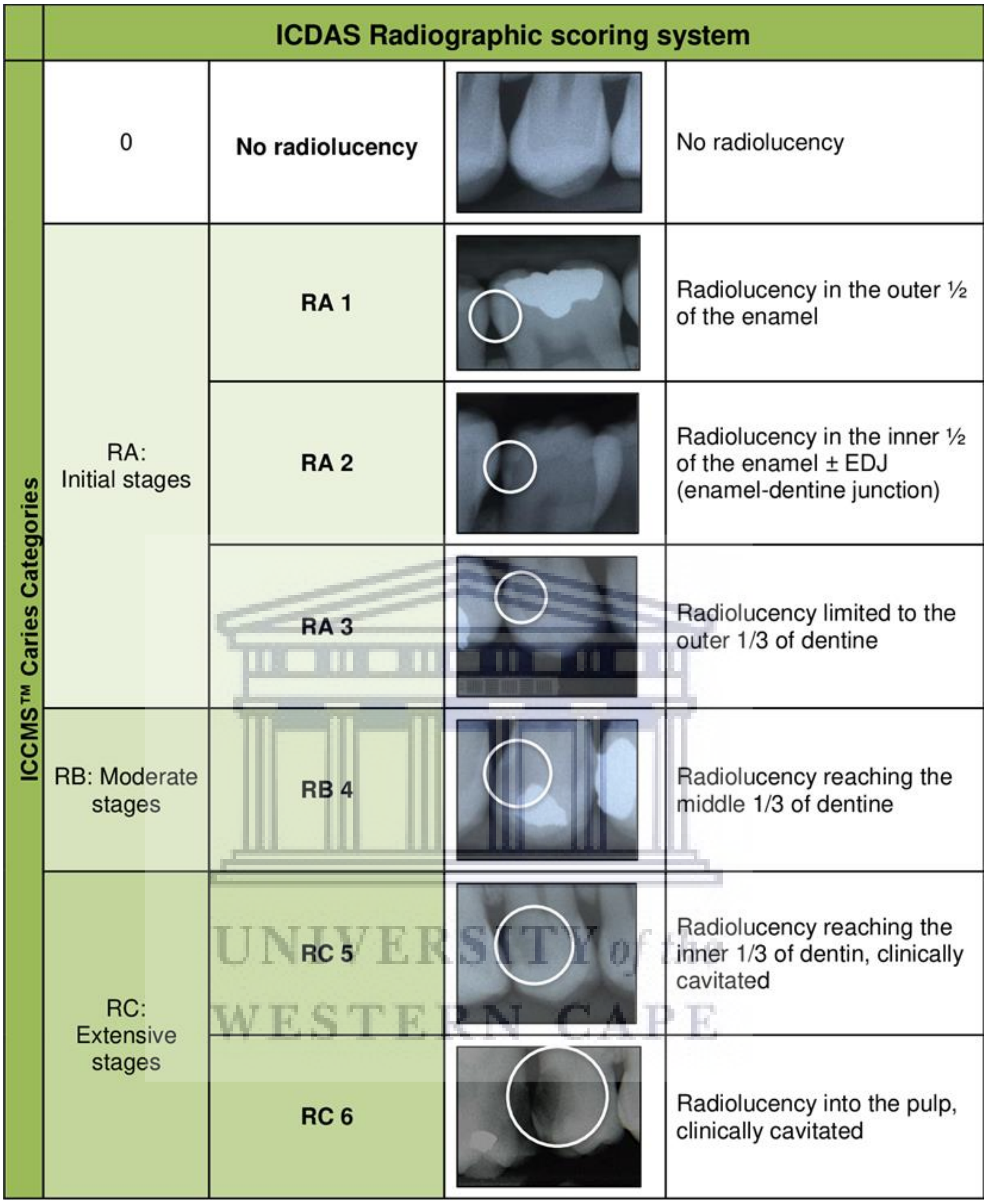


Figure 26: Printed film on paper with an intact surface (R0).

The radiographs were divided into 3 categories: intact surface, early-stage interproximal caries and advanced stage interproximal caries.

The students had to detect the size of the caries present given the choice of one or more of the following; R0 Intact surface, R1 Radiolucency (RL) in outer half of enamel, R2 RL in inner half of enamel, R3 RL in outer half of dentin, R4 RL in inner half of dentin. In summary, the students viewed 9 different radiographs with different readings.

A control group (gold standard) was used in order to compare the students' results. Specialists from both the Radiology Department and Restorative Department including myself have finalized the answers regarding the presence/absence of caries and its depth on all 3 different techniques. The control group consists of 4 faculty staff. The same radiographs were examined by each member in the control group. The agreement was made when 2 of the control groups share the same answer. When conflicts in the answer takes place, a third opinion is taken into consideration.



ICCMS™ Caries Categories	ICDAS Radiographic scoring system			
	0	**No radiolucency**		No radiolucency
	RA: Initial stages	**RA 1**		Radiolucency in the outer ½ of the enamel
		RA 2		Radiolucency in the inner ½ of the enamel ± EDJ (enamel-dentine junction)
		RA 3		Radiolucency limited to the outer 1/3 of dentine
	RB: Moderate stages	**RB 4**		Radiolucency reaching the middle 1/3 of dentine
	RC: Extensive stages	**RC 5**		Radiolucency reaching the inner 1/3 of dentin, clinically cavitated
		RC 6		Radiolucency into the pulp, clinically cavitated

Figure 27: The International Caries Classification and Management System (ICDAS)/ International Caries Classification and Management System (ICCMS™) radiographic scoring system (Pitts et al., 2014).

4.2.7 Data Collection Tool

The data was collected using a questionnaire that consists of 28 questions. The first section (Questions 1-10) pertains to measure the student's general knowledge in radiography. The second section (Questions 11-28) includes direct tasks of identifying caries presence and measuring its size.

Questionnaire:

Please answer the following questions and tick (✓) the appropriate response:

NILT: Near-infrared light transillumination
CBCT: Cone beam computed tomography
IOC: Intra oral camera
R0: Intact surface, **R1**: RL in outer half of enamel, **R2**: RL in inner half of enamel,
R3: RL in outer half of dentin, **R4**: RL in inner half of dentin.

1.	What is your gender?	Male	Female			
2.	Have you used bitewing radiographs for diagnosing caries?	Yes	No			
3.	Have you faced any kind of difficulty diagnosing a caries radiographically?	Yes	No			
4.	If yes, what was the cause of the difficulty?	Not enough knowledge	Technical error	Exposure error	Poor image sharpness	
5.	What is the most common diagnostic method you have used?	Bitewing	Digital radiography	NILT	CBCT	IOC
6.	Which diagnostic method would you prefer using for diagnosing interproximal caries?	Bitewing	Digital radiography	NILT	CBCT	IOC
7.	What is the reason for your choice?	High accuracy level	Easy to use and handle	Availability at the hospital	Patient friendly	Time saver
8.	How difficult is it to detect early interproximal caries radiographically?	Extremely easy	Slightly easy	Average	Slightly difficult	Extremely difficult
9.	How often do you think is your diagnosis of early interproximal caries correct?	Always	Sometimes	Never		
10.	How often have you misdiagnosed interproximal caries on their early stage?	Always	Sometimes	Never		

11.	**BITEWING FILM** Are you able to identify the presence of interproximal caries?	Definitely present	Probably present	I cannot tell	Probably absent	Definitely absent
12.	**BITEWING FILM** What is the size of the caries present?	***R0*** Intact surface	**R1** RL in outer half of enamel	**R2** RL in inner half of enamel	**R3** RL in outer half of dentin	**R4** RL in inner half of dentin
13.	**DIGITAL X-RAY** Are you able to identify the presence of interproximal caries?	Definitely present	Probably present	I cannot tell	Probably absent	Definitely absent
14.	**DIGITAL X-RAY** What is the size of the caries present?	***R0*** Intact surface	**R1** RL in outer half of enamel	**R2** RL in inner half of enamel	**R3** RL in outer half of dentin	**R4** RL in inner half of dentin
15.	**FILM ON PAPER** Are you able to identify the presence of interproximal caries?	Definitely present	Probably present	I cannot tell	Probably absent	Definitely absent
16.	**FILM ON PAPER** What is the size of the caries present?	***R0*** Intact surface	**R1** RL in outer half of enamel	**R2** RL in inner half of enamel	**R3** RL in outer half of dentin	**R4** RL in inner half of dentin

17.	**BITEWING FILM** Are you able to identify the presence of interproximal caries?	Definitely present	Probably present	I cannot tell	Probably absent	Definitely absent
18.	**BITEWING FILM** What is the size of the caries present?	***R0*** Intact surface	**R1** RL in outer half of enamel	**R2** RL in inner half of enamel	**R3** RL in outer half of dentin	**R4** RL in inner half of dentin
19.	**DIGITAL X-RAY** Are you able to identify the presence of interproximal caries?	Definitely present	Probably present	I cannot tell	Probably absent	Definitely absent
20.	**DIGITAL X-RAY** What is the size of the caries present?	***R0*** Intact surface	**R1** RL in outer half of enamel	**R2** RL in inner half of enamel	**R3** RL in outer half of dentin	**R4** RL in inner half of dentin
21.	**FILM ON PAPER** Are you able to identify the presence of interproximal caries?	Definitely present	Probably present	I cannot tell	Probably absent	Definitely absent

22.	**FILM ON PAPER** What is the size of the caries present?	***R0*** Intact surface	**R1** RL in outer half of enamel	**R2** RL in inner half of enamel	**R3** RL in outer half of dentin	**R4** RL in inner half of dentin

23.	**BITEWING FILM** Are you able to identify the presence of interproximal caries?	Definitely present	Probably present	I cannot tell	Probably absent	Definitely absent
24.	**BITEWING FILM** What is the size of the caries present?	***R0*** Intact surface	**R1** RL in outer half of enamel	**R2** RL in inner half of enamel	**R3** RL in outer half of dentin	**R4** RL in inner half of dentin
25.	**DIGITAL X-RAY** Are you able to identify the presence of interproximal caries?	Definitely present	Probably present	I cannot tell	Probably absent	Definitely absent
26.	**DIGITAL X-RAY** What is the size of the caries present?	***R0*** Intact surface	**R1** RL in outer half of enamel	**R2** RL in inner half of enamel	**R3** RL in outer half of dentin	**R4** RL in inner half of dentin
27.	**FILM ON PAPER** Are you able to identify the presence of interproximal caries?	Definitely present	Probably present	I cannot tell	Probably absent	Definitely absent
28.	**FILM ON PAPER** What is the size of the caries present?	***R0*** Intact surface	**R1** RL in outer half of enamel	**R2** RL in inner half of enamel	**R3** RL in outer half of dentin	**R4** RL in inner half of dentin

Printer and Paper description:

This printer was used to print the digital films used in this study.

- Printer used: Konica Minolta (bizhub 223)
- Printer Resolution dots per inch (dpi): 1,800 x 600 dpi 1,200 x 1,200 dpi
- Copy Resolution (dpi): 600 x 600 dpi
- Paper used: Mondi Rotatrim white paper 80g/m. A4 (210x297mm)

Room conditions for reading radiographs:

In order to get the optimum reading of the radiographs, each group of radiographs was used under specific room conditions.

- Conventional film: Dark room with a light box.
- Printed film on paper: Lighting using a desk lamp.

- Digital radiograph: Normal clinical environment using standard screens next to the clinical cubicles.

Figure 28: Konica Minolta Printer (bizhub 223)

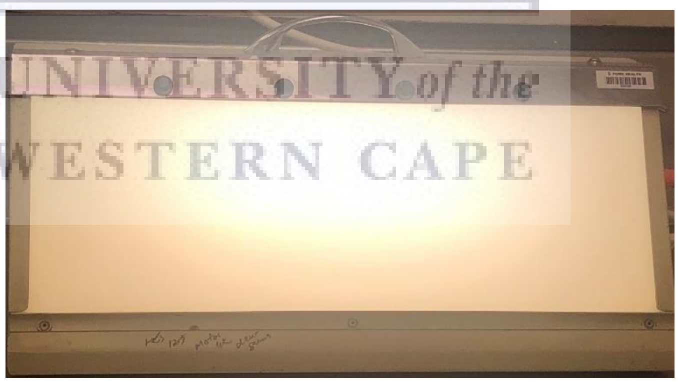


Figure 29: X-Ray lightbox

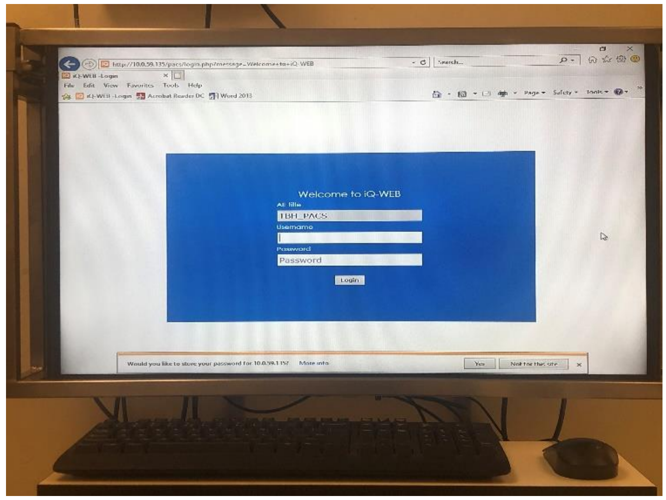


Figure 30: Digital screens using the Picture Archiving and Communication System (PACS)

4.3 Data Analysis

For all our analysis, the p-value that was <0.05 was viewed as statistically significant. The total scores of all mean values were out of 100.

The analysis was performed using the SPSS 14.0 statistics toolkit (SPSS©, Inc. Chicago, IL, USA) and reported into a Microsoft Excel 2019 ®Version 2106.

