IN VITRO COMPARISON OF EARLY OCCLUSAL ENAMEL CARIES DETECTION AND REMINERALISATION USING ICDAS II AND DIAGNODENT PEN IN PERMANENT POSTERIOR TEETH

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2022

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by

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Thesis submitted in fulfilment of the requirement
for the degree of
Master of Science

April 2022

ACKNOWLEDGEMENT

First and foremost, praises and thanks to Allah the Almighty for His showers of blessings upon my research work and for the timely successful completion.

I would like to express my deep and sincere gratitude to my supervisor Dr. Tahir Yousaf Noorani and my co-supervisor Dr. Mohamad Syahrizal Halim for giving me the opportunity to research and providing invaluable guidance throughout. Their dynamism, vision, sincerity, and motivation have deeply inspired me. They have comprehensively taught me the methodology to carry out the research and to present the research as clearly as possible.

I am extremely grateful to my parents for their love, prayers, care, and sacrifices for education and for supporting me for my future. I am very much thankful to my wife for supporting me and standing beside me. She had to bear extra load and responsibility while I prepared for my research, provided nurturing care and love for my children, prayed for me and continuously supported me to complete this research work.

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LIST OF ABBREVIATIONS

AUROC	Area under the receiver operator characteristics curve
CPI	Community Periodontal Index
CPP-ACP	Casein phosphopeptide-amorphous calcium phosphate
D	Downers histological score
DDPen	DIAGNOdent Pen
F	Fluoride
HUSM	Hospital Universiti Sains Malaysia
ICC	Intraclass Correlation Coefficient
ICDAS	International Caries Detection and Assessment System
ICW-CCT	International Consensus Workshop on Caries Clinical Trials
LF	Laser fluorescence
LR	Likelihood ratios
MID	Minimal intervention dentistry
Sn	Sensitivity
Sp	Specificity
WHO	World Health Organization

PERBANDINGAN IN VITRO ICDAS II DAN DIAGNODENT PEN DALAM PENGESANAN KARIES ENAMEL OKLUSI AWAL DAN PROSES REMINERALISASI PADA GIGI GERAHAM KEKAL

ABSTRAK

Karies gigi adalah antara penyakit mulut atau jangkitan kronik yang paling kerap berlaku. Pelbagai kajian in-vitro telah dilakukan menggunakan peranti LF yang mana kadar kebolehulangan yang sangat baik, sebagai pilihan tambahan dalam mendiagnosa karies. Duraphat® (5% sodium fluoride) dan Tooth Mousse Plus® (casein phosphopeptide-amorphous calcium phosphate fluoride) adalah antara formulasi yang biasa digunakan untuk remineralisasi karies (Cardoso et al., 2014; Nhu et al., 2017). Sebanyak 120 gigi yang telah dicabut dan mempunya karies di bahagian oklusal dinilai menggunakan ICDAS II dan DDPen. Kemudian, proses remineralisasi dilakukan dengan menggunakan Colgate Duraphat® atau GC Tooth Mousse Plus®. Remineralisasi lesi karies kemudian dinilai semula menggunakan ICDAS II dan DDPen sebelum dilakukan pemeriksaan histologi. Sensitiviti dan spesifisiti ICDAS II dan DDPen untuk mengesan remineralisasi dihitung dan dibandingkan dengan pemeriksaan histologi. Pencartaan ICDAS-II yang dilakukan semasa pra-dan pasca-remineralisasi menunjukkan perbezaan yang sangat ketara bagi kumpulan GC Tooth Mousse Plus® berbanding dengan kumpulan kawalan dan perbezaan yang lebih rendah tetapi signifikan bagi kumpulan Colgate Duraphat® berbanding dengan kumpulan kawalan. Pencartaan DDPen untuk pra-dan pasca-remineralisasi menunjukkan bahawa terdapat perbezaan yang serupa tetapi ketara dengan penggunaan Colgate Duraphat® atau GC Tooth Mousse Plus®.

Had nilai untuk DDPen dianalisa untuk menentukan julat mana yang sesuai dengan skor histologi Downer. Nilai 0-13 untuk gigi sihat, 14-20 untuk karies enamel dan> 21 untuk karies dentin dikenal pasti paling sesuai. Korelasi peringkat spearman ICDAS-II dan DDPen dengan skor histologi Downer (standard) menunjukkan hubungan skor DDPen yang lebih tinggi (.738) berbanding dengan skor ICDAS-II (.430). Nilai di bawah nilai lekuk ciri operator penerima (AUROC) skor DDPen dan ICDAS-II dibandingkan sesuai dengan klasifikasi histologi Downer. Nilai AUROC pada tahap 1 Downer adalah 0.972 untuk julat skor DDPen (0-13) dan 0.811 untuk kod ICDAS-II 0. Nilai AUROC pada tahap 2 Downer adalah 0.894 untuk julat skor DDPen (14-20) dan 0.667 untuk ICDAS- Kod II 1-2. Nilai AUROC pada tahap 3 Downer adalah 0.838 untuk julat skor DDPen (> 21) dan 0.721 untuk kod 3 ICDAS-II. Dapat disimpulkan bahawa kedua-dua ICDAS II dan DDPen dapat mengesan remineralisasi. Had nilai untuk DDPen yang paling sesuai untuk mengesan remineralisasi ditentukan sebagai 0-13 yang baik, 14-20 menjadi karies enamel, dan> 21 adalah karies dentin. DDPen didapati lebih sensitif daripada ICDAS-II untuk mengesan remineralisasi jika dibandingkan dengan skor histologi Downers. Ini boleh menjadi kepentingan khusus pada wanita hamil dan kanak-kanak di mana pendedahan yang tidak perlu kepada sinaran mengion perlu dielakkan untuk memantau perkembangan lesi karies awal.

