Examining the Validity of a Synthesized Summary Measure for Caries Detected Using the International Caries Detection and Assessment System

By

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A thesis submitted in partial fulfillment of the requirements for the degree of

Doctor of Philosophy

Medical Sciences – Dentistry

University of Alberta

Abstract

Background: The International Caries Detection and Assessment System (ICDAS) was developed as a standardized system based on the best available evidence for detecting early and later stages of carious lesions. The aim of developing this system was to improve the quality of collected data on caries to be used for clinical research, clinical practice, and epidemiological studies. There is no synthesis about how studies that used the ICDAS summarized and reported caries and whether the system was used to its full potential.

Objectives: This dissertation aimed to review how studies that employed the ICDAS system reported patient caries level and to identify a potential summative measure that could reflects patient's caries level in children examined with the ICDAS. Values captured on specific surfaces from the ICDAS examination were examined as a short form of ICDAS to potentially be used to predict caries treatment need for children by classifying them into primary, secondary and tertiary prevention. In addition, the relationship between the proposed summative measures and oral health (OH) behaviors and oral health-related quality of life (OHRQoL) was evaluated.

Methods: Participants were 1 to 15-year-old children cohorts from Kuwait, Brazil, and Spain. Children's teeth were examined using the ICDAS. Multiple measures of central tendency and dentition specific indices (short ICDAS) were considered as potential summative measures. The relationship between the summative measures and number of caries lesions were evaluated. The agreement between the short and full ICDAS in classifying children into primary, secondary, and tertiary treatment need categories was examined. Sensitivity and specificity, predictive values, likelihood ratios, and the area under the receiver operating characteristic (ROC) curve were used

to measure the diagnostic accuracy of the short ICDAS compared to the full ICDAS. Initial analysis was conducted in the Kuwait sample, and the results were cross-validated using Brazil and Spain samples.

In addition, 13-14 years-old children completed a previously validated OH behaviors and OHRQoL questionnaires. Linear regression analysis was used to examine the relationship between dental caries measured using the total score of the full and the short ICDAS and both OH behaviors and OHRQoL.

Results: A total of 3,076 children participated in the present study. Total ICDAS score and mean ICDAS score showed a strong correlation with the number of caries lesions at different caries severity levels in both primary, mixed and permanent dentitions. The total ICDAS of 51 Buccal (B), 61B, 54 Occlusal (O), 55O, 64O, 65O, 74O, 75O, 84O, 85O surfaces in primary dentition and total ICDAS of 14O, 16L, 16O, 24O, 26L, 26O, 36B, 36O, 37O, 46O, 46B, 47O surfaces in permanent dentition or mixed dentition (if present) showed strong correlations (Spearman correlation coefficients >0.7) with the number of caries lesions at different caries severity levels.

The total score of the full ICDAS and the short ICDAS were highly correlated (ρ=0.901, $p<0.001$). The proposed short ICDAS and the full ICDAS showed a very good agreement on treatment need determination with Kappa scores of more than 0.833 in all dentitions. The short ICDAS showed excellent operating characteristics in all types of dentitions. The area under the ROC curve was more than 0.90 in primary dentition, 0.89 in permanent dentition, and 0.86 in mixed dentition. Lowest area under the ROC curve and sensitivity values were seen in discriminating between secondary and tertiary prevention.

The full and the short ICDAS showed similar relationships with oral health behaviors and OHRQoL. Children who brushed their teeth once a day or less had significantly higher levels of caries compared to children who brushed their teeth more than once a day. The frequency of sugar consumption was significantly associated with caries level. No significant association between flossing, use of mouthrinse, chewing gum and caries level was found. Both the total score of the full and the short ICDAS were significantly and moderately correlated with total CPQ_{11-14}, oral symptoms, and functional limitations. The total score of the full ICDAS was weakly correlated with the emotional well-being and not significantly correlated with the social well-being.

Conclusions: There is a lack of consistency in the reporting of caries in studies using ICDAS. Total ICDAS and mean ICDAS scores were the best summary measures of overall caries level at different dentitions. A short version of ICDAS consisting of selectively examined 10 surfaces in primary dentition and 12 surfaces in permanent dentition can give an excellent summary measure for patient's overall caries level with high diagnostic accuracy. The proposed short version of the ICDAS demonstrated a good diagnostic accuracy in classifying children into primary, secondary, and tertiary prevention groups according to their treatment need.