Furthermore, the data were sorted according to the student's gender, techniques' difficulty and preference, to find out if such factors could affect the students final scores.

1. The students mean scores for correct detection along with the standard deviations.

2. The statistical significant difference between the three different diagnostic techniques considering the students' performance.

3. The correlations between the 3 different diagnostic techniques using a pair sample correlation test.

4.4 Data Storage Policy

- It is the researcher's responsibility to ensure that materials generated and collected from their research activities are stored securely in a durable and accessible format and in a manner that ensures its authenticity and integrity as well as meeting all legal and confidentiality requirements (University of Pretoria, 2018). Access is permitted to the primary researcher only.
- Non-digital research data must be retained securely within the department; in the researcher's own office or the laboratory in which they were generated. In cases where the data is confidential it must be secured appropriately in compliance with ethical and legal requirements (University of Pretoria, 2018).

4.5 Ethical Consideration

All data collected is subject to the POPI Act of 2013, particularly Section 19 (Use of Identifiable Personal Information in Scientific Research).

- The scientific methodology and ethics of this study was approved by the Biomedical Research and Ethics Committee of the University of the Western Cape (BMREC) and Health Research ethic committee (HREC): BM19/9/8.
- Permission from the registrar of the university, the Faculty Dean of Dentistry and the selected participants was obtained, this was done by providing a voluntary informed consent. Research purpose, objectives and the participants' rights has been explained in the participant information sheet in clear simple words.
- Confidentiality was maintained in addition to that, the participants had the right to withdraw at any time without any deprivation of their rights, in case the participant decided to complete the study, he/she will have the right to benefit from the researcher knowledge and skills.

CHAPTER 5: RESULT

The results of the present study are divided into two components: Scoping review result which was demonstrated through the PRISMA flow diagram and the cross-sectional part which was analyzed through the use of the SPSS version 26.

The results of the scoping review will show the most commonly used diagnostic methods in the detection of early interproximal caries. In the other hand, the data analyzed for the cross-sectional study will conclude the student's capability in detecting the presence and depth of the caries using 3 different diagnostic methods. A comparison of the result involving all three different diagnostic methods will also be shown.

5.1 Result for Scoping Review

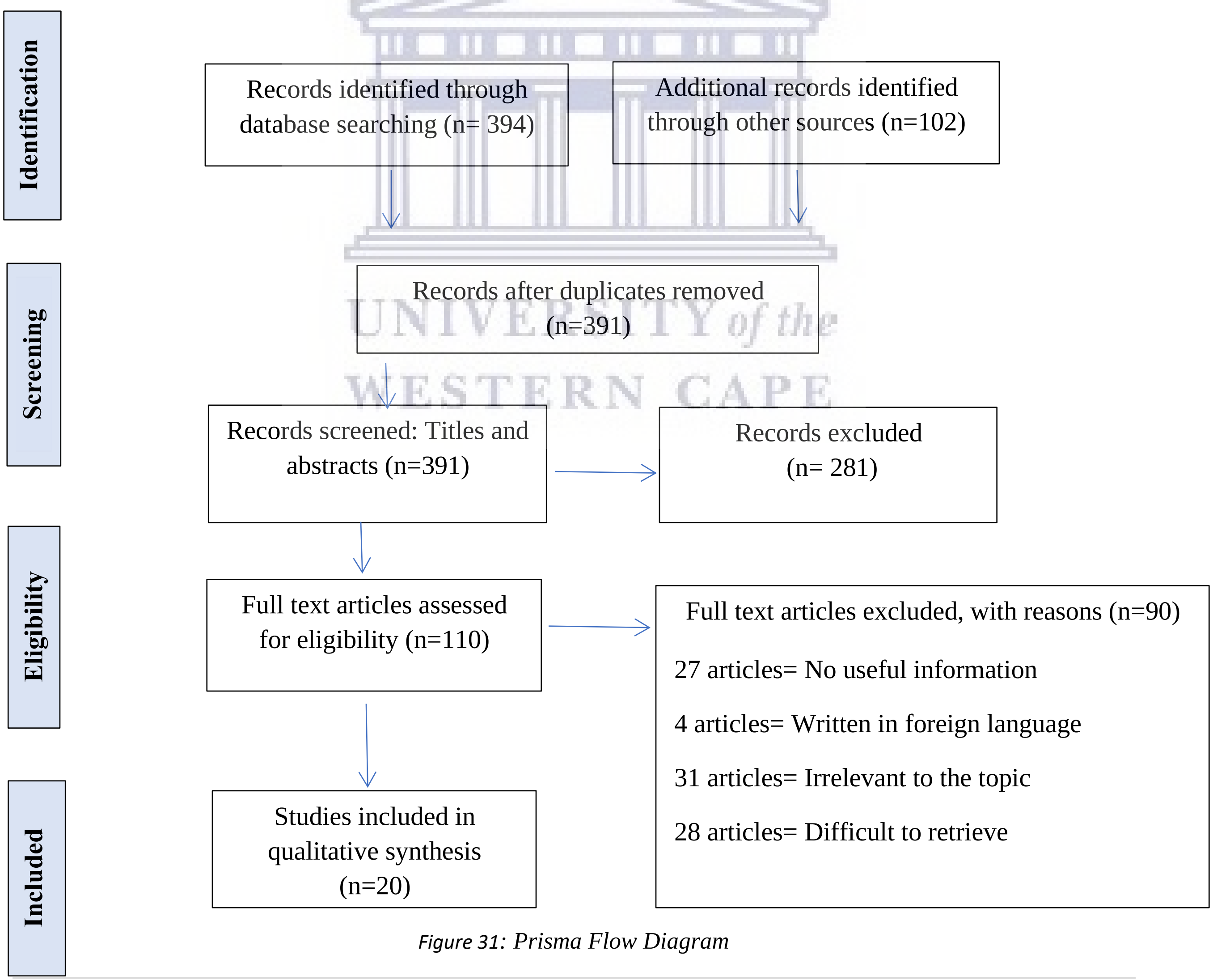


Figure 31: Prisma Flow Diagram

Identification:

The database searches identified 394 titles, to which an additional 102 articles were added following hand searching which then increased to 496 (N=496). Searches from the following databases indicates the number of articles retrieved from each below:

Cochrane library: 4 articles

PubMed: 20 articles

Wiley Online Library: 214 articles

Ebscohost: 18 articles

Science Direct: 136 articles

Scopus: 2 articles

Others (Journals, conference abstracts, unpublished articles): 102 articles

Screening:

Of the 496 titles identified through database searching and the other search sources, 105 were duplicates and 281 were unrelated to the objectives and the research question of the current scoping review. This was observed by viewing the titles of these articles. The objectives of this study is to determine the capability of 5th year dental students in detecting early interproximal caries using three different diagnostic methods (BW, digital radiography and printed film on paper). In addition to that, comparing the results of all 3 methods.

The research question for the scoping review is 'What are the different diagnostic methods used to detect early interproximal caries?'

Eligibility:

After reading the abstracts, full-text versions of the 110 studies were assessed for eligibility by two reviewers (MA and SK).

Included:

This rigorous and structured process allowed the identification of 20 articles for inclusion and the data was subsequently extracted in presented in a tabular form *(Appendix 4)*.

The characteristics of the included studies are summarized in ***(Table 1)*** below, (studies that involved students/dental practitioners, studies that compare diagnostic methods in detecting interproximal caries, in vivo studies and in vitro studies).

(Table 1) shows 7 different study designs, in-vivo being the most used with a total of 9 studies. 2 cross-sectional studies, 3 in vitro studies involving human extracted teeth, 2 retrospective data, 2 systematic reviews, 1 randomized control trial and finally 1 observational study.

Table 1*: *Table of included studies

	Author, Year & Country	Study Design	Sample Size	Diagnostic Methods	Conclusion
1	Radwan et al., 2020 Saudi Arabia.	Cross-sectional Observational Study	N= 496 students.	Fiber-optic Transillumination.	Traditional/invasive methods of caries detection are prevalent. Advanced diagnostic methods are low.
2	(Nemati et al., 2017) Iran.	Cross-sectional Study	N= 39 senior students.	Digital bitewing Radiographs.	Detecting caries: good accuracy. Depth of caries: moderate accuracy.
3	Xing et al., 2021) China, USA.	In Vitro (Lab Study)	N= 30 extracted premolars.	Cross-polarized optical coherence tomography (CP-OCT).	CP-OCT could be used to detect non-cavitated approximal caries.
4	(Kühnisch et al., 2016) Germany, Switzerland.	In Vivo (Clinical Study)	N= 127 teeth.	Visual, radiographic diagnoses, laser fluorescence measurements were available, NILT.	NILT and Bitewing: Same detection level.
5	(Phillips et al., 2020) Chile, UK.	Retrospective data	N= 125 young adults.	Bitewing radiographs.	Location and proximal DMFS are detected.

6	(Bijle et al., 2018) China, India.	In Vivo (Clinical Study)	N= 25 children	ICDAS (visual), FOTI (transillumination), conventional bitewing (C-BWR) and digital bitewing (D-BWR) radiography (radiographic), and DIAGNOdent pen (laser fluorescence).	ICDAS and bitewing radiography: reliable methods
7	(Baltacioglu & Orhan, 2017) Turkey.	In Vivo Study	N= 52 teeth.	Bitewing radiographs using digital phosphor plates (PSP-Bitewing) and NILT (Near Infra-red Light Transillumination).	The NILT method: Recommended to use.
8	(Brignardello-Petersen, 2018)	In Vivo Study	N= 26 patients.	Near-infrared light transillumination (NILT) and digital phosphor plate bitewing radiograph (DPBR).	DPBR is more accurate than NILT.
9	(Bussaneli et al., 2016) Brazil.	In Vivo Study	N= 45 children, 59 surfaces.	NYVAD (Visual examination), interproximal radiography (BW), laser fluorescence device (DIAGNOdent Pen-DDPen)	The performance of visual, radiographic, and DDpen exams were good.
10	(Cortes et al., 2018) Columbia, Denmar, UK.	In Vivo Study (Clinical Study)	N= 62 children.	Bitewing radiographs and silicone impressions of interproximal area (IPA)	Morphology of approximal surfaces influences the risk of developing caries.
11	(de Zutter et al., 2020) Belgium.	In Vivo Study	N= 35 patients.	Near-infrared light transillumination (NILT) Visual inspection (ICDAS) with bitewing (BW)	NILT: Not recommended for primary teeth.
12	(Terry et al., 2016) USA.	In Vivo (Clinical Study)	N= 20 patients, resulting in 489 surfaces.	Extraoral panoramic bitewings (BWs) to intraoral photostimulable	No significant difference between the modalities.

				phosphor (PSP) plate BWs.	
13	(Takahashi et al., 2019) Japan, USA.	Retrospective data	N= 241 interproximal surfaces.	Intraoral bitewing radiographs (BTW), periapical radiographs (PA).	BTWs have an advantage over PAs.
14	(Ei et al., 2019) Japan, Egypt, USA.	In Vitro Study	N= 50 extracted teeth.	3D swept-source optical coherence tomography (SS-OCT).	3D SS-OCT is a valuable diagnostic tool.
15	(Nadanovsky et al., 2018) Brazil.	Randomized Controlled Trial	N= 101 dentists.	Bitewing Radiography	Several of the dentists interpreted the test result correctly.
16	(Ortiz et al., 2020) Brazil.	Systematic Review and Meta Analysis	N= 13 studies.	Near-infrared light transillumination (NILT), bitewing radiograph.	NILT is accurate in permanent dentition. More suitable for pregnant women or children.
17	(Mahmoudi & Manouchehri, 2016) Iran.	Observational study	N= 42 teeth.	Radiographs, photo stimulable phosphor (PSP) and CBCT.	The PSP than CBCT in the disclosure of proximal caries.
18	(Moreira da Silva Neto et al., 2017) Brazil.	Ex-Vivo Study	N= 44 teeth, 88 proximal surfaces.	Visual clinical examination under fluorescent illumination, bitewing radiograph.	Bitewing radiography is not a trustworthy method for detection of interproximal caries.
19	(Kamburog et al., 2016) Turkey.	In Vitro Study	N= 80 teeth, 160 proximal surfaces.	Intraoral bitewing radiography, extraoral bitewing radiography and panoramic radiography.	Intraoral bitewing radiography was superior.
20	(Winand et al., 2016) Canada, Brazil, Saudi Arabia.	Systematic Review & Meta Analysis	N= 4 articles.	Digital intraoral imaging modalities, specifically phosphor plates (PSPs) and direct digital sensors (DDSs).	DDS and PSP systems were excellent at identifying surfaces without caries.

For this scoping review, studies are summarized under specific themes in regards to their study designs ***(Tables 2,3,4 and 5)***. The studies that were eliminated or excluded had little or no useful information, were irrelevant to the review's topics of interest, were written in a foreign language and the remainder were difficult to retrieve.

Two of the extracted articles, Radwan *et al*., (2020) and Nemati *et al*., (2017), mainly focused on the students' abilities in diagnosing interproximal caries and their advanced methods used for its detection ***(Table 2)***. Their sample size ranged from 39 to 496 students to specialists involved in the study. The diagnostic methods used by Radwan *et al*., (2020) and Nemati *et al*., (2017) to detect interproximal caries was Fiber Optic Transillumination (FOTI) and digital BW respectively. The authors of the first study, Radwan *et al*., (2020), observed that the students faced difficulties using advanced techniques, such as FOTI. They related this outcome to the lack of training amongst the students. Their data fit best a linear regression that correlates competency of using FOTI with experience. On the other hand, the students were familiar with the traditional methods of caries detection. In contrast with Radwan eta l, 2020, the author of the second article Nemati *et al.,* 2017 found out that the students had good accuracy in detecting the presence of caries using traditional methods. However, their diagnosis of the caries depth was in a substantial agreement with the gold standard. Their conclusion was based on a kappa coefficient of 0.912 and 0.638 for detecting the presence and depth of caries respectively (Radwan *et al.*, 2020; Nemati et al., 2017). When the value of kappa is <1, the strength of agreement is known to be substantial.