IN VITRO COMPARISON OF EARLY OCCLUSAL ENAMEL CARIES DETECTION AND REMINERALISATION USING ICDAS II AND DIAGNODENT PEN IN PERMANENT POSTERIOR TEETH

ABSTRACT

Dental caries is among the most commonly occurring oral diseases or chronic infection. Various in-vitro studies have been carried out using LF devices which reported excellent reproducibility as an adjunct caries diagnostic option. Duraphat® (5% sodium fluoride) and Tooth Mousse Plus® (casein phosphopeptide-amorphous calcium phosphate fluoride) are among commonly used formulations for achieving remineralization of carious lesions (Cardoso et al., 2014; Nhu et al., 2017). The occlusal carious lesion of 120 extracted teeth were evaluated using ICDAS II and DDPen. Then the process of remineralization was carried out by applying either the Colgate Duraphat® or GC Tooth Mousse Plus®. The remineralized lesions were then re-evaluated using ICDAS II and DDPen before performing sectioning and histological examination. The sensitivity and specificity of ICDAS II and DDPen to detect remineralization was calculated and a comparison with the gold standard histological examination was also performed. ICDAS-II scoring performed for the pre- and post-remineralization revealed highly significant difference for the GC Tooth Mousse Plus® group as compared to the control group and a lesser but significant difference for the Colgate Duraphat® group as compared to control group. DDPen scoring for the pre- and post-remineralization revealed that there was similar but significant difference with the use of Colgate Duraphat® or GC Tooth Mousse Plus®. Different cut-off limits for the DDPen

were analysed to determine which range was corresponded closest to the Downer's histological scores. A value of 0-13 for sound teeth, 14-20 for enamel caries and >21 for dentine caries was identified as the most suitable. The spearman's rank correlation of ICDAS-II and DDPen with the Downer's histological score (gold standard) revealed a higher association of DDPen score (.738) as compared to ICDAS-II scores (.430). The Area under the receiver operator characteristics curve (AUROC) value of DDPen score and ICDAS-II were compared corresponding to Downer's histological classification. The AUROC value at Downer's level 1 was 0.972 for DDPen score range (0-13) and 0.811 for ICDAS-II code 0. The AUROC value at Downer's level 2 was 0.894 for DDPen score range (14-20) and 0.667 for ICDAS-II code 1-2. The AUROC value at c 3 was 0.838 for DDPen score range (>21) and 0.721 for ICDAS-II code 3. The study concluded that both ICDAS II and DDPen were able to detect remineralization. The cut-off values for DDPen most suitable for detecting remineralization were determined as 0-13 being sound, 14-20 being enamel caries, and >21 being dentine caries. The DDPen was found more sensitive than ICDAS-II to detect remineralization when compared with the Downers histological scores. This can be of particular interest in pregnant women and children in which unnecessary exposure to ionizing radiations has to be avoided to monitor the progression of early carious lesions.

CHAPTER 1

INTRODUCTION

1.1 Background of the study

Dental caries is a gradually progressive disease which has been identified as the most commonly occurring oral disease/ chronic infection (Frencken *et al.*, 2012; Akgul *et al.*, 2018). If dental caries is not detected and treated early it can progress further to cause pain, infection and eventually loss of a tooth. It can be classified according to caries activity as cavitated and non-cavitated. Initially caries progresses as a non-cavitated lesion, if left untreated can progress in to a cavitated stage (Young *et al.*, 2015).

Commonly employed caries diagnostic include visuo-tactile evaluation using a mirror together with World Health Organization (WHO) probe/explorer, and dental radiographs (Rechmann *et al.*, 2012). The diagnosis of a non-cavitated carious lesion is considered challenging because this lesion can be masked by the remineralization effect of fluorides (Carvalho and Mestrinho, 2014). Different forms of fluoride application can increase the enamel surface resistance making it difficult to distinguish between hypoplastic enamel conditions and fluorosis (Seremidi *et al.*, 2012).

Bitewing radiograph is another commonly used diagnostic aid for detection of interproximal caries. However, the sensitivity of a bitewing radiograph in detection of early carious lesion is low particularly when the caries does not involve the dentin. Furthermore, the occlusal caries cannot be detected radiographically until it becomes very large (Featherstone, 2000; Gomez *et al.*, 2013). Low sensitivity of conventional radiograph have been reported while distinguishing early carious lesion not extending

beyond enamel (Verdonschot *et al.*, 1992; Fejerskov and Thylstrup, 1994; Hintze and Wenzel, 1994). Minimal intervention dentistry requires early detection of carious activity to ensure effectiveness of minimally invasive procedures which include placement of fissure sealants, topical fluoride application, preventive resin restorations, laser therapy, and antibacterial treatment (Featherstone, 2000; Rossete *et al.*, 2013; Holmgren *et al.*, 2014).

Visuo-tactile inspection of carious lesion is an inexpensive and the most utilized method of caries assessment (Floriano *et al.*, 2015). The accuracy and reliability of a diagnosis depends on the expertise and training of the assessor. To resolve the differences among assessors, a standardized caries assessment system is paramount (Tellez and Lim, 2020).

The International Caries Detection and Assessment System (ICDAS) is a caries scoring system which has high sensitivity and specificity to identify minimal progression of carious lesion. It is a valuable and inexpensive tool to assess carious lesion in absence of appropriate diagnostic aids (Ekstrand *et al.*, 2018). Therefore, ICDAS scoring system can be used to detect early stages of carious lesions to facilitate minimal intervention dentistry (MID) and to ensure better effectiveness (Ismail *et al.*, 2007).

Laser fluorescence (LF) is a relatively new method which can be utilized to detect caries. The ability of LF devices to detect early signs of caries has been documented (Tassoker *et al.*, 2020). LF allows clinicians to easily distinguish between calculus deposits and early dental caries. In addition, wide applications of LF devices in detection of proximal caries, endodontics, periodontics and restorative dentistry are reported (Shakibaie *et al.*, 2011).

DIAGNOdent Pen (DDPen) is a LF device which emits fluorescent light channelled via handpiece and then the quality of light is assessed by a detector in the handpiece and a numeric value is displayed to the assessor. An increase in the numeric value between two intervals indicates an increased amount of fluorescence detected which reveals a progression of lesion. DIAGNOdent enables long-term monitoring of caries progression, which facilitates the provision of timely minimal interventions (Altenburger *et al.*, 2010).

In-vitro studies carried out using DDPen have reported excellent reproducibility and performance for the detection and quantification of smooth surface or occlusal caries as they found good to excellent inter-examiner agreement (Lussi *et al.*, 1999a; Shi *et al.*, 2000; Shi *et al.*, 2001a). A sensitivity ranging from 89-92.4% and a specificity of 92-98% have been reported which proves it to be a reliable diagnostic tool (Kockanat and Unal, 2017; Melo *et al.*, 2017). However, some in-vivo studies did not support these results in the case of primary and permanent teeth. A DDPen study reported a sensitivity of 68% and a specificity of 37% (Mehta *et al.*, 2015).

Topically applied fluoride-based compositions are widely used to enhance remineralization to slow down progression of active carious lesion and to prevent further incidence of caries. These substances adhere to the tooth surfaces where they are applied and continue to release fluoride ions which are essential for the formation of fluoroapatite crystals. Duraphat® (5% sodium fluoride) and Tooth Mousse Plus® (casein phosphopeptide-amorphous calcium phosphate fluoride) are commonly used formulations for achieving remineralization of non-cavitated carious lesions (Cardoso et al., 2014; Nhu et al., 2017).

The potential of ICDAS II and DDPen to detect remineralization after topical application of a remineralization agents has not been studied. Thus, this study aimed to compare the change in ICDAS II score and DDPen scores before and after remineralization on the occlusal surface of enamel using Duraphat® and Tooth Mousse Plus®.

1.2 Operational definition

1.2.1 Sensitivity

The ability of ICDAS II and DDPen to identify the presence of a carious lesion is identified as sensitivity of the diagnostic tool.

1.2.2 Specificity

The ability of ICDAS II and DDPen to correctly detect the absence of a carious lesion in a sound tooth.

1.2.3 Remineralization

It is defined as the ability of a certain dental material to incorporate certain minerals in the hydroxyapatite crystals which will be assessed by stereomicroscopic examination.

1.3 Problem statement

Braga *et al.* (2009) concluded that future studies should include caries detection methods that include non-cavitated lesions. Previous studies have compared the ability of ICDAS II and DDPen to detect caries however their potential of detecting remineralization of enamel caries has not been explored (Alomari *et al.*, 2015; Iranzo-Cortés *et al.*, 2017). Moreover, the use of the DDPen on the white spot

carious lesion (Abrams *et al.*, 2017) and on an enamel window at the buccal surface in the middle one-third of the crown (Patil *et al.*, 2013) has been reported. However, the use of DDPen on the fissures, pits and the smooth surfaces has not been explored. Previous studies employed relatively smaller sample size in their studies (Achilleos *et al.*, 2013; Zaidi *et al.*, 2016). Larger sample sizes will give more reliable results with greater precision and power. A large sample size is necessary to produce results among variables that are significantly different. For qualitative studies, where the goal is to "reduce the chances of discovery failure," a large sample size broadens the range of possible data and forms a better picture for analysis. However, to the best of our knowledge none of the previous studies used ICDAS II and/or DDPen for the evaluation of surface re-mineralization after Duraphat and Tooth Mousse Plus® application. Furthermore, a previous study applied the Tooth Mousse Plus® for a short period of time (seven days) which may not be enough to re-mineralize the carious lesion on the teeth (Patil *et al.*, 2013).

1.4 Justification of study

The main objective of the minimal intervention is to prevent and treat caries over time for patients, with the minimal invasive approach. ICDAS supplies a consistent method of lesion detection and evaluation, leading to the diagnosis of caries (Ekstrand *et al.*, 2018). The previous researchers have shown that ICDAS provides good reproducibility and accurate detection in both in vivo and in vitro for initial caries lesions at different stages. The laser fluorescence method (DIAGNOdent) assists in the occlusal detection and approximal caries (Frencken *et al.*, 2012).

This will compare the ability to detect re-mineralization of early enamel caries lesion using ICDAS II and DDPen in permanent posterior teeth. Certainly, many

studies have evaluated the effect of Colgate Duraphat® and GC Tooth Mousse Plus® on the progression of carious lesions, but the potential of remineralization of enamel caries between these two materials still remains unclear. Currently, the tool widely utilized for clinical assessment of remineralization is based on the visual appearance of the affected area. This study will compare the remineralization of enamel caries with Colgate Duraphat® and GC Tooth Mousse Plus® using modern caries assessment tools (ICDAS II and DDPen) on occlusal surface of molar tooth. Moreover, no previous studies have carried out simultaneous comparison between the three assessment tools ICDAS II, DIAGNOdent and histological examination on tooth surface remineralization.

1.5 General Objective

To evaluate the sensitivity and specificity of ICDAS II and DDPen to detect remineralization of early enamel caries in human permanent posterior teeth achieved by applying the Colgate Duraphat® or GC Tooth Mousse Plus® and to compare it with histological examination.

1.5.1 Specific objectives

1. To investigate whether the ICDAS II and DDPen are able to detect remineralisation of early carious lesion after the application of topical fluoride gel (Colgate Duraphat®) and Cassein Phosphopeptide-Amorphous Calcium Phosphate Flouride (Tooth Mouse Plus) at the occlusal surface of extracted human permanent posterior teeth.
2. To identify the diagnostic criteria (cut-off values) of DDPen and to compare it with the histological examination score after remineralization process.

3. To evaluate the sensitivity and specificity of ICDAS II and DDPen in detecting remineralization of early enamel caries at occlusal surface of teeth using histological sections as a gold standard.