Table 2: Table including cross-sectional studies

	Author, Year & Country	Study Design	Sample Size	Diagnostic Methods	Conclusion
1	Radwan et al., 2020 Saudi Arabia.	Cross-sectional Observational Study	N= 496 students.	Fiber-optic Transillumination.	Traditional/invasive methods of caries detection are prevalent. Advanced diagnostic methods are low.
2	(Nemati et al., 2017) Iran.	Cross-sectional Study	N= 39 senior students.	Digital bitewing Radiographs.	Detecting caries: good accuracy. Depth of caries: moderate accuracy.

It was observed that there was a huge variation of the sample sizes used for each study. The lowest sample size with N=4 followed by N=13 was reported in a systematic review study by Winand *et al.*, (2016) and Ortiz *et al*., (2020) respectively ***(Table 3)***. While the highest sample size with N=496 was reported in a cross-sectional study (Radwan *et al.*, 2020). The former studies had study samples that contained 4 different articles and 13 different articles that the authors systematically reviewed using the PRISMA flow diagram *(Figure 30)*. The latter study sample, (Radwan *et al.*, 2020) contained data of the accuracy of dental staff ranked according to their experience from students up to consultants.

Table 3: Table including Reviews (Systematic Reviews & Meta Analysis)

	Author, Year & Country	**Study Design**	**Sample Size**	**Diagnostic Methods**	**Conclusion**
1	(Ortiz et al., 2020) Brazil.	Systematic Review and Meta Analysis	N= 13 studies.	Near-infrared light transillumination (NILT), bitewing radiograph.	NILT is accurate in permanent dentition. More suitable for pregnant women or children.
2	(Winand et al., 2016) Canada, Brazil, Saudi Arabia.	Systematic Review & Meta Analysis	N= 4 articles.	Digital intraoral imaging modalities, specifically phosphor plates (PSPs) and direct digital sensors (DDSs).	DDS and PSP systems were excellent at identifying surfaces without caries.

As shown in a few in-vivo studies ***(Table 4)*** conducted by (Kühnisch *et al.*, 2016), (Bussaneli *et al.*, 2015) and (De Zutter *et al.*, 2020), various detection methods were used in a single study. The methods that were used were visual inspection (ICDAS), bitewing (BW), Near Infrared Light Transillumination (NILT) and Laser fluorescence (LF). The majority of the studies concluded that, visual inspection (ICDAS) and BW radiography, are the most reliable methods for interproximal caries detection. NILT is reported to give similar results to BW Baltacioglu and Orhan, (2017) Kühnisch *et al.*, (2016) Bijle, Chunawala and Bohari, (2018). On the other hand, da Silva Neto *et al.*, (2008) concluded that radiographic examinations for interproximal surfaces are not the most reliable for carious detection. The explanation for this is that interproximal caries began to be visible radiographically at the level of the inner half of the enamel, but only in rare cases. This indicates that radiography is not the best approach for detecting early carious lesions restricted to the enamel, but is more useful for lesions that have already entered the dento-enamel junction (DEJ). The visual tactile examination appears to be the most effective for detecting proximal caries. Interproximal radiography is useful for detecting deep proximal dentin carious lesions.

Table 4: Table including In-Vivo Studies

	Author, Year & Country	Study Design	Sample Size	Diagnostic Methods	Conclusion
1	(Kühnisch et al., 2016) Germany, Switzerland.	In Vivo (Clinical Study)	N= 127 teeth.	Visual, radiographic diagnoses, laser fluorescence measurements were available, NILT.	NILT and Bitewing: Same detection level.
2	(Bijle et al., 2018) China, India.	In Vivo (Clinical Study)	N= 25 children	ICDAS (visual), FOTI (transillumination), conventional bitewing (C-BWR) and digital bitewing (D-BWR) radiography (radiographic), and DIAGNOdent pen (laser fluorescence).	ICDAS and bitewing radiography: reliable methods
3	(Bijle et al., 2018) China, India.	In Vivo (Clinical Study)	N= 25 children	ICDAS (visual), FOTI (transillumination), conventional bitewing (C-BWR) and digital bitewing (D-BWR) radiography (radiographic), and DIAGNOdent pen (laser fluorescence).	ICDAS and bitewing radiography: reliable methods
4	(Baltacioglu & Orhan, 2017) Turkey.	In Vivo Study	N= 52 teeth.	Bitewing radiographs using digital phosphor plates (PSP-Bitewing) and NILT (Near Infra-red Light Transillumination).	The NILT method: Recommended to use.

5	(Brignardello-Petersen, 2018)	In Vivo Study	N= 26 patients.	Near-infrared light transillumination (NILT) and digital phosphor plate bitewing radiograph (DPBR).	DPBR is more accurate than NILT.
6	(Bussaneli et al., 2016) Brazil.	In Vivo Study	N= 45 children, 59 surfaces.	NYVAD (Visual examination), interproximal radiography (BW), laser fluorescence device (DIAGNOdent Pen-DDPen)	The performance of visual, radiographic, and DDpen exams were good.
7	(Cortes et al., 2018) Columbia, Denmar, UK.	In Vivo Study (Clinical Study)	N= 62 children.	Bitewing radiographs and silicone impressions of interproximal area (IPA)	Morphology of approximal surfaces influences the risk of developing caries.
8	(de Zutter et al., 2020) Belgium.	In Vivo Study	N= 35 patients.	Near-infrared light transillumination (NILT) Visual inspection (ICDAS) with bitewing (BW)	NILT: Not recommended for primary teeth.
9	(Terry et al., 2016) USA.	In Vivo (Clinical Study)	N= 20 patients, resulting in 489 surfaces.	Extraoral panoramic bitewings (BWs) to intraoral photostimulable phosphor (PSP) plate BWs.	No significant difference between the modalities.

The rest of the study designs shown in ***(Table 5)*** were diverse in an interesting way where different designs such as *in-vitro, ex-vivo, observational study, randomized control trial and retrospective data* were used. Their results were contradictory in some ways. This may be due to the different study designs and methodology used in each study for the same diagnostic technique. Kamburog *et al*., (2016) and Takahashi *et al*., (2019) used different methods but agreed on the same conclusion that intraoral bitewings are more superior than the rest of the devices such as, extraoral bitewing radiography, panoramic radiography and periapical radiographs. While (Moreira da Silva Neto *et al*., 2017) disagrees and the conclusion of the study was bitewing radiography is not a trustworthy method for detection of interproximal caries.

Moreira da Silva Neto *et al*., (2017) used an ex-vivo study design. Mahmoudi & Manouchehri, (2016), Xing *et al*., (2021) and Ei *et al*., (2019) tested the accuracy of different types of the same device, optical coherence tomography for the detection of interproximal caries. The latter 2 concluded that CP-OCT and 3D SS-OCT are valuable devices and could be used for the detection of early interproximal caries. In the other hand, Mahmoudi & Manouchehri, (2016) study concluded that CBCT cannot be used to detect interproximal caries due to the high dose of radiation, therefore is it advised to use PSP. A randomized control trial conducted by Nadanovsky *et al*., (2018) evaluated the dentists' diagnostic inferences in regards to the natural frequencies versus the conditional probability of the presence of interproximal caries. The results have shown that some of the dentists interpreted the results correctly.

Table 5: Table including other study designs

	Author, Year & Country	**Study Design**	**Sample Size**	**Diagnostic Methods**	**Conclusion**
1	(Mahmoudi & Manouchehri, 2016) Iran.	Observational study	N= 42 teeth.	Radiographs, photo stimulable phosphor (PSP) and CBCT.	The PSP is better than CBCT in the disclosure of proximal caries.
2	(Xing et al., 2021) China, USA.	In Vitro (Lab Study)	N= 30 extracted premolars.	Cross-polarized optical coherence tomography (CP-OCT).	CP-OCT could be used to detect non-cavitated approximal caries.
3	(Ei et al., 2019) Japan, Egypt, USA.	In Vitro Study	N= 50 extracted teeth.	3D swept-source optical coherence tomography (SS-OCT).	3D SS-OCT is a valuable diagnostic tool.
4	(Kamburog et al., 2016) Turkey.	In Vitro Study	N= 80 teeth, 160 proximal surfaces.	Intraoral bitewing radiography, extraoral bitewing radiography and panoramic radiography.	Intraoral bitewing radiography was superior.
5	(Moreira da Silva Neto et al., 2017) Brazil.	Ex-Vivo Study	N= 44 teeth, 88 proximal surfaces.	Visual clinical examination under fluorescent illumination, bitewing radiograph.	Bitewing radiography is not a trustworthy method for detection of interproximal caries.

6	(Nadanovsky et al., 2018) Brazil.	Randomized Controlled Trial	N= 101 dentists.	Bitewing Radiography	Several of the dentists interpreted the test result correctly.
7	(Takahashi et al., 2019) Japan, USA.	Retrospective data	N= 241 interproximal surfaces.	Intraoral bitewing radiographs (BTW), periapical radiographs (PA).	BTWs have an advantage over PAs.

In this study, the approach was to interpret the data to investigate the capability of students to detect early interproximal caries and the diagnostic methods used globally for its detection. The results are synthesized narratively. Extraction of the data was from primary studies, meta-analyses and systematic reviews. It was conducted using a data extraction sheet *(Appendix 9)*.

The MMAT tool is an appraisal tool used in systematic reviews. In this study, objective one was to conduct a scoping review to answer the following research question "What are the most common and different diagnostic methods used to detect early interproximal caries? But following the criteria stipulated on the tool for each study, the initial screening questions could not be answered for each of the included studies. Therefore, it was not the appropriate tool for this study. The scoping review included cross-sectional studies, in vitro studies involving human extracted teeth, in vivo studies, retrospective data, systematic reviews, randomized control trial and observational study.

5.2 Result for Cross-Sectional Study:

In this study, the student's capability of detecting early interproximal caries was evaluated. This includes both, identifying the presence and estimating the size of the caries. The students were asked to use three different radiographic diagnostic techniques to complete the above task, namely, bitewing radiography, digital radiography and printed film on paper.

5.2.1 Introduction of the results:

To analyze the data, we employed Anova and *t*-test statistical techniques to evaluate the following:

4. The students mean scores for correct detection along with the standard deviations.
5. The statistically significant difference between the three different diagnostic techniques considering the students' performance.
6. The correlations between the 3 different diagnostic techniques using a pair sample correlation test.

A total number of 66 students out of 76 participated in this study, 18 students were male (27.3%) and 48 were female (72.7%) making up the majority of the class. 97% of the participants have used bitewing radiography to help in diagnosing interproximal caries. Table 6 shows the mean values of the correct detection for 6 different scenarios. As evident from the p-values shown in ***(Table 6)***, there was no significant difference between the accuracy of males and females in correct detection while using the 3 different techniques.

Table 6: Description of the sample according to gender

GENDER		N	Mean	Std. Deviation	Std. Error Mean	P- value
Caries presence in BW	Male	18	50.00	17.493	4.123	0.892
	Female	48	50.69	18.485	2.668	
Caries size in BW	Male	18	22.17	25.618	6.038	0.829
	Female	48	23.44	19.347	2.792	
Caries presence in DR	Male	18	44.33	16.492	3.887	0.474
	Female	48	47.90	18.376	2.652	
Caries size in DR	Male	18	57.44	39.343	9.273	0.340
	Female	48	49.31	26.796	3.868	
Caries presence in printed film on paper	Male	18	64.94	26.829	6.324	0.901
	Female	48	64.02	26.569	3.835	
Caries size in printed film on paper	Male	18	24.00	25.114	5.919	0.934
	Female	48	23.48	21.694	3.131	

Key: Bitewing Radiography (BW), Digital Radiography (DR), Printed film on paper (PP)

Next, the same analysis was conducted while categorized according to students preferred diagnostic method. 49 students (74.2%), stated that they have used bitewing radiography as the most common diagnostic method while 17 students (25.8%) used digital radiography. The acquired results shown in ***(Table 7)*** indicates that there was no significant difference.

Table 7*: *Most common method used for the detection of interproximal caries

COMMON METHOD		N	Mean	Std. Deviation	Std. Error Mean	P- Value
Caries presence in BW	BITEWING	49	50.33	18.465	2.638	0.896
	DIGITAL	17	51.00	17.493	4.243	
Caries size in BW	BITEWING	49	25.71	21.817	3.117	0.085
	DIGITAL	17	15.53	16.978	4.118	
Caries presence in DR	BITEWING	49	47.59	18.307	2.615	0.609
	DIGITAL	17	45.00	16.748	4.062	
Caries size in DR	BITEWING	49	49.67	29.895	4.271	0.407
	DIGITAL	17	56.88	32.952	7.992	
Caries presence in PP	BITEWING	49	61.33	26.773	3.825	0.125
	DIGITAL	17	72.76	24.198	5.869	
Caries size in PP	BITEWING	49	24.41	24.367	3.481	0.633
	DIGITAL	17	21.35	16.256	3.943	

Key: Bitewing Radiography (BW), Digital Radiography (DR), Printed film on paper (PP)

Lastly, the students were grouped with regards to the difficulties faced in diagnosing early interproximal caries while using a specific method. Although, most of the students answered that they do face difficulty when it comes to diagnosing, their mean values were similar to those who faced no difficulty. As evident from the p-value shown in ***(Table 8)***, there was no significant difference between the two situations for the three diagnostic techniques.