1.5.2 Research question

1. Is ICDAS II and DDPen able to detect remineralisation of early enamel caries achieved by application of either of the two re-mineralising agents?
2. Which cut-off values of DDPen correlate significantly with the histological gold standards?
3. Is there a significant difference in the sensitivity and specificity of ICDAS II and DDPen in detecting remineralization of early enamel caries at the occlusal surface of extracted human permanent posterior teeth by using histological sections as a gold standard?

1.5.3 Research hypothesis

1. ICDAS II and DDPen were able to detect remineralisation of early enamel caries achieved by application of either of the two re-mineralising agents
2. The sensitivity and specificity of ICDAS II and DDPen was not significantly different in detecting remineralization of early enamel caries at the occlusal surface of tooth caries detection by using histological sections as a gold standard.

CHAPTER 2

LITERATURE REVIEW

2.1 Visual examination of the International System for Caries Detection and Assessment System

2.1.1 International Caries Detection and Assessment System Comparability with Other Caries Detection Systems

The ICDAS codes were developed to allow backward comparability with other systems of caries detection such as the WHO basic methods (Organization, 1997). Some interesting work has been done using these two criterion systems in parallel which demonstrated the additional caries yield found at the D1 threshold of detection using the ICDAS. Figure 2.1 gives a side-by-side comparison of ICDAS and WHO basic method codes. It should be noted that the loose definition of the WHO Basic Method codes has meant that there has been a difference in how the codes have been interpreted in different parts of the world, particularly in the threshold at which carries is recorded as present or absent. In particular, there has been a great deal of variation between surveys and countries as to whether enamel cavitation is marked as 0 “sound” according to WHO code which would be ICDAS code 3 (Kühnisch et al., 2008). These inherent differences make comparability between different indices a difficult task to achieve.

According to WHO basic coding for the primary tooth, the crown was coded as sound if there is no evidence of treated or untreated tooth caries. Other conditions similar to the early stage of caries are excluded because they cannot be reliably diagnosed. Caries is coded as decayed when a lesion in a pit or fissure, or on a smooth surface, has a distinctive cavity, undermined enamel, or a detectable softened wall. A

Community Periodontal Index (CPI) probe must be used to confirm the evidence of caries on the occlusal, buccal and lingual surfaces (Goswami and Rajwar, 2015). These codes lead to continuing difficulties in comparing studies using WHO basic criteria (Organization, 2013).

Comparison between WHO[1] and ICDAS II[2] Codes

WHO codes	ICDAS II codes	Visual caries detection threshold	
	00	Sound	
0, A (sound)	01	Non-cavitated	Enamel caries (visually)
	02		
	03	Surface discontinuity[3]	
	04, 14, 24	Non-cavitated[4]	Obvious dentinal caries (visually)
1, B (decayed crown)	05, 15, 25, 80–85	Cavitated	
	06, 16, 26, 86		
2, C (filled and decayed)	All 2-digit codes starting with 3, 4, 5, 6 and ending 4, 5, or 6		
3, D (filled, no decay)	All 2-digit codes starting with 3, 4, 5, 6 and ending 0, 1 or 3 (see exception below for crowns/ abutments placed for reasons other than caries)		
4, E (missing due to caries)	97		
5 (permanent tooth missing for other reasons)	98		
6, F (sealant)	10, 20, 11, 21, 13, 23 – also WHO may include composite restorations restoring an investigated occlusal fissure to be in this category, i.e. some instances of codes 30, 31, 32, 33		
7, G (bridge abutment or special crown)	Any 2-digit code starting 6 and ending 0, 1, 2 or 3 and placed for some reason other than for caries, e.g. bridge abutment or because of trauma		
8 (unerupted)	99		

[1] Oral Surveys – Basic Methods, ed 4. http://www.whocollab.of.mah.se/expl/orhsurvey97.html (accessed December 14, 2007).

[2] ICDAS II codes http://www.icdas.org/ (accessed December 14, 2007).

[3] ICDAS II code 3 is enamel caries with surface discontinuity but no dentine is exposed. At the dentinal threshold for visual detection therefore this would be coded as sound even though it is known that many of these lesions would histologically involve dentine. Please note that interpretation of the WHO criteria varies internationally as to whether ICDAS code 3 lesions would be regarded as sound or not.

[4] There may be microcavitation but no cavity exposing dentine.

Figure 2.1 Comparison between WHO codes and ICDAS (Pitts, 2009)

2.1.2 Background and history of ICDAS

The International Consensus Workshop on Caries Clinical Trials (ICW-CCT) concluded that many terms have been associated to the dental caries diagnosis, lesion detection and lesion assessment which overlap in their meanings without clear demarcation (Pitts and Stamm, 2004). Furthermore, it has been concluded that the carious process is quite complex and not only restricted to D2 or D3 level of cavitation (Pitts and Stamm, 2004). One of the challenges presented by the ICW-CCT

workshop was that most of the caries detection systems have proved to be ambiguous and do not measure the progression of the lesion at different stages (Ismail 2004).

Additionally, challenges presented by the ICW-CCT workshop and other sources of evidence (Ekstrand *et al.*, 1997; Fyffe *et al.*, 2000; Ekstrand *et al.*, 2001; Ricketts *et al.*, 2002; Ekstrand *et al.*, 2005) led to a dedicated group to start ICDAS development. Large group of co-workers from number of countries offered volunteer services since 2002 (Pitts *et al.*, 2013). The major objective of this team was to build and create an incorporated system helpful in diagnosing and clinically evaluating decay in oral cavity for clinical practices as well as research purposes in order to label the stage at which the dental caries are present (Pitts *et al.*, 2014). In the year 2005, a workshop was organized to discuss and share the advancements in ICDAS criteria (Dikmen, 2015).Invitations were sent to more than 60 researchers, in return who were already accepted and agreed upon the idea to revise the ICDAS I version for dental caries detection (Bader *et al.,* 2001; Organization, 2013).