Table 8: Table that shows the difficulty in diagnosing early interproximal caries

DIFFICULTY		N	Mean	Std. Deviation	Std. Error Mean	P-value
Caries presence in BW	Yes	62	50.53	18.158	2.306	0.955
	No	4	50.00	19.630	9.815	
Caries size in BW	Yes	62	24.05	21.044	2.673	0.147
	No	4	8.25	16.500	8.250	
Caries presence in DR	Yes	62	46.18	17.752	2.255	0.182
	No	4	58.50	17.000	8.500	
Caries size in DR	Yes	62	50.02	30.165	3.831	0.114
	No	4	75.00	32.031	16.016	
Caries presence in PP	Yes	62	63.56	26.887	3.415	0.396
	No	4	75.25	16.500	8.250	
Caries size in PP	Yes	62	23.55	22.912	2.910	0.918
	No	4	24.75	16.500	8.250	

Key: Bitewing Radiography (BW), Digital Radiography (DR), Printed film on paper (PP)

In the next sections, we will discuss in details the analysis outcomes. More detailed tables are shown in the appendices.

5.2.2 Students' capability in detecting the presence of interproximal caries

To approach our first study objective on measuring the 5th year students' capability in detecting early interproximal caries, we analyzed the questionnaire and extracted the mean of the correct answers. We also calculated the P-values which indicates the significant difference in the outcome between the 3 diagnostic techniques. It is worth to note that in all scenarios, the students had higher accuracy in detecting the presence of caries compared to measuring the size except when using DR as stated in ***(Table 9)***. This is may be due to the fact that the digital viewing through the PACS system offers an option of magnifying the radiographic image.

Table 9: Caries presence and size in the 3 different methods

	Caries Presence in BW	Caries Size in BW	Caries Presence in DR	Caries Size in DR	Caries Presence in PP	Caries Size in PP
Mean	50.5	23.09091	46.92424	51.5303	64.27273	23.62121
Standard Error	2.226588	2.589627	2.194538	3.768612	3.254084	2.767002
Mean of caries presence + size	36.795455		35.007575		49.22727	

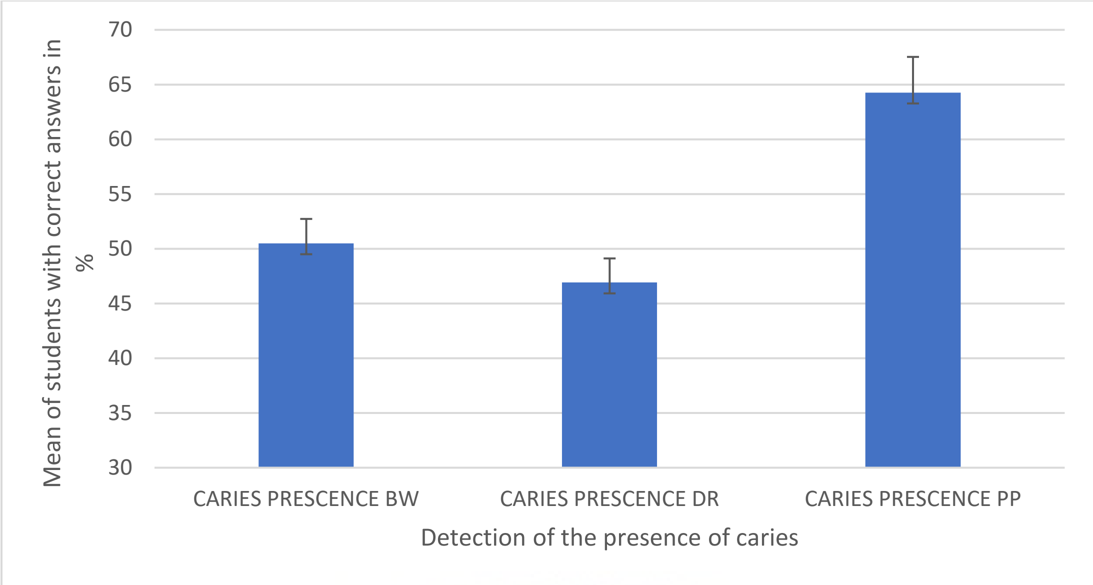
Key: Bitewing Radiography (BW), Digital Radiography (DR), Printed film on paper (PP)

Although the students chose bitewing and digital radiography as their preferred method for diagnosis, yet the students scored the highest mean of correct detection when using the printed film on paper method as seen in ***(Table 10)***. This result can be understood by considering the previous finding that reported in the previous section (5.2.1). In this section we argued that the students' choice of method does not influence the detection accuracy. In other words, there is no significant statistical difference, between using a preferred method and achieving a correct diagnosis (refer to the P-value in ***Table 7***). The students' mean values for the correct caries detection are illustrated in (*Figure* 32).

Table 10*: *Mean of the caries presence in the 3 different diagnostic methods

	Mean	Standard Error
Caries presence in BW	50.5	2.226587593
Caries presence in DR	46.92424242	2.194537678
Caries presence in PP	64.27272727	3.25408443

Key: Bitewing Radiography (BW), Digital Radiography (DR), Printed film on paper (PP)



Key: Bitewing Radiography (BW), Digital Radiography (DR), Printed film on paper (PP)

Figure 31: Mean of the caries presence in the 3 different diagnostic methods

Moreover, an Anova test was carried out for the 3 different diagnostic methods. As evident from the P-value listed in ***(Table 11)*** below, there is a statistical significant difference for the correct caries detection depending on the used technique.

Table 11: One Way Anova test for comparison between the presence of the caries in 3 different diagnostic methods.

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*
Between Groups	11075.76768	2	5537.883838	12.36188	0.000008817865
Within Groups	87356.21212	195	447.980575		
Total	98431.9798	197			

In this table *SS, df, MS, F,* and *P-value* are the sum of squares, degree of freedom, mean squares, the ratio between the two mean squares variables and the *P-value* respectively.

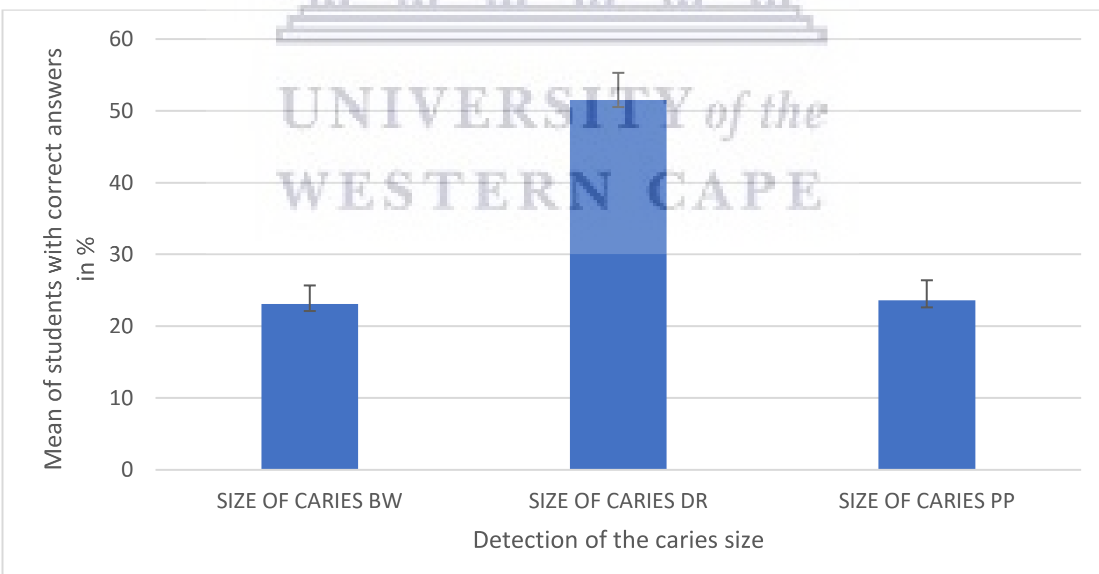
5.2.3 Students' capability in detecting the size of interproximal caries

For the caries size estimation, we found that the students scored the highest mean for correct measure when using the digital radiography method. The results are listed in ***(Table 12)***. The mean values of the correct size estimations are illustrated in *(Figure 32)*.

Table 12: Mean of the caries size in the 3 different diagnostic methods

	Mean	Standard Error
Caries size in BW	23.09090909	2.589626722
Caries size in DR	51.53030303	3.768611604
Caries size in PP	23.62121212	2.767002127

Key: Bitewing Radiography (BW), Digital Radiography (DR), Printed film on paper (PP)



Key: Bitewing Radiography (BW), Digital Radiography (DR), Printed film on paper (PP)

Figure 32: Mean of the caries size in the 3 different diagnostic methods

The Anova test on the 3 different diagnostic methods showed that the type of method used affect the size measuring accuracy, where the P-value confirms a statistical significant differences. This result is shown in (***Table 13***).

Table 13: One Way Anova test for comparison between the size of the caries in 3 different diagnostic methods

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*
Between Groups	34935.94949	2	17467.97475	27.79631	0.0000000000239314
Within Groups	122543.4242	195	628.4278166		
Total	157479.3737	197			

In this table *SS, df, MS, F,* and *P-value* are the sum of squares, degree of freedom, mean squares, the ratio between the two mean squares variables and the *P-value* respectively.

5.2.4 Paired- sample correlation test

We ran a paired sample correlation test to evaluate the correlations between the outcomes of each pair of diagnostic techniques. The results for the caries presence detection and size estimation are listed in ***(Tables 14 and 15)***. Since all the values are less than 0.5, it was concluded that there is no correlation between one method with another for correct detection.

Table 14: Paired sample correlation test for caries presence detection

	Caries presence in BW	Caries presence in DR	Caries presence in PP
Caries presence in BW	1		
Caries presence in DR	0.390867301	1	
Caries presence in PP	0.019335196	0.149510195	1

Key: Bitewing Radiography (BW), Digital Radiography (DR), Printed film on paper (PP)

***Table 15*: Paired sample correlation test for caries size measurement**

	Caries size in BW	Caries size in DR	Caries size in PP
Caries size in BW	1		
Caries size in DR	-0.21093225	1	
Caries size in PP	0.009833203	-0.016446657	1

Key: Bitewing Radiography (BW), Digital Radiography (DR), Printed film on paper (PP)

CHAPTER 6: DISCUSSION

In this chapter, the results of the scoping review and the cross-sectional study are discussed.

6.1 Introduction

When caries can be detected early on at the initial stage of development, this will limit their progression and avoid the need for complicated restorative therapy. Furthermore, if the caries depth is correctly detected, a proper treatment may be performed. The treatment choice differs whether it is a primary or a permanent tooth. The treatment can range from preventive to restorative. Extensive studies have always been the subject of determining the optimum approach for diagnosing and monitoring caries (Banerjee *et al.*, 2017; Mount, 2005). For different diagnostic methods, it was reported that using paired methods of detection is more beneficial to correctly detect the presence and size of dental caries. Some of these methods are visual tactile sensation in addition to bitewing radiography, or NILT in addition to BW (Kühnisch *et al.*, 2016b).

The students must understand the diagnostic process and the use of detection methods in daily practice. This is extremely important to prevent and control the carious lesions, particularly in their reversible early phases. This study acquired a significant amount of information about 5th year dental students' understanding and usage of caries detection and risk assessment procedures.

Radwan *et al*., (2020) used a cross-sectional observational study design to assess the methods of caries detection among dental students and dental practitioners in Riyadh, and reported that conventional and invasive methods of caries detection are common among their participants, while scoring low in the advanced diagnostic methods. As a result, Radwan *et al*., (2020) promotes minimally invasive approaches and advocates the use and availability of advanced diagnostic methods. In agreement with this, the students of this current study were assessed using conventional diagnostic methods that they are familiar with, bitewing radiography and digital radiography. In addition to the previous methods, a third one was used, the printed film on paper. The students have scored good results in the accuracy when detecting the presence of dental caries but the detection of the size is reported to be poor.

Also, another cross-sectional study by Nemati *et al*., (2017) reported to investigate the accuracy of senior students at Rasht Dental School in detecting proximal caries. The accuracy of the students in diagnosing caries was shown to be considerably good in this study. Despite this, they were only somewhat accurate in identifying the depth of caries, and they understated the depth of caries at the level of the dento-enamel junction (DEJ). The 5th year students in the study reported by Nemati *et al*., (2017), had outstanding recognition of the presence of caries including detecting the depth as well.

Bitewing radiography is reported as a non-reliable method for early interproximal caries detection. This result was obtained by Moreira da Silva Neto *et al*., (2017) in an *ex-vivo* study. Despite this report, bitewing radiography is the most commonly used method for detection of interproximal caries. It is currently being used by students in teaching hospitals for clinical training worldwide. Underestimation of the size of the carious lesion is reported during the use of BW. Radwan *et al*., (2020) encouraged the introduction of the advanced diagnostic methods to clinical practice and training for students and dental practitioners.

In a study reported by Kuhnisch *et al*., (2016), stated that bitewing radiography can be replaced by NILT due to the similarity in their performance. The reason for NILT being superior is its ability to detect the enamel lesion of proximal permanent teeth more accurate than BW. This research suggests that NILT may help to minimize the use of bitewings. Baltacioglu and Orhan, (2017a) concluded that NILT examination provides a high sensitivity and diagnostic accuracy. It may be used to diagnose caries without using ionizing radiation. Whereas Brignardello-Petersen (2018) concludes that DPBR shows better accuracy than NILT in detecting early interproximal lesions. Current literature shows that NILT has a relatively equivalent accuracy to BW for identifying interproximal carious lesions in the permanent teeth. Due to its high accuracy level in detecting interproximal primary caries, NILT is therefore recommended in many special cases only. For example, NILT is more likely to be used for patients prone to dental caries. Furthermore, it is favorable in cases when radiation exposure needs to be minimal such as pregnancy and pediatric patients (Ortiz *et al*., 2020).

Caries progression was associated with the DMFS of proximal surface and the location of the carious lesion (Phillips *et al*., 2020).