2.1.3 Application of the International Caries Detection and Assessment System

In the past caries were detected histologically along with several typical methods including radiography, tactile sensations and visually appearing lesions (Lussi *et al.*, 1999b; Gomez, 2015). In the year 2002, ICDAS was introduced for better diagnosis of dental caries based on clinical scoring system (Dikmen, 2015). Under this scoring system better understanding of activity and detection of dental caries was made clearer and easier for clinicians and epidemiologists to carry out their work (Al Dhubayb *et al.*, 2021). (Figure 2.2) ICDAS works equally good and

efficiently for both cavitated and non-cavitate dental decay (Ismail *et al.*, 2007; Varma *et al.*, 2008).

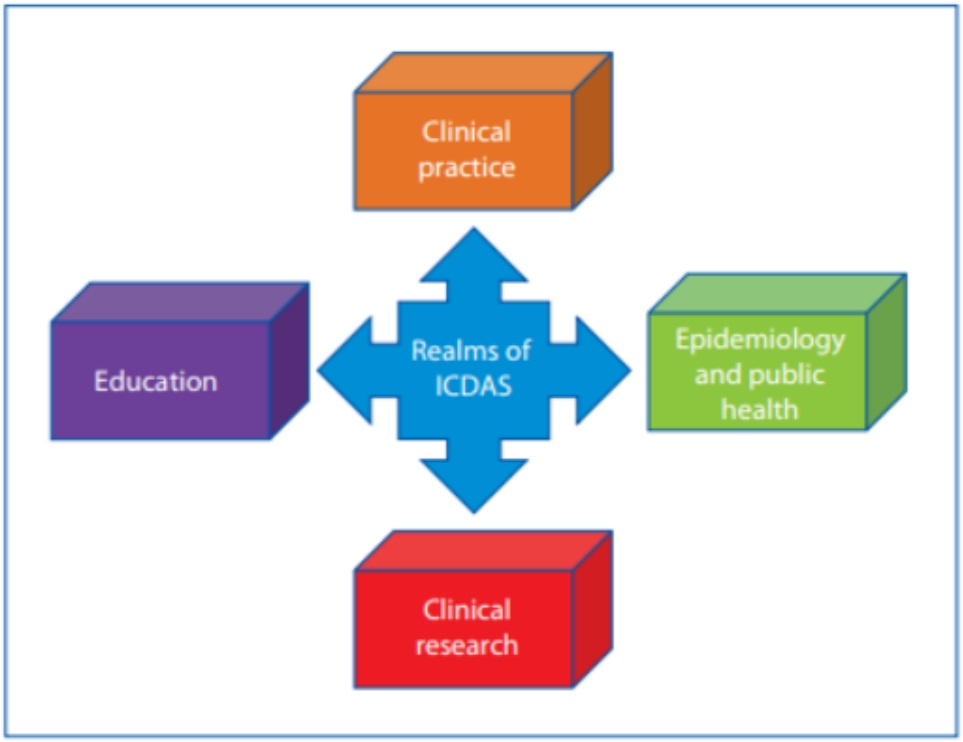

Figure 2.2 Application of ICDAS across different areas of dentistry (Pitts, 2009)

2.1.4 Practical implications of ICDAS

2.1.4(a) Clinical Practice

Proper detection and diagnosis of caries in oral cavity is one of the major skills acquired by professional students during their training period in a dental school (Pitts, 2011; Pitts *et al.*, 2013). ICDAS was introduced to be used as a universal coding language in clinical practice (Pitts and Stamm, 2004; Pishipati *et al.*, 2021). Two-digit code is assigned for tooth surfaces giving an added advantage for every surface to be monitored in future for clinical practice and research purposes. A 0-6 scale Is used in this system to measure the severity of disease where each stage is clearly defined (Diniz *et al.*, 2009a). Besides this simple classification makes it further simple, quick

and most important helping in decision of the treatment more stage specific (Evans *et al.*, 2018). In the past early signs of dental decay was ignored and diagnosis was solely made on cavitation of dentine (Brown *et al.*, 2015). This laid the basic concept of ICDAS, with correct diagnosis and appropriate clinical management skills at patient as well as community level more quality oriented treatment and prevention can be offered to the patients (Pitts and Stamm, 2004).

2.1.4(b) Clinical Research

This system is now being recognised worldwide for almost a decade ICDAS has been used in research as an effective measure against already established means of caries detection (e.g. WHO index) (Kühnisch *et al.*, 2008; Braga *et al.*, 2010; Khattak *et al.*, 2019). Mapping of high risk patients of dental caries by assessing and diagnosing is made easy using ICDAS (Pitts *et al.*, 2011).

2.1.4(c) Education

The dental academicians across numerous dental schools have played a vital role in the development of ICDAS (Pitts *et al.*, 2014). It was found necessary that ICDAS system was built on the needs experienced over time for both under graduate as well as post graduate students (Pitts *et al.*, 2013). A curriculum in cariology was developed to facilitate undergraduate students across Europe, after conducting a survey which helped in the development of the curriculum (Schulte *et al.*, 2011). ICDAS has helped in mapping of risk assessment and diagnosis of dental caries (Pitts *et al.*, 2011), illustrating straight forward decision making skill equally required for both mild as well as severe caries and putting this knowledge and information in clinical dental practice (Pitts *et al.*, 2013). Due to the association between external symptoms and signs of dental caries and the changes taking place internally beneath

the tissues ICDAS can be a useful and easy to use tool between the dental students and the staff at the dental school (Ekstrand *et al.*, 2007).

2.1.4(d) Epidemiology

ICDAS was used in number of studies for epidemiological surveys (Ekstrand *et al.*, 2007; Ismail *et al.*, 2007; Jablonski-Momeni *et al.*, 2008). One example is a dental health survey for children aged 6, 12 and 15 years in Iceland in 2005, (Eggertsson *et al.*, 2007) In another study conducted invitro (2009), to access the reproducibility as well as accuracy of ICDAS was found to be having good at reproducible and more accurate in diagnosing caries (Diniz *et al.*, 2009b).

2.1.5 Examination Conditions

Enamel caries, in recent past have emerged as an important oral problem of cariology as shown in number of previous studies (Gileva *et al.*, 2021). The enamel caries develops and transparent changes start to occur and become more obvious with time (Zeng *et al.*, 2021). Porosities of the enamel surface increases caused by demineralization or mineral loss within inner layers (Veeramachaneni *et al.*). Dental caries appears opaque as they are white spot lesions, this is due to variation in refractive index in enamel (Sezici *et al.*, 2020). Non cavitated lesion in enamel can be measured through some methods in which the observations are made after dehydrating the tooth surface properly as indicated in ICDAS (Ismail *et al.*, 2007).

At this stage, such lesions can be seen without dehydrating the surface of the lesion. This property of demineralized enamel leads to one of the basic requirements for the full ICDAS application.

Dental caries, often develops in areas where plaque is stagnant, therefore at times the dental caries continue to stay hidden, so plaque removal is a mandatory step before examining dental caries (Topping and Pitts, 2009). This can be done by adopting proper tooth brushing and flossing for removal of any accumulated plaque in proximal areas. An explorer with a ball-end is used to assist in the diagnosing of dental caries in ICDAS system especially where restorations of tooth colour are present, as its (ICDAS) examination is visual (Ekstrand *et al.*, 1987). Any sharp ended explorer is not advisable as it can damage the enamel that is covering early dental decay. (Banerjee and Doméjean, 2013; Radwan *et al.*, 2020).

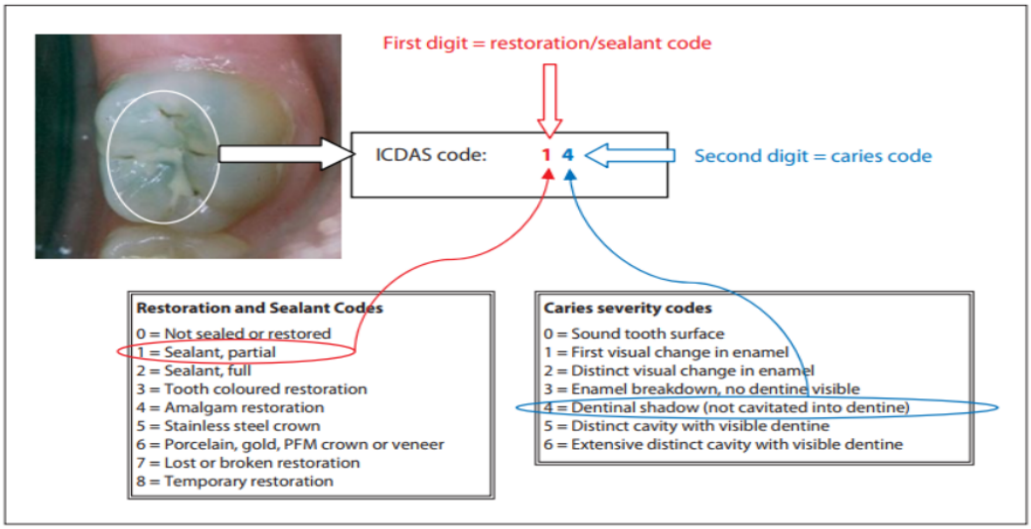

Figure 2.3 ICDAS II is coding for restoration status and caries severity, PFM=Porcelain Fused to Metal (Pitts, 2009)

2.1.6 Two Stages of ICDAS Coding

Diagnosing and detection of dental caries using ICDAS is a completed in 2 stages. It is shown in the Figure 2.3, the codes in ICDAS is composed of 2 digits which is the status of restoration that precedes a code for the severity of dental caries (Topping and Pitts, 2009).

In the first step each tooth is classified according to the status of its restoration. This step helps to differentiate various materials for restoration as well as partial and full sealed surfaces of teeth. These are the first 2 digit code describing the status of each surface of tooth (Table 2.1) (Ismail *et al.*, 2007).

Table 2.1 ICDAS II codes for restoration status (Ismail *et al.*, 2007)

Code	**Description**
0	unrestored and unsealed
1	partial sealant-a sealant which does not cover all pits and fissure of the tooth surface
2	Full sealant
3	Tooth-coloured restoration
4	Amalgam restoration
5	Stainless-steel crown
6	Porcelain, gold or performed metal crown or veneer
7	Lost or broken restoration