The detection capacity and influence of the analyzing plane of CP-OCT for non-cavitated approximal caries were discussed in a study by Xing *et al*., (2021). CP-OCT might be utilized to identify non-cavitated approximal caries, the researchers concluded. The Coronal-plane analysis is superior compared to the Horizontal-plane analysis. Presence of a neighboring tooth makes it difficult to detect interproximal caries on their non cavitated stage. CP-OCT is a nondestructive caries detection technology that does not use ionizing radiation. The Coronal-plane appears to be superior than the Horizontal-plane for detecting non-cavitated approximal caries on CP-OCT.

The visual, radiographic, and DDpen tests performed well, as did their correlations; but, the clinical examination using the Nyvad criteria was adequate for diagnosing interproximal lesions in primary teeth (Bussaneli *et al*., 2016). De Zutter *et al.*, (2020) concluded that for interproximal caries detection in primary teeth, NILT cannot be used alone as an independent diagnostic technique. There were far too many false negatives for dentine caries, particularly in first primary molars. NILT may be more accurate than BW radiography in the case of permanent teeth as it is able to detect lesion extension. The reason could be related to underestimation of the size of the carious lesion during the use of BW.

However, another study found that ICDAS and bitewing radiography are the most reliable techniques for proximal caries diagnosis, with a larger proportion of examiner agreement than the other methods examined in this study (Bijle et al., 2018).

Terry *et al.*, (2016) compared between bitewings (Intraoral and extraoral panoramic), and concluded no significant difference when it comes to detection in the posterior interproximal caries. Extraoral panoramic BWs were considerably better than panoramic radiography in detecting open posterior interproximal contacts (81.7 percent vs 48.5 percent), but fell short of intraoral BWs' 95.9% value. In agreement with the study conducted by Terry *et al.*, (2016), the students of the current study scored poorly in detecting the presence and depth of caries using intraoral bitewing radiographs. However, according to another study by Takahashi *et al.*, (2019), BTWs had a substantial advantage over PAs in diagnosing early stages of interproximal caries.

The diagnosis of proximal caries of posterior teeth using intraoral bitewing radiography surpasses both extraoral bitewing and panoramic radiography. Extraoral bitewing and panoramic radiography both had similar intra and inter-observer agreement. Intra-observer is the amount of variation one observer experiences when observing the same material more than once. While interobserver means the occurring between or involving two or more observers (Kamburog *et al.*, 2016). In the current study, similar results were reported as the students had very close means in detecting the presence and size of dental caries.

Cortes *et al*., (2018) came to a finding that the interproximal surfaces of the primary molars are concave in shape and it is a high caries risk surface. This concave morphology is predicted to be more prone to future dental caries supporting specific homecare and in-office preventive strategies. SS-OCT was used to detect the existence of micro-cracks inside the superficial enamel in proximal contact regions, which was associated with the amount of demineralization (Ei *et al*., 2019).

When assessed whether dentists' diagnostic inferences differ when test accuracy information is communicated using natural frequencies versus conditional probabilities. Dentists were encouraged in making diagnostic conclusions by representing diagnostic test accuracy in natural frequencies. When presented with information in conditional probabilities, nearly twice as many dentists overestimated the occurrence of interproximal caries (Nadanovsky *et al*., 2018).

The correctness of CBCT, regular radiographs and the non-direct digital system in the disclosure of interproximal caries was examined and recognized. The result was that the digital system was better than CBCT in the disclosure of proximal caries; therefore, CBCT is not to be used for detection of caries due to high dose levels (Mahmoudi & Manouchehri, 2016).

While both the DDS and PSP systems were good at detecting surfaces that were free of caries, specificity, they lacked the sensitivity to consistently identify areas with caries. There was no visible difference in performance between the DDS and PSP digital systems. Specificity means the ability of a test to correctly classify an individual as *disease- free*. Sensitivity means the ability of a test to correctly classify an individual as ′diseased′.

However, because of their limited sensitivity, dentists must be attentive in confirming any radiographic findings with a thorough clinical examination for early interproximal lesions (Winand *et al*., 2016). The students scored highly in sensitivity in comparison to specificity.

In summary, the senior dental students were capable of detecting the presence /absence of early interproximal caries but may need further practice in determining the depth/size of the carious lesion.

CHAPTER 7: CONCLUSION

This chapter presents the conclusions drawn from the results of this research.

7.1: Conclusions

In this study, two conclusions were drawn from the scoping review analysis and the cross-sectional study.

- The studies we reviewed showed that clinical examination and bitewing radiography are the most convenient and popular methods for detecting proximal caries. CBCT has shown good accuracy in detecting early interproximal caries but it is not highly recommended due to the high dose of radiation emitted. NILT is a good method that may replace bitewing radiography.

- Senior dental students at the University of the Western Cape have shown good detection accuracy. The caries presence was identified with a success rate of ~ 64% while using the printed film on paper. Although the accuracy in detecting the size of carious lesions was poor. In the case of digital radiography, the students showed moderate ability in measuring the size. The highest average for detecting and measuring the size of caries combined was correspondent to the printed film on paper method. This appears to be a reasonable level of understanding and use of diagnostic caries risk assessment methodologies in restorative treatment planning.

CHAPTER 8: LIMITATIONS AND RECOMMENDATIONS

In research with so many factors to examine, numerous subtle modifications and recommendations, these factors can be introduced for future studies. This chapter specifies these recommendations.

8.1: Limitations

Some of the factors such as reliability of the data is considered limited due to the lack of studies reported involving senior dental students or 5th year dental students in detecting early interproximal caries. Because the dental community's views and tendencies have recently shifted toward a minimally invasive and preventative approach, senior dental students require extra clinical training in advanced methods of early interproximal caries detection. We propose that comparable studies be conducted on a nationwide basis to better understand and assess caries detection. Although difficulties will be faced due to the high cost of the different diagnostic devices in the market.

8.2: Recommendations

Additional education in the use of advanced radiographic detection methods for both students and practitioners are recommended. More exposure to bitewing radiographs and case study discussions may help in improving the student’s accuracy in detecting the size of the interproximal caries. It is recommended to conduct a study in the future that compares different teaching approaches. This is useful to investigate a potential relation between the teaching approach and the students’ performance. Also, a study that includes the assessment of the dental staff in detecting interproximal caries should be conducted. For this study, it is recommended to use advanced diagnostic techniques as there is lack of such data in the literature.

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APPENDICES

Appendix 1: Ethical Approval

OFFICE OF THE DIRECTOR: RESEARCH
RESEARCH AND INNOVATION DIVISION

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18 November 2019

Dr M Abdalla
Faculty of Dentistry

Ethics Reference Number: BM19/9/8

Project Title: Ability of 5th year students to detect early interproximal caries.

Approval Period: 15 November 2019 – 15 November 2020

I hereby certify that the Biomedical Science Research Ethics Committee of the University of the Western Cape approved the scientific methodology and ethics of the above mentioned research project.

Any amendments, extension or other modifications to the protocol must be submitted to the Ethics Committee for approval.

Please remember to submit a progress report in good time for annual renewal.

The Committee must be informed of any serious adverse event and/or termination of the study.

Ms Patricia Josias
Research Ethics Committee Officer
University of the Western Cape

BMREC REGISTRATION NUMBER -130416-050

FROM HOPE TO ACTION THROUGH KNOWLEDGE.

Appendix 2: Questionnaire

Questionnaire:

Please answer the following questions and tick (✓) the appropriate response:

NILT: Near-infrared light transillumination
CBCT: Cone beam computed tomography
IOC: Intra oral camera
R0: Intact surface, **R1**: RL in outer half of enamel, **R2**: RL in inner half of enamel,
R3: RL in outer half of dentin, **R4**: RL in inner half of dentin.

1.	What is your gender?	Male	Female			
2.	Have you used bitewing radiographs for diagnosing caries?	Yes	No			
3.	Have you faced any kind of difficulty diagnosing a caries radiographically?	Yes	No			
4.	If yes, what was the cause of the difficulty?	Not enough knowledge	Technical error	Exposure error	Poor image sharpness	
5.	What is the most common diagnostic method you have used?	Bitewing	Digital radiography	NILT	CBCT	IOC
6.	Which diagnostic method would you prefer using for diagnosing interproximal caries?	Bitewing	Digital radiography	NILT	CBCT	IOC
7.	What is the reason for your choice?	High accuracy level	Easy to use and handle	Availability at the hospital	Patient friendly	Time saver
8.	How difficult is it to detect early interproximal caries radiographically?	Extremely easy	Slightly easy	Average	Slightly difficult	Extremely difficult
9.	How often do you think is your diagnosis of early interproximal caries correct?	Always	Sometimes	Never		
10.	How often have you misdiagnosed interproximal caries on their early stage?	Always	Sometimes	Never		

11.	**<u>BITEWING FILM</u>** Are you able to identify the presence of interproximal caries?	Definitely present	Probably present	I cannot tell	Probably absent	Definitely absent
12.	**<u>BITEWING FILM</u>** What is the size of the caries present?	***R0*** Intact surface	**R1** RL in outer half of enamel	**R2** RL in inner half of enamel	**R3** RL in outer half of dentin	**R4** RL in inner half of dentin
13.	**<u>DIGITAL X-RAY</u>** Are you able to identify the presence of interproximal caries?	Definitely present	Probably present	I cannot tell	Probably absent	Definitely absent
14.	**<u>DIGITAL X-RAY</u>** What is the size of the caries present?	***R0*** Intact surface	**R1** RL in outer half of enamel	**R2** RL in inner half of enamel	**R3** RL in outer half of dentin	**R4** RL in inner half of dentin
15.	**<u>FILM ON PAPER</u>** Are you able to identify the presence of interproximal caries?	Definitely present	Probably present	I cannot tell	Probably absent	Definitely absent
16.	**<u>FILM ON PAPER</u>** What is the size of the caries present?	***R0*** Intact surface	**R1** RL in outer half of enamel	**R2** RL in inner half of enamel	**R3** RL in outer half of dentin	**R4** RL in inner half of dentin

17.	**<u>BITEWING FILM</u>** Are you able to identify the presence of interproximal caries?	Definitely present	Probably present	I cannot tell	Probably absent	Definitely absent
18.	**<u>BITEWING FILM</u>** What is the size of the caries present?	***R0*** Intact surface	**R1** RL in outer half of enamel	**R2** RL in inner half of enamel	**R3** RL in outer half of dentin	**R4** RL in inner half of dentin
19.	**<u>DIGITAL X-RAY</u>** Are you able to identify the presence of interproximal caries?	Definitely present	Probably present	I cannot tell	Probably absent	Definitely absent
20.	**<u>DIGITAL X-RAY</u>** What is the size of the caries present?	***R0*** Intact surface	**R1** RL in outer half of enamel	**R2** RL in inner half of enamel	**R3** RL in outer half of dentin	**R4** RL in inner half of dentin
21.	**<u>FILM ON PAPER</u>** Are you able to identify the presence of interproximal caries?	Definitely present	Probably present	I cannot tell	Probably absent	Definitely absent

22.	**FILM ON PAPER** What is the size of the caries present?	***R0*** Intact surface	**R1** RL in outer half of enamel	**R2** RL in inner half of enamel	**R3** RL in outer half of dentin	**R4** RL in inner half of dentin

23.	**BITEWING FILM** Are you able to identify the presence of interproximal caries?	Definitely present	Probably present	I cannot tell	Probably absent	Definitely absent
24.	**BITEWING FILM** What is the size of the caries present?	***R0*** Intact surface	**R1** RL in outer half of enamel	**R2** RL in inner half of enamel	**R3** RL in outer half of dentin	**R4** RL in inner half of dentin
25.	**DIGITAL X-RAY** Are you able to identify the presence of interproximal caries?	Definitely present	Probably present	I cannot tell	Probably absent	Definitely absent
26.	**DIGITAL X-RAY** What is the size of the caries present?	***R0*** Intact surface	**R1** RL in outer half of enamel	**R2** RL in inner half of enamel	**R3** RL in outer half of dentin	**R4** RL in inner half of dentin
27.	**FILM ON PAPER** Are you able to identify the presence of interproximal caries?	Definitely present	Probably present	I cannot tell	Probably absent	Definitely absent
28.	**FILM ON PAPER** What is the size of the caries present?	***R0*** Intact surface	**R1** RL in outer half of enamel	**R2** RL in inner half of enamel	**R3** RL in outer half of dentin	**R4** RL in inner half of dentin

Appendix 3: 27 Item Checklist for PRISMA

PRISMA 2020 Checklist

Section and Topic	Item #	Checklist item	Location where item is reported
TITLE			
Title	1	Identify the report as a systematic review.	
ABSTRACT			
Abstract	2	See the PRISMA 2020 for Abstracts checklist.	
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of existing knowledge.	
Objectives	4	Provide an explicit statement of the objective(s) or question(s) the review addresses.	
METHODS			
Eligibility criteria	5	Specify the inclusion and exclusion criteria for the review and how studies were grouped for the syntheses.	
Information sources	6	Specify all databases, registers, websites, organisations, reference lists and other sources searched or consulted to identify studies. Specify the date when each source was last searched or consulted.	
Search strategy	7	Present the full search strategies for all databases, registers and websites, including any filters and limits used.	
Selection process	8	Specify the methods used to decide whether a study met the inclusion criteria of the review, including how many reviewers screened each record and each report retrieved, whether they worked independently, and if applicable, details of automation tools used in the process.	
Data collection process	9	Specify the methods used to collect data from reports, including how many reviewers collected data from each report, whether they worked independently, any processes for obtaining or confirming data from study investigators, and if applicable, details of automation tools used in the process.	
Data items	10a	List and define all outcomes for which data were sought. Specify whether all results that were compatible with each outcome domain in each study were sought (e.g. for all measures, time points, analyses), and if not, the methods used to decide which results to collect.	
	10b	List and define all other variables for which data were sought (e.g. participant and intervention characteristics, funding sources). Describe any assumptions made about any missing or unclear information.	
Study risk of bias assessment	11	Specify the methods used to assess risk of bias in the included studies, including details of the tool(s) used, how many reviewers assessed each study and whether they worked independently, and if applicable, details of automation tools used in the process.	
Effect measures	12	Specify for each outcome the effect measure(s) (e.g. risk ratio, mean difference) used in the synthesis or presentation of results.	
Synthesis methods	13a	Describe the processes used to decide which studies were eligible for each synthesis (e.g. tabulating the study intervention characteristics and comparing against the planned groups for each synthesis (item #5)).	
	13b	Describe any methods required to prepare the data for presentation or synthesis, such as handling of missing summary statistics, or data conversions.	
	13c	Describe any methods used to tabulate or visually display results of individual studies and syntheses.	
	13d	Describe any methods used to synthesize results and provide a rationale for the choice(s). If meta-analysis was performed, describe the model(s), method(s) to identify the presence and extent of statistical heterogeneity, and software package(s) used.	
	13e	Describe any methods used to explore possible causes of heterogeneity among study results (e.g. subgroup analysis, meta-regression).	
	13f	Describe any sensitivity analyses conducted to assess robustness of the synthesized results.	
Reporting bias assessment	14	Describe any methods used to assess risk of bias due to missing results in a synthesis (arising from reporting biases).	
Certainty assessment	15	Describe any methods used to assess certainty (or confidence) in the body of evidence for an outcome.	

PRISMA 2020 Checklist

Section and Topic	Item #	Checklist item	Location where item is reported
RESULTS			
Study selection	16a	Describe the results of the search and selection process, from the number of records identified in the search to the number of studies included in the review, ideally using a flow diagram.	
	16b	Cite studies that might appear to meet the inclusion criteria, but which were excluded, and explain why they were excluded.	
Study characteristics	17	Cite each included study and present its characteristics.	
Risk of bias in studies	18	Present assessments of risk of bias for each included study.	
Results of individual studies	19	For all outcomes, present, for each study: (a) summary statistics for each group (where appropriate) and (b) an effect estimate and its precision (e.g. confidence/credible interval), ideally using structured tables or plots.	
Results of syntheses	20a	For each synthesis, briefly summarise the characteristics and risk of bias among contributing studies.	
	20b	Present results of all statistical syntheses conducted. If meta-analysis was done, present for each the summary estimate and its precision (e.g. confidence/credible interval) and measures of statistical heterogeneity. If comparing groups, describe the direction of the effect.	
	20c	Present results of all investigations of possible causes of heterogeneity among study results.	
	20d	Present results of all sensitivity analyses conducted to assess the robustness of the synthesized results.	
Reporting biases	21	Present assessments of risk of bias due to missing results (arising from reporting biases) for each synthesis assessed.	
Certainty of evidence	22	Present assessments of certainty (or confidence) in the body of evidence for each outcome assessed.	
DISCUSSION			
Discussion	23a	Provide a general interpretation of the results in the context of other evidence.	
	23b	Discuss any limitations of the evidence included in the review.	
	23c	Discuss any limitations of the review processes used.	
	23d	Discuss implications of the results for practice, policy, and future research.	
OTHER INFORMATION			
Registration and protocol	24a	Provide registration information for the review, including register name and registration number, or state that the review was not registered.	
	24b	Indicate where the review protocol can be accessed, or state that a protocol was not prepared.	
	24c	Describe and explain any amendments to information provided at registration or in the protocol.	
Support	25	Describe sources of financial or non-financial support for the review, and the role of the funders or sponsors in the review.	
Competing interests	26	Declare any competing interests of review authors.	
Availability of data, code and other materials	27	Report which of the following are publicly available and where they can be found: template data collection forms; data extracted from included studies; data used for all analyses; analytic code; any other materials used in the review.	

From: Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:n71. doi: 10.1136/bmj.n71

For more information, visit: http://www.prisma-statement.org/

Appendix 4: Raw Data of Included Articles

	Study title	Aim/objective	Methodology	Result	Conclusion
1	**Knowledge and Use of Caries Detection Methods among Dental Students and Dental Practitioners in Riyadh, Saudi Arabia** (Radwan et al., 2020)	Assess the methods of caries detection among dental students and dental practitioners in Riyadh using a cross-sectional observational study design	The sample comprised 496 dental students, interns, postgraduate residents, general dental practitioners, specialists, and consultants from the Riyadh region of Saudi Arabia. A survey was designed to assess caries detection methods, risk assessment practices, and knowledge of advanced diagnostic methods. (e responses were correlated with demographic and educational variables. Regression models were used to predict associations.	42.3% and 32.7% use sharp explorers in diagnosing caries always and most of the time, respectively. When conducting caries risk assessment practices, 64.4%was very likely to review the patient's medical history and lifestyle. In terms of knowledge of advanced diagnostic methods, 47.8%know "much" to "very much" about Fiber Optic Transillumination (FOTI). The knowledge of advanced caries diagnostic methods and practices of advanced diagnostic methods were significantly positively correlated. Linear regression analysis indicated that higher experience (10+ years) was associated with higher knowledge regarding advanced caries diagnostic methods. The mean rank for risk assessment practices was significantly lower in GPs compared to consultants.	The use of traditional and invasive methods of caries detection is prevalent among our respondents, while the usage of advanced diagnostic methods is for the most part low. Therefore, we advocate for more minimally invasive approaches and as such encourage the practice and availability of advanced diagnostic methods.
2	**The Accuracy of Senior Students of Rasht Dental School in Detecting Proximal Caries in Digital Bitewing Radiographs** (Nemati et al., 2017)	Investigate the accuracy of senior students at Rasht Dental School in detecting proximal caries.	Ten standard-quality bitewing radiographs (152 dental surfaces) were selected. The samples were then examined for the presence and depth of interproximal caries by 39 senior students (as observers) and five faculty members as the gold standard. The findings were analyzed using statistics including sensitivity, specificity, Positive Predictive Value (PPV), Negative Predictive Value (NPV), accuracy, and kappa.	The rate of agreement (kappa) between the students and the gold standard in detecting the presence and depth of caries was 0.696 and 0.502, respectively. The students' reliability in the detection of caries and its depth yielded a kappa coefficient of 0.912 and 0.638, respectively.	The student's accuracy in detecting caries was significantly good. Nonetheless, they had moderate accuracy in detecting the depth of caries, and they underestimated the depth especially in the case of caries at the DEJ level. The students' reliability in detecting the presence of caries was almost excellent and their

					reliability for detecting the depth was significantly good, too.
3	**Detection and analyzing plane of non-cavitated approximal caries by cross-polarized optical coherence tomography (CP-OCT)** (Xing et al., 2021)	The detection ability and the effect of analyzing plane of CP-OCT for non-cavitated approximal caries.	Thirty human extracted premolars were selected based on micro-computed tomography. Teeth were mounted in a custom-made device to simulate approximal contact and scanned from the marginal ridge above the contact area. CP-OCT images were analyzed by deepest caries extension from horizontal and coronal planes, and repeated 48-hrs later. Sensitivity, specificity, percent correct, area under the ROC curve (Az), intra-examiner repeatability and correlation with µ-CT were determined.	Sensitivity/specificity/Az for Horizontal plane, Coronal-plane, and Deepest from both planes were 94percent/58percent/0.76,81percent/100percent/0.90, and 94 %/58 %/0.82. Coronal-plane had significantly higher specificity than Horizontal-plane and Deepest (p = 0.004) but Horizontal-plane and Deepest were not different (p = 1.00). Horizontal-plane had significantly lower Az than Deepest (p = 0.048), but Coronal-plane was not different than Horizontal-plane (p = 0.07) or Deepest (p = 0.20).	CP-OCT could be used to detect non-cavitated approximal caries. Analysis using the Coronal-plane is superior to the Horizontal-plane. Clinical Significance: It is challenging to detect non-cavitated approximal caries clinically due to the adjacent tooth. CP-OCT is a nondestructive, no ionized-radiation caries detection technique. CP-OCT seems suitable to detect non-cavitated approximal caries and observing the Coronal-plane appears better than Horizontal-plane.
4	**In vivo validation of near-infrared light transillumination for interproximal dentin caries detection**	Investigate The diagnostic accuracy of near-infrared light transillumination (NILT) as a novel x-ray-free method for proximal dentin Caries detection and to compare this method to established	A total of 127 interproximal dentin caries lesions without any cavity within visible dentin in posterior teeth from 85 consecutively selected patients were included. Visual and radiographic diagnoses and laser fluorescence measurements were	The diagnostic accuracy with respect to the reference standard was 1.6 % for visual inspection, 66.7 % for laser fluorescence, 96.1 % for digital radiography, 29.1 % for NILT-dentin and 99.2 % for NILT-EDJ. Bitewings (Az 0.984) and NILT-EDJ (Az 0.992) performed equally.	The Diagnostic accuracy of NILT achieved the same level as bitewings for the detection of proximal dentin caries. This study might indicate that NILT could reduce the usage of bitewings.

	(Kühnisch et al., 2016)	Diagnostic methods	available. NILT images were obtained, and a dentin lesion was predicted if a demineralization involved the enamel-dentin junction (NILT-EDJ) or a shadow in dentin was detectable (NILT-dentin). Included lesions were opened and validated (reference standard).		
5	**Radiographic assessment of proximal surface carious lesion progression in Chilean young adults** (Phillips et al., 2020)	Investigate the rate and associations of interproximal carious lesion Progression by radiographic assessment	Retrospective data were analyzed from 125 young adults (age range: 18-29 years) with repeated bitewing radiographs collected over a 6-year period. Participants were submitted to different protocols of radiographic examination frequency. Transitions from outer enamel to outer dentine (OE-to-OD) and from outer dentine to dentine (OD-to-D) were selected because of their clinical relevance. Factors associated with each transition were assessed in Cox regression models.	One hundred seven (85.6%) and 52 (41.6%) participants experienced OE-to-OD and OD-to-D transitions, respectively. In addition, 16.8% of 537 eligible surfaces progressed from OE-to-OD whereas 59.4% of 128 eligible surfaces progressed from OD-to-D. Incidence rates were 6.6 and 44.1 per 100 tooth surface-years, respectively. Mean survival time for OE-to-OD transition was 6.4 years (95% confidence interval: 6.0-6.9) and the median survival time for OD-to-D transition was 1.6 years (95%CI: 1.3-1.7). In adjusted Cox regression models, location in the lower jaw (hazard ratio: 0.34; 95% CI: 0.21-0.57) was inversely associated with OE-to-OD progression.	Location of the caries lesion and proximal DMFS were the only factors associated with caries progression that can detect by radiographic assessment.
6	**Interrater agreement and reliability assessment of proximal caries detection**	Assess the interrater agreement and reliability of ICDAS (visual), transillumination, radiographic, and laser fluorescence	Two calibrated examiners assessed the nonobvious non-cavitated apparently sound 100 interproximal sites using predefined criteria. Interrater agreement was	The maximum interrater agreement was projected with conventional bitewing radiography (97%), and the minimum with DIAGNOdent pen (84%), with significant difference ($P < .001$) in the proportion of agreement. All methods showed substantial	ICDAS and bitewing radiography seem to be the most reliable methods, with a higher proportion of agreement between the

	tools in mixed dentition: An in-vivo study (Bijle et al., 2018)	proximal caries detection tools in between primary and adjacently erupted permanent molars.	analyzed as proportion of agreement. Interrater reliability assessment was performed using weighted kappa statistics and intraclass correlation coefficient.	interrater reliability, except fiber-optic transillumination. Maximum interrater reliability was noticed for ICDAS (International Caries Detection and Assessment System) method with a weighted kappa value of 0.80 (96% CI, 0.58 - 0.93) followed by conventional and digital bitewing radiography, with values of 0.74 (95% CI, 0.51 - 0.96) and 0.73 (95% CI, 0.43 - 0.92) respectively.	examiners compared to the other methods addressed in this study for proximal caries detection.
7	**Comparison of diagnostic methods for early interproximal caries detection with near-infrared light transillumination: an in vivo study** (Baltacioglu & Orhan, 2017)	Evaluate the diagnostic capability of near infrared light transillumination (NILT) and PSP-Bitewing radiographs and to compare the interobserver and intraobserver differences in addition to observers' experience level to detect early interproximal caries lesions in vivo.	A total of 52 untreated posterior teeth with and without varying degrees of early interproximal carious lesions were included. Bitewing radiographs using digital phosphor plates (PSP-Bitewing) and NILT were used to clarify the diagnosis. A separate appointment for clinical validation and restoration was made. Kappa coefficients were calculated to assess both intraobserver and interobserver agreements for each evaluation method. Scores obtained from PSP-Bitewing and NILT were compared with the clinical validation via receiver operating characteristic (ROC) analysis.	No significant differences were found between PSP-Bitewing radiography and NILT for detecting early interproximal carious lesions with high average Az results. Both intraobserver and interobserver agreement values were relatively higher for NILT evaluation. The Az values increased at second evaluations for both caries detection methods.	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 ionizing radiation.
8	**Insufficient evidence of the superiority of near-infrared light**	Assess the performance of near-infrared light transillumination (NILT) and digital phosphor plate bitewing	26 participants who had a total of 52 untreated EICL according to the assessors and who agreed to undergo a	The accuracy of DPBR was 68% when used by both assessors, and the accuracy of NILT was 80% when used by the OMFR and 82% when used by the RDC.	DPBR is more accurate in detecting EICL than NILT.

	transillumination over bitewing digital radiograph for detecting early interproximal carious lesions (Brignardello-Petersen, 2018)	radiograph (DPBR) in detecting EICL and the extent to which the observer's experience affects this performance.	diagnosis validation and restorative treatment. The assessors examined the lesions using NILT and assessed the presence of caries according to this method. Lesions for which the diagnosis made using NILT was caries being "present" or "unclear" underwent testing with the reference standard. The reference standard for diagnosing caries was confirmation of the presence of caries when performing a restorative intervention.		
9	**Proximal caries lesion detection in primary teeth: does this justify the association of diagnostic methods?** (Bussaneli et al., 2016)	evaluate and compare the performance of visual exam with use of the Nyvad criteria (visual examination - (VE)), interproximal radiography (BW), laser fluorescence device (DIAGNOdent Pen-DDPen), and their association in the diagnosis of proximal lesions in primary teeth.	45 children (n= 59 surfaces) of both sexes, aged between 5 and 9 years were selected, who presented healthy primary molars or primary molars with signs suggestive of the presence of caries lesions. The surfaces were clinically evaluated and coded according to the Nyvad criteria and immediately afterwards with the DDPen. Radiographic exam was performed only on the surfaces coded with Nyvad scores 2, 3, 5, or 6. Active caries lesions and/or those with discontinuous surfaces were restored, considering the depth of lesion as reference standard.	The DDPen presented the highest sensitivity values. Association with one or more methods resulted in an increase in specificity.	The performance of visual, radiographic, and DDpen exams and their associations were good; however, the clinical examination with the Nyvad criteria was sufficient for the diagnosis of interproximal lesions in primary teeth.