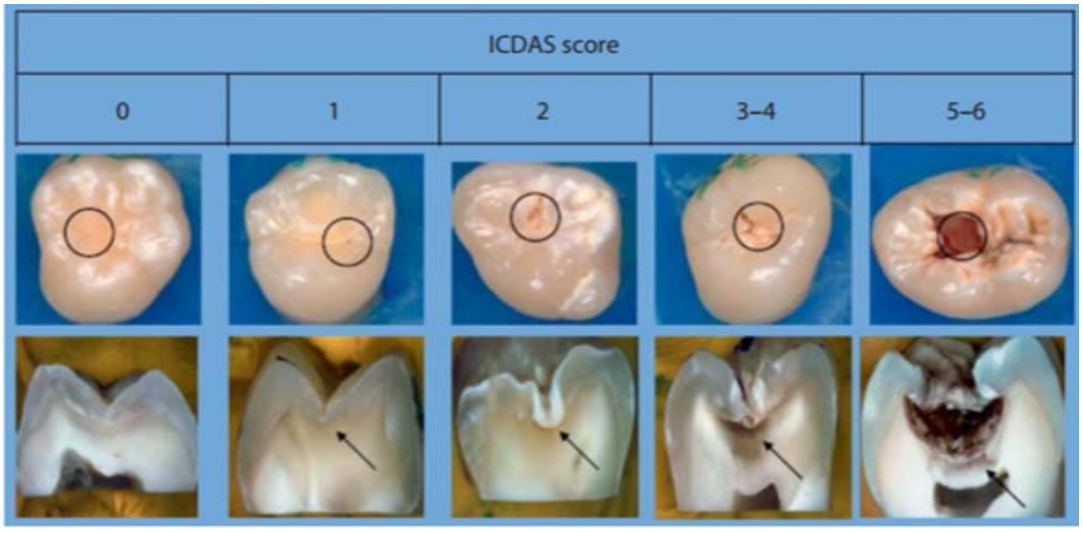

Figure 2.4 ICDAS II codes and histology (Image provided by Dr Andréa G Ferreira Zandoná, Oral Health Research Unit, University of Indiana, USA)

2.1.7 Coding System for detection and assessment of dental caries

Severity of dental caries is presented by the second digit in ICDAS system. A change in colour of enamel and cavity formation are the visual signs representing the extent of advancement in carious lesions (Topping and Pitts, 2009). Before ICDAS, certain concepts were already conducted (Ekstrand et al.), a relation between histological depth and the severity of caries was seen. (Ekstrand *et al.*, 1997) and some systems were explained in a systemic review by Ismail (2004) explained detection of cavitated or non cavitated enamel and/or dentine carious lesion should be explained on visual examination. These systems are not accurate, validity of correlation and validity with the depth in carious lesion can be seen. ICDAS system, based on the surface changes, on the other hand intends to measure both the histological depth as well as surface changes of visually occurring carious lesions (Figure 2.4). Codes in ICDAS ranges from 0 to 6 where 0 is healthy and 6 is cavitated tooth as seen clinically Figure 2.5 and described in Table 2.2.

0		Sound tooth surface
1		First visual change in enamel
2		Distinct visual change in enamel
3		Localised enamel breakdown due to caries with no visible dentine
4		Underlying dark shadow from dentine (with or without enamel breakdown)
5		Distinct cavity with visible dentine
6		Extensive distinct cavity with visible dentine

Figure 2.5 ICDAS codes for caries severity (Image provided by Dr Andréa G Ferreira Zandoná, Oral Health Research Unit, University of Indiana, USA)

Table 2.2 Clinical description of occlusal pits and fissures (Ismail *et al.*, 2007)

ICDAS Score	**Description of coronal primary caries**
Sound (0)	There should be no sign of caries after air drying for a long time (5 seconds). the Surfaces with developing defects (enamel hypoplasia, fluorosis), attrition, abrasion and erosion), and extrinsic or intrinsic stains will be recorded as sound.
First visual change in the enamel (1)	When seen as wet there is no sign of any change in colour attributable to the carious activity, but after air drying for a long time the carious opacity or discolouration (white or brown lesion) that is not compatible with the clinical appearance of the sound enamel of the tooth.
A distinct change in the enamel (2)	Wet teeth should be seen. When wet, there is a (a) carious opacity (white spot lesion) and/or (b) brown carious discolouration, it is wider than the natural fissure/fossa that is not reliable with the clinical appearance of the sound enamel.
Localized enamel breakdown due to caries without visible dentin or under the shadow (3)	The wet surface of the teeth may be the clear carious opacity (white spot lesion) and/or brown carious discolouration, it is wider than the natural fissure/fossa that is not reliable with the clinical appearance of sound enamel. Once treated for 5 seconds there is a loss of tooth structure at the entrance to, or within, the pit or fissure/fossa. If there is doubt, or to confirm the visual assessment, the CPI probe is gently applied to the surface of the tooth to make sure that the cavity appears confined to the enamel.
Underlying dark shadow from dentin with or without localized enamel breakdown (4)	This lesion appears as a shadow of coloured dentin visible through the surface of the enamel that appears intact, which may appear or show no signs of local breakdown (loss of continuity of the surface that does not appear dentin.
Distinct cavity with visible dentin (5)	Cavitation is opaque or discoloured enamel to expose the dentin underneath.
Extensive distinct cavity with visible dentin (6)	It is clear that the loss of the tooth structure, the cavity is deep and wide and can be seen clearly on the walls and at the base. An extensive cavity at least half the surface of the tooth or may reach the pulp.

2.1.8 ICDAS Reproducibility, Sensitivity, and Specificity

Sensitivity Is the ability to identify dental caries present in the oral cavity and report it as positive when they are present among the total number of cases already developed. While specificity is the ability to report negative when the disease is absent and classify it as negative, given the total number of cases in which the disease has not developed. The average number of cases are evaluated keeping in mind the present or absent disease through spot diagnosis.

Additionally, there are two major standards that should be considered for effective detection of dental caries: it should be reproducible (reproducibility) and valid (validity). The method of obtaining same results and agreeing on the results obtained from all tests done at different times conducted by separate examiners. One method of assessing this is Kappa's score or ICC (Intraclass Correlation Coefficient), compatibility among the examiners is evaluated. Evaluation ability of a method that is intended to be evaluated is the basic concept of validity. It is the calculation of correct results proportion considering the gold standard (the true and definitive diagnosis reference), which is considered as a final diagnostic reference (Diniz *et al.*, 2012). It was founded that the specificity in visual assessment is high, but the sensitivity and reproducibility are low. Calculations of sensitivity (Sn) and specificity (Sp) are summarized in Table 2.3.