10	**Approximal morphology as predictor of approximal caries in primary molar teeth** (Cortes et al., 2018)	Evaluate the predictive power of the morphology of the distal surface on 1st and mesial surface on 2nd primary molar teeth on caries development in young children	62 children. Upper and lower molar teeth of one randomly selected side received a 2-day temporarily separation. Bitewing radiographs and silicone impressions of interproximal area (IPA) was obtained. One-year procedures were repeated in 52 children (84%). The morphology of the distal surfaces of the first molar teeth and the mesial surfaces on the second molar teeth (n=208) was scored from the occlusal aspect on images from the baseline resin models resulting in four IPA variants: concave-concave; concave-convex; convex-concave, and convex-convex. Approximal caries on the surface in question was radiographically assessed as absent/ present.	Of the 52 children examined at follow-up, 31 children (60%) had 1–4 concave surfaces. In total 53 (25%) of the 208 surfaces were concave. A total of 22 children (43%) had 1–4 approximal lesions adding up to 59 lesions.	Morphology of approximal surfaces in primary molar teeth, in particular both surfaces being concave, significantly influences the risk of developing caries. the concave morphology of approximal surfaces can predict future caries lesions supporting specific homecare and in-office preventive strategies.
11	**In vivo correlation of near-infrared transillumination and visual inspection with bitewing radiography for the detection of interproxim**	Evaluate near-infrared light transillumination (NILT) for interproximal caries detection in children by comparing the correlation between both NILT and visual inspection (ICDAS) with bitewing (BW) radiography and by investigating	From 35 patients, 121 and 63 interproximal surfaces in, respectively, primary and permanent teeth were included. NILT images were obtained using DIAGNOcam™ (KaVo) and scored by two calibrated raters. A consensus diagnosis was reached for BW radiography, whereas the ICDAS scores were obtained by one	The correlation between NILT and BW radiography was moderate to substantial for primary teeth [Rater 1: wκ=0.61 (95% CI=0.49–0.75), Rater 2: wκ=0.55 (95% CI=0.41–0.69)] and fair for permanent teeth [Rater 1: wκ=0.34 (95% CI=0.15–0.53), Rater 2: wκ=0.33 (95% CI=0.08–0.58)]. The correlation between ICDAS and BW radiography was moderate for primary teeth [wκ=0.49 (95% CI=0.35–0.63)] and substantial for permanent teeth [wκ=0.62 (95% CI=0.32–0.92)].	NILT cannot be recommended as a single diagnostic tool for interproximal caries detection in primary teeth. The number of false negatives for dentine caries, especially in first primary molars, was too high. For the use in permanent teeth, NILT could be more

	al caries in permanent and primary teeth (de Zutter et al., 2020)	possible differences in caries detection with NILT between primary and permanent teeth.	calibrated rater. Weighted Kappa (wκ) was used to evaluate inter- and intra-rater reliability of NILT and to evaluate the correlation between NILT, ICDAS and BW radiography.	No significant differences were found between primary and permanent teeth.	accurate than BW radiography.
12	**A clinical comparison of extraoral panoramic and intraoral radiographic modalities for detecting proximal caries and visualizing open posterior interproximal contacts** (Terry et al., 2016)	Compare extraoral panoramic bitewings (BWs) to intraoral photostimulable phosphor (PSP) plate BWs for the detection of proximal surface caries and to establish if there were any difference between extraoral BWs, intraoral BWs and panoramic radiographs in visualizing open posterior interproximal contacts	Extraoral panoramic and intraoral BW images were acquired on each of 20 patients, resulting in 489 total non-restored, readable surfaces that were evaluated by 4 observers. The ANOVA analysis to determine diagnostic variability between and within each subject was utilized. The surfaces included in the study extended from the distal of each canine to the last posterior contact in each arch with non-readable proximal surfaces excluded (i.e. surfaces where over half the enamel layer was overlapped or where those surfaces were not visible in one or both modalities).	The statistical analysis indicated that the overall mean area under the receiver operating characteristic curves across all observers for the intraoral BWs and extraoral panoramic BWs were 0.832 and 0.827, respectively, and the difference of 0.005 was not significant at p 5 0.7781. The percentage of non-readable proximal surfaces across the three modalities were 4.1% for intraoral BWs, 18.3% for extraoral panoramic BWs and 51.5% for the standard panoramic images	The investigators concluded there was no significant difference in posterior proximal surface caries detection between the modalities. Extraoral panoramic BWs were much better than panoramic radiographs in visualizing open posterior interproximal contacts, 81.7% vs 48.5%, but below the 95.9% value for intraoral BWs.
13	**A comparison of diagnosis of early stage interproxim al caries with bitewing radiographs**	Assess the diagnostic property of intraoral bitewing radiographs (BTW) for early-stage interproximal caries, and to compare them with peri-apical	A total of 241 interproximal surfaces of BTW and corresponding PAs were used. Seven teaching faculty consisting of three oral and maxillofacial radiologists, two operative faculty, and	There was no significant difference in the specificity of BTW and PAs. BTW showed significantly higher sensitivity than PAs in all levels of caries progression (p<0.01). Positive-predictive value and negative-predictive value of BTWs were also significantly higher than	BTWs offer a significant advantage over PAs in the diagnoses of early stages of interproximal carious lesions

	and periapical images using consensus reference (Takahashi et al., 2019)	radiographs (PA) at different levels of caries progression	two prosthodontists evaluated the images. The observers graded images as either "intact", "enamel caries <1/2 width", "enamel caries >1/2 width", or "caries into dentin". The gold-standard was established by consensus of two experienced faculty with 35 years and 27 years of experience. Specificity, sensitivity, positive-predictive value, and negative-predictive value was calculated for the different level of caries progression. Furthermore, receiver operating curves) of BTW and PAs of each evaluator were made and the area under the curve of BTW and PAs were compared.	PAs. One-way ANOVA and Tukey HSD test showed a significant difference in sensitivity with different levels of caries progression. The average area under the curve was significantly higher for BTWs than PAs ($p<0.01$).	
14	**Three-dimensional assessment of proximal contact enamel using optical coherence tomography** (Ei et al., 2019)	Detect and investigate the association of enamel microcracks with demineralization at proximal contact areas of premolars, using 3D sweptsource optical coherence tomography (SS-OCT).	Extracted maxillary and mandibular premolars (n= 50 each), without any visible tooth cracks, were examined for demineralization of interproximal contact areas, using the International Caries Detection and Assessment System (ICDAS). SS-OCT was used to evaluate demineralization and detect microcracks.	Microcracks confined within the superficial enamel in proximal contact areas were seen as bright lines on SS-OCT. There were significant positive correlations among ICDAS codes, demineralization levels, and microcrack distribution ($p \leq 0.001$). The mesial side of maxillary premolars showed significantly more demineralization (n= 36) and microcracks (n = 27) than that of the mandibular premolars (n= 20 and n= 14, respectively; $p < 0.001$).	The presence of microcracks within the superficial enamel in proximal contact areas could be determined using SS-OCT and correlated with the level of demineralization. 3D SS-OCT is a valuable diagnostic tool for comprehensive assessment of microstructural changes related to enamel de-mineralization and crack development.

15	**Clinical accuracy data presented as natural frequencies improve dentists' caries diagnostic inference** (Nadanovsky et al., 2018)	Assessed whether dentists' diagnostic inferences differ when test accuracy information is communicated using natural frequencies versus conditional probabilities	A parallel, randomized controlled trial with dentists was carried out in Rio de Janeiro, Brazil. The dentists received a question on the probability of a patient having interproximal caries, given a positive bite-wing radiograph. This question was asked using information that was formulated into either natural frequencies or conditional probabilities	Only 14 (13.9%) of the dentists gave the correct answer; 13 in the natural frequencies group, and 1 in the conditional probabilities group ($P < .001$). There were 7 nearly correct answers in the natural frequencies group and none in the conditional probabilities group (P ¼ .005).	Representing diagnostic test accuracy in natural frequencies substantially helped dentists make diagnostic inferences. Nearly twice as many dentists overestimated the presence of interproximal caries when given information in conditional probabilities.
16	**Accuracy of near-infrared light transillumination (NILT) compared to bitewing radiograph for detection of interproximal caries in the permanent dentition: A systematic review and meta-analysis** (Ortiz et al., 2020)	Evaluate the accuracy of the near-infrared light transillumination (NILT) for the detection of interproximal dental caries in permanent dentition when compared to bitewing X-ray (BW).	PubMed, Cochrane Library, Web of Science, Scopus, Lilacs/BBO and grey literature databases were surveyed	From 1594 retrieved articles, 13 studies were included. Six studies had a low risk of bias and a low level of concern regarding applicability. Four studies had an unclear risk of bias, while three presented a high risk of bias. The meta-analysis of six studies demonstrated that NILT presented good overall accuracy. Of 6110 teeth, 92.3 % (5639) were accurately classified (776 as true positive and 4863 as true negative). The pooled sensitivity was 0.97 (0.96 to 0.98; $p = 0.0000$; $I2 = 93.2$ %) with moderate certainty of evidence, and the pooled specificity was 0.91 (0.91 to 0.92; $p = 0.0000$; $I2 = 98.3$ %) with high certainty of evidence. Symmetric (0.9837) and asymmetric (0.9836) SROC showed a high discrimination and determination effect of NILT.	The current literature, with moderate certainty and a middling quality of evidence, demonstrates that NILT presents a reasonably comparable accuracy to that of BW for detecting interproximal carious lesions in the permanent dentition. Since NILT presented good overall accuracy for the detection of interproximal primary caries, it could be routinely used in dental check-ups, especially in high-risk caries populations and in patients where the use of radiation

					should be reduced, like pregnant women or children.
17	**Diagnostic accuracy of Cone Beam Computed Tomography , conventional and digital radiographs in detecting interproximal caries** (Mahmoudi & Manouchehri, 2016)	Recognize and examine the correctness of cone-beam computed tomography (CBCT), regular radiographs and the nondirect digital system in the disclosure of interproximal caries.	Forty-two extracted non-cavitated, unrestored person molar and premolar teeth were placed in the blocks with proximal surfaces in touch. Then they were appraised by CBCT, formal radiographs and the non-direct digital system for the disclosure of interproximal caries. Four oral and maxillofacial radiologists used a 4-point scale to assess the pictures for the existence or absence of proximal caries. Caries depth was specified by histological examination.	Statistics demonstrated that the accuracy of the indirect digital system was somewhat better than conventional systems. The accuracy of the indirect digital system was better than cone beam system, and this difference was statistically significant.	The digital system was better than CBCT in the disclosure of proximal caries. The formal radiography fell in between the two other systems without a statistically significant deviation in detecting caries. Thus, CBCT is not advised to detect proximal caries because of the higher radiation dose.
18	**Radiographic Diagnosis of Incipient Proximal Caries: An Ex-Vivo Study** (Moreira da Silva Neto et al., 2017)	Compare visual clinical and radiographic examinations to the histological analysis for proximal caries diagnosis in extracted permanent molars and premolars.	Eighty-eight proximal surfaces (44 freshly extracted teeth) were longitudinally sectioned with a 370-µm diamond disk, thinned with wet silicon carbide paper and observed with a stereomicroscope at ×40 magnification.	Sensitivity and specificity were 65.6% and 83.3% for clinical examination and 29.7% and 95.8% for radiographic examination, respectively. Kappa values ranged from 0.64 to 0.91. The white spots corresponded to lesions restricted to enamel, while the dark spots corresponded to lesions that reached the dentinoenamel junction. In most cases, cavitation corresponded to dentin lesions.	Interproximal radiographic examination is not a reliable method for detection of incipient proximal carious lesions.
19	**Proximal caries detection accuracy using intraoral bitewing**	Compare proximal caries detection using intraoral bitewing, extraoral bitewing and panoramic	80 extracted human premolar and molar teeth with and without proximal caries were used. Intraoral radiographs were taken with Kodak Insight film	Kappa coefficients ranged from 0.883 to 0.963 for the intraoral bitewing, from0.715 to 0.893 for the extraoral bitewing, and from 0.659 to 0.884 for the panoramic radiography. Interobserver agreements for the first and	Intraoral bitewing radiography was superior to extraoral bitewing and panoramic radiography in diagnosing

	radiography, extraoral bitewing radiography and panoramic radiography (Kamburog et al., 2016)	radiography.	using the bitewing technique. Extraoral bitewing and panoramic images were obtained using Digital Panoramic X-ray unit. Images were evaluated by three observers twice. In total, 160 proximal surfaces were assessed. Intra- and interobserver kappa coefficients were calculated. Scores obtained from the three techniques were compared with the histological gold standard using receiver operating characteristic analysis.	second readings for the intraoral bitewing images were between 0.717 and 0.780, the extraoral bitewing readings were between0.569 and 0.707, and the panoramic images were between 0.477 and 0.740. The Az values for both readings of all three observers were highest for the intraoral bitewing. Az values for the extraoral bitewing images were higher than those of the panoramic images without statistical significance (p.0.05).	proximal caries of premolar and molar teeth ex vivo. Similar intra- and Interobserver coefficients were calculated for extraoral bitewing and panoramic radiography.
20	**Digital imaging capability for interproximal caries detection: A meta-analysis** (Winand et al., 2016)	Identify the diagnostic capability of photostimulable phosphor plates (PSPs) and direct digital sensors (DDSs) in the detection of interproximal caries.	This systematic review searched several electronic databases. In addition, Google Scholar and reference lists of the finally included studies were screened. QUADAS-2 was applied to evaluate the risk of bias among included studies	Six studies were finally included; 4 of which were considered homogeneous enough to conduct a meta-analysis. The meta-analysis evaluated 668 interproximal human tooth surfaces. All studies used extracted human teeth ranging from no caries present to caries into dentin. Each tooth was radiographed by both PSP and DDS technologies and then submitted for histologic analysis as the gold standard.	While DDS and PSP systems were excellent at identifying surfaces without caries (specificity), both lacked sufficient sensitivity to reliably identify surfaces with caries. No significant difference was noted between the performances of DDS and PSP digital systems. However, their low sensitivity dictates that the clinician must remain vigilant in corroborating all radiographic findings with a careful clinical evaluation for early interproximal lesions.

Appendix 5: Consent Form

UNIVERSITY of the WESTERN CAPE

DEPARTMENT OF RESTORATIVE DENTISTRY
FACULTY OF DENTISTRY
Private Bag x1, Tygerberg , 7505,
Cape Town, South Africa
T: +27 721836364
E-mail: skhan@uwc.ac.za

Appendix 5: Consent Form

CONSENT FORM

Title: Ability of 5th year Students to Detect Early Interproximal Caries

The study has been described to me in language that I understand and I freely and voluntarily agree to participate. My questions about the study have been answered. I understand that my identity will not be disclosed and that I may withdraw from the study without giving a reason at any time and this will not negatively affect me in any way.

Participant's name.......................................

Participant' signature ....

Date..

FROM HOPE TO ACTION THROUGH KNOWLEDGE.

Appendix 6: Participant Information Sheet

UNIVERSITY of the WESTERN CAPE

DEPARTMENT OF RESTORATIVE DENTISTRY

FACULTY OF DENTISTRY
Private Bag x1, Tygerberg , 7505,
Cape Town, South Africa
T: +27 721836364
E-mail:skhan@uwc.ac.za

Appendix 6: Participant Information Sheet

Study Title: **Ability of 5th year Students to Detect Early Interproximal Caries**

What is this study about?

This is a research project being conducted by Dr Muzan Abdalla at the University of the Western Cape in South Africa. We are inviting you to participate in this research project because you meet the set criterion for the population of interest and your participation will help other people. The purpose of this research project is to determine the capability of the 5th year students in detecting and diagnosing early interproximal caries using bitewing films, digital and printed film on paper.

What will I be asked to do if I agree to participate?

You will be asked to sign a consent form agreeing to take part in the study and will be assigned a study participant number, which will keep you anonymous and you will be asked to fill in a questionnaire. Any enquiry regarding the questionnaire will be met immediately by the researcher and if you needed any help filling in the questionnaire it will be provided.

Would my participation in this study be kept confidential?

Your personal information will be kept confidential. To help protect your confidentiality you will be assigned a study participant number to identify your data. Only the researchers will have access to your personal data, which will only be used to make the initial group allocation. Your data and any results we obtain will be kept under password protection and in locked cabinets. Your results and opinions will be kept confidential and no personal data will be made public.

What are the risks of this research?

There are no risks from participating in this research study.

What are the benefits of this research?

You will have the right to benefit from the researcher knowledge and skills.

Do I have to be in this research and may I stop participating at any time?

Your participation in this research is completely voluntary. You may choose not to take part at all. If you decide to participate in this research, you may stop participating at any time. If you decide not to participate in this study or if you stop participating at any time, you will not be penalized or be discriminated against.

FROM HOPE TO ACTION THROUGH KNOWLEDGE.

What if I have questions?

Should you have any questions regarding this study and your rights as a research participant or if you wish to report any problems you have experienced related to the study, please contact: Dr Muzan Abdalla (principal investigator) at muzan.a@hotmail.com, Dr Saadika Khan (Supervisor) at skhan@uwc.ac.za; tel. +27 (72)183-6364 or Research Ethics Committee at BMREC, UWC, Private Bag x17, Bellville, 7535, Tel: + 27 21 959 4111,

Email: research-ethics@uwc.ac.za

Appendix 7: Letter to the Faculty Dean

UNIVERSITY of the WESTERN CAPE

DEPARTMENT OF PROSTHETIC DENTISTRY
FACULTY OF DENTISTRY
Private Bag x1, Tygerberg , 7505,
Cape Town, South Africa
T: +27 721836364
E-mail: skhan@uwc.ac.za

25 August 2019

For Attention: The Dean
Faculty of Dentistry
University of the Western Cape
Tygerberg
7505

Dear Prof YI Osman

RE: Application to conduct a research study at the Tygerberg Oral Health Center of the University of the Western Cape

I am student Muzan Abdalla and I am planning to conduct a research study as part of the postgraduate program, Masters in Restorative Dentistry.

The title of the study is "Radiographic Detection of Early Interproximal Caries Amongst 5th year Dental Students". It is a cross sectional study. I want to determine and compare the capability of the senior students to diagnose and detect interproximal caries using 3 different techniques: Bitewing Films, Digital/PACS, printed film on paper. It will also help to identify procedures that the students are finding as a challenge.

A questionnaire for the final year students will be conducted at the Tygerberg Oral Health Center, where 77 students will be participating. Ethical approval has been requested from the UWC Biomedical research ethics committee in order to continue with the study

Please do not hesitate to contact me should you require anything further.

Yours sincerely
Muzan

Dr Khan (Supervisor)

FROM HOPE TO ACTION THROUGH KNOWLEDGE.

Appendix 8: Letter to the Registrar

UNIVERSITY of the WESTERN CAPE

DEPARTMENT OF PROSTHETIC DENTISTRY
FACULTY OF DENTISTRY
Private Bag x1, Tygerberg , 7505,
Cape Town, South Africa
T: +27 721836364
E-mail: skhan@uwc.ac.za

25 August 2019

For Attention: The Registrar
Faculty of Dentistry
University of the Western Cape
Tygerberg
7505

Dear Sir/Madam,

RE: Application to conduct a research study with students at University of the Western Cape

I, Muzan Abdalla is planning to conduct a research study as part of the postgraduate program, Masters in Restorative Dentistry.

The title of the study is "Radiographic Detection of Early Interproximal Caries Amongst 5th year Dental Students". It is a cross sectional study. It will be to determine and compare the capability of the senior students to diagnose and detect interproximal caries using 3 different techniques: Bitewing Films, Digital/PACS, printed film on paper. It will also help to identify procedures that the students are finding it as a challenge.

A questionnaire for the final year students will be conducted at the Tygerberg Oral Health Center, where 77 students will be participating. Ethical approval has been requested from the UWC Biomedical research ethics committee in order to continue with the study

Please do not hesitate to contact me should you require anything further.

Thank You
Muzan

Dr Khan (Supervisor)

FROM HOPE TO ACTION THROUGH KNOWLEDGE.

Appendix 9: Data Extraction Form

--- DATA EXTRACTION FORM ---

A. SOURCE

Study ID: ______________________________________ Date: ________________________

Reviewer ID: ___________________________________ Revision Date: ________________

Authors: ____

Title: ____

____

____

____

B. METHODS

Study Duration: ____

	Yes	No	Unclear	Comment
Study Design:				
Cross-sectional design				
Clinical Trial				
Cohort/ longitudinal				
Lab Study: Human				
Lab Study: Animal				
Narrative reporting of result:				
Statistics:				

C. PARTICIPANTS/ SPECIMENS

Total N = ____

Final N = ____

Age: Adults - ____________________________________

Sex: F = ___________________________ M = ______________________________________

Country: ____

Socio-Economic Status:____

____

Ethnicity: ____

____

D. **INTERVENTIONS (I) and OUTCOMES**

	Total I	Specific I	Duration	Details
Experimental Group				
Control Group				
Laboratory Group				

Primary Outcomes: ____

____

Secondary Outcomes: ____

____

Adverse Events: ____

E. **RESULTS**

	N	Missing	Summary Data	Measure Effect	Subgroup Analysis
Experimental Group:					
Control Group:					
Laboratory Group					
Outcomes:					

F. **NOTES**

Conclusions: ____

Funding: ____

Correspondence Needed: ____

____

____

Conflict of interest Statement:

____

Appendix 10: Detailed tables of the results

Description of the sample according to the previous use of bitewing radiography

USED BITEWING BEFORE		N	Mean	Std. Deviation	Std. Error Mean	P-Value
Caries presence in BW	Yes	64	51.05	18.099	2.262	0.000
	No	2	33.00	0.000	0.000	
Caries size in BW	Yes	64	23.30	21.133	2.642	0.656
	No	2	16.50	23.335	16.500	
Caries presence in DR	Yes	64	46.83	17.846	2.231	0.806
	No	2	50.00	24.042	17.000	
Caries size in DR	Yes	64	52.09	30.345	3.793	0.402
	No	2	33.50	47.376	33.500	
Caries presence in PP	Yes	64	64.72	26.556	3.320	0.442
	No	2	50.00	24.042	17.000	
Caries size in PP	Yes	64	23.84	22.607	2.826	0.653
	No	2	16.50	23.335	16.500	

Key: Bitewing Radiography (BW), Digital Radiography (DR), Printed film on paper (PP)

Description of the sample according to the difficulty in diagnosing early interproximal caries

DIFFICULTY		N	Mean	Std. Deviation	Std. Error Mean	P-Value
Caries presence in BW	Yes	62	50.53	18.158	2.306	0.955
	No	4	50.00	19.630	9.815	
Caries size in BW	Yes	62	24.05	21.044	2.673	0.147
	No	4	8.25	16.500	8.250	
Caries presence in DR	Yes	62	46.18	17.752	2.255	0.182
	No	4	58.50	17.000	8.500	
Caries size in DR	Yes	62	50.02	30.165	3.831	0.114
	No	4	75.00	32.031	16.016	
Caries presence in PP	Yes	62	63.56	26.887	3.415	0.396
	No	4	75.25	16.500	8.250	
Caries size in PP	Yes	62	23.55	22.912	2.910	0.918
	No	4	24.75	16.500	8.250	

Key: Bitewing Radiography (BW), Digital Radiography (DR), Printed film on paper (PP)

Description of the sample according to the reasons for difficulty

		Not enough knowledge	Technical error	Exposure error	Poor image sharpness	P-Value
Caries presence in BW	Mean	53.92	52.58	47.57	45.75	0.682
	Std. Deviation	17.217	19.547	18.174	17.000	
Caries size in BW	Mean	28.08	25.54	14.14	22.69	0.732
	Std. Deviation	23.009	23.720	17.639	15.798	
Caries presence in DR	Mean	51.31	42.15	47.57	47.94	0.868
	Std. Deviation	17.642	15.380	18.174	21.240	
Caries size in DR	Mean	48.77	55.19	47.57	43.69	0.500
	Std. Deviation	29.397	32.688	32.669	26.608	
Caries presence in PP	Mean	56.62	61.62	66.71	71.00	0.766
	Std. Deviation	21.211	32.321	27.354	20.675	
Caries size in PP	Mean	35.92	19.12	23.57	20.69	1.732
	Std. Deviation	28.903	21.407	16.102	20.581	

Key: Bitewing Radiography (BW), Digital Radiography (DR), Printed film on paper (PP)

Description of the sample according to the preferred method of use

		BITEWING	DIGITAL	IOC	P-Value
Caries presence in BW	Mean	49.58	50.81	67.00	0.417
	Std. Deviation	18.664	17.400	0.000	
Caries size in BW	Mean	23.12	22.10	33.00	0.788
	Std. Deviation	21.234	21.927	0.000	
Caries presence in DR	Mean	45.67	47.57	67.00	0.253
	Std. Deviation	18.148	17.241	0.000	
Caries size in DR	Mean	51.98	52.38	33.00	0.691
	Std. Deviation	32.076	29.159	0.000	
Caries presence in PP	Mean	65.21	62.10	67.00	0.900
	Std. Deviation	25.261	30.392	0.000	
Caries size in PP	Mean	23.93	22.10	33.00	0.802
	Std. Deviation	23.402	21.927	0.000	

Key: Bitewing Radiography (BW), Digital Radiography (DR), Printed film on paper (PP)

Description of the sample according the reason for preferred method of use

		HIGH ACCURACY LEVEL	EASY TO USE	AVAILABILITY AT THE HOSPITAL	TIME SAVER	P-Value
Caries presence in BW	Mean	52.09	53.92	42.44	67.00	0.076
	Std. Deviation	19.108	17.217	15.670	0.000	
Caries size in BW	Mean	18.63	33.15	22.06	33.33	0.159
	Std. Deviation	20.575	19.343	19.738	33.501	
Caries presence in DR	Mean	47.88	53.92	40.61	44.33	0.222
	Std. Deviation	17.137	17.217	18.513	19.630	
Caries size in DR	Mean	54.19	41.00	51.89	66.67	0.482
	Std. Deviation	29.169	24.369	36.643	33.501	
Caries presence in PP	Mean	66.78	56.54	63.11	78.00	0.533
	Std. Deviation	25.486	37.044	19.599	19.053	
Caries depth in PP	Mean	22.78	15.23	33.28	11.00	0.103
	Std. Deviation	21.465	17.123	25.695	19.053	

Key: Bitewing Radiography (BW), Digital Radiography (DR), Printed film on paper (PP)