Table 2.3 Calculation of sensitivity (Sn) and specificity (Sp) (Diniz *et al.*, 2012)

	Disease present (+)	**Disease absent (-)**	
Positive Test (+)	A	B	Total positive tests (A + B)
Negative Test (-)	C	D	Total negative tests (C + D)
	Sn %: A/ (A + C)	**Sp %: D/ (B + D)**	Total number (A+ B + C + D)

According to this data, strong support was provided to the conclusion made by ICDAS II to translate conventional codes of ICDAS I (code 3 & 4) to represent progressive development of tooth decay. Dental caries present in dentine, had a likelihood ratio (LR) that a code 2,3,4,5 or 6 is assigned with code 0 or 1. According to these ratios, ICDAS II codes 3 and 4 are interchangeable as shown as histological extension into dentine where higher ratio was found.

A study was using two examiners were conducted by Ekstrand et al to find relationship of the 7 points scoring of ICDAS I applied to the surfaces (occlusal and proximal etc) of extracted posterior teeth. As a result, strong association was drawn. The study also found that ICDAS I 7 points have greater accuracy compared to the histological scoring system

Martignon *et al.* (2007) found that ICDAS scores and histological criteria have excellent relationship between permanent teeth and primary teeth lesion. However, this study was performed on approximal surface carious lesions of permanent teeth and deciduous teeth assessed using ICDAS criteria and histological scoring system.

2.2 Caries Detection Devices

Various caries diagnostic methods have been utilized historically for the quantification and evaluation of any carious lesion. Periapical and bitewing radiographic investigations have been primarily used for diagnostic purposes, however other diagnostic methods and devices have also been studied which include ICDAS-II, Fiber-optic Transillumination (Vaarkamp *et al.*, 2000), Soprolife (Panayotov *et al.*, 2013), Qualitative light fluorescence (Ando *et al.*, 2001), Canary system (Abrams *et al.*, 2011) and others.

2.2.1 Laser Fluorescence

Electromagnetic waves having same amount of wavelength are omitted from laser light. Certain oral structures and other materials acquire fluorescence qualities. In fluorescence, a specific wavelength is carried out by the light but as soon as it gets absorbed by any material this wavelength increases many folds. In the course of absorption method, the major wavelength occurring because of energy is lost. The wavelength can be measurable when filtering technique is used. This length is equal to the characteristics of the material. In case where the properties are well known already as sound enamel or dentine, reference can be given. Presence of bacterial load or demineralization are the factors that can bring large effect in the wavelength. Developing carious lesion through fluorescence phenomena can be studied through longitudinal studies. Mineral loss associated with progression of carious lesion can be measured through this phenomenon.

2.2.2 Laser-induced Fluorescence (DIAGNOdent)

Laser fluorescence (LF) has been increasingly used in the detection procedure for caries over the past decade. In DIAGNOdent device (Kavo, Biberach, Germany), a

655-nm monochromatic light is released from an optical tip/sensor, (Lussi *et al.*, 1999a). The light beam passes through the enamel into the dentine or be partially scattered. A regular crystalline structure such as mature enamel is more transparent. The light can pass through the enamel layer with minimal aberration. If the enamel layer is more homogeneous, it will diffuse more light. The scattered part of the light raises either the dental hard substance itself or the so-called fluorophores inside the lesion, which are particles with a fluorescing property when excited by a specific wavelength of electromagnetic energy.

In the case of 655 nm, the fluorescence was identified as bacterial protoporphyrin's. Thus, when pore size is exceeded by critical size, the amount of fluorescence scattered in theory will be proportional to the amount of bacterial infection, pore size and the depth of the lesion (Konigm *et al.*, 1998; Buchalla *et al.*, 2008).

The measurements on the DIAGNOdent screen will give values between 0 (at least fluorescence) and 99 (at maximum fluorescence), making a quantitative measurement of caries possible (Fig. 1a, b). An additional newly developed LF device (DDPen) have 2 tips for both occlusal and approximal caries assessment Figure 2.6, although data supporting approximal caries detection between teeth contact point in vitro and in vivo is very limited at present.

Figure 2.6 A tapered wedge-shaped tip often allows approximal measurement. The probe has to be angulated correctly for introduction into proximal space (Pitts, 2009)

This device is not without drawbacks. There are many factors that could give false-positive readings in clinical practice and research. The factors include: the presence of stain (Francescut and Lussi, 2003), polishing pastes (Lussi and Reich, 2005) or adjacent filling materials (Lussi *et al*., 2006b), improper angulation of DDPen (Figure 2.7). Therefore, the tooth must be cleaned professionally and dried before examining with the LF device. The LF device is more sensitive to occlusal caries as compared with the approximal caries detection. Similarly, the detection ability for deep enamel or dentine caries is stronger than initial caries lesions. Due to the diverse nature and quality of the studies reported in the literature, in addition to the heterogeneity of the results and the range of comparators used, it is not possible to make a specific recommendation linked to the strength of evidence.

2.2.2(a) Cut-off values

The cut-off points found for the various degrees of caries extent are based on histological evaluation – judged under the microscope – where carious 'involvement'

representing small penetrations of the lesion into the enamel and dentin can be detected. Caution is indicated, however, before extrapolating these cut-offs into the clinical situation.

Varying cut-off values have been used and recommended by previous studies (Shi *et al.*, 2001a; Shi *et al.*, 2001b). However, these values are dependent on various factors which include, type of surface (smooth or fissure), physical properties (demineralization or remineralization), extent of lesion (lesion confined to enamel only, lesion involving enamel and dentin. According to the manufacturer's criteria: 0–14 denotes no caries, whereas 15-29 denotes enamel caries. Hamishaki *et al.* (2014) used the following cut-off values while using DDPen to evaluate carious lesion, 0-13 denotes no caries, 14-20 denotes initial enamel caries, and 21-29 denotes deep enamel caries. Jayarajan *et al.* (2011) used following criteria to measure artificial demineralization followed by remineralization of teeth: 3-7 denoted normal tooth, 7-9 denoted white spot lesion whereas a moment value of >9 denoted demineralization. Different cut-off values have been described in literature however till date no study has evaluated pre- and post- remineralization relevance of cut-off values. Multiple cut-off values can be utilized to explore the most suitable one according to any particular study.