Preface

This thesis is an original work by Mohamed ElSalhy. The research project, of which this thesis is a part, received research ethics approval from the University of Alberta Research Ethics Board, Project Name “ICDAS Caries Index: An Index of Caries Severity and Treatment Need and its Relationship with Oral Health Habits and Oral Health Related Quality of Life”, No. Pro00050417, September 11, 2014 (Appendix I).

A version of Chapter 3 of this dissertation has been published as ElSalhy M, Alsumait A, Lai H, Almerich-Silla JM, Piovesan C, Flores-Mir C, Amin M: Identifying a Potential Summary Measure for Overall Caries Level in Children Examined with the International Caries Detection and Assessment System. Caries Res 2017; 51:568-575. I was responsible for the study design, data collection and analysis as well as the manuscript composition. Alsumait A assisted with the data collection and contributed to manuscript edits. Lai H, Flores-Mir C, and Amin M assisted in study design, data analysis, and contributed to manuscript edits. Almerich-Silla JM and Piovesan C provided the data they collected in Spain and Brazil for cross-validation of the results and contributed to manuscript edits.

Dedication

This thesis is dedicated to my parents and brothers who walked the journey with me

Acknowledgements

I am deeply appreciative of my supervisor Dr. Maryam Amin for her infinite guidance during the past 4 years. Her passion for knowledge and her work ethic were contagious. Thank you for trusting me as a researcher and supporting my ideas. Thank you for the unlimited support to achieve my goals. My growth as an independent researcher and future faculty member should be attributed to you.

I would also like to thank my committee members, Dr Carlos Flores-Mir and Dr Hollis Lai, for their guidance and support to help me complete my research. Their knowledge and experience added a huge value to my work.

I express sincere gratitude to Dr. Aishah Alsumait and Dr. Sahar Behzadi who dedicated their time and effort to help me through this dissertation journey. I am deeply appreciative of the support I have received from friends, family, colleagues, administrators, and faculty during my Ph.D. training.

I would like to acknowledge the generous financial support I received during my Ph.D. from Alberta Innovates Health Solutions (AIHS), The Killam Trusts, Alpha Omega Foundation, Women and Children's Health Research Institute (WCHRI), Government of Alberta, School of Dentistry, Faculty of Graduate Studies and Research, and Faculty of Medicine and Dentistry.

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List of Abbreviations

CPQ_{11-14}: Child Perception Questionnaire among 11- to 14-year-old

d/D: decayed

dmf: decayed, missing, or filled primary teeth

DMF: decayed, missing, or filled permanent teeth

dmft/DMFT: decayed, missing, or filled teeth index

dmfs/DMFS: decayed, missing, or filled surfaces index

ICDAS: International Caries Detection and Assessment System

NPV: Negative predictive values

LR-: Negative likelihood ratio

LR+: Positive likelihood ratio

OH: Oral Health

OHRQoL: Oral Health-Related Quality of Life

OHSI: Oral Health Status Index

PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-Analyses

ROC: Receiver Operating Characteristic

WHO: World Health Organization

1. Chapter One

Introduction

1.1 BACKGROUND

1.1.1 Dental Caries

Dental caries is a behavior-associated multifactorial chronic disease. It is the outcome of a complex interaction between the tooth, bacteria, and diet. It is affected and modulated by personal and environmental factors [Fejerskov and Kidd, 2009]. Fisher-Owens et al. created a multi-level conceptual model to understand oral health outcomes in children based on over 25 years of collective knowledge developed on dental caries [Fisher-Owens et al., 2007]. Fisher-Owens's model describes five domains that affect caries occurrence and outcomes. These five domains are 1) genetic and biological factors, 2) the social environment, 3) the physical environment, 4) health behaviors, and 5) dental and medical care. The model acknowledges the presence of a complex interplay between different determinants [Fisher-Owens et al., 2007].

Dental caries is one of the world's most prevalent chronic diseases [Petersen, 2009]. It is 5 times more common than asthma, 4 times more common than early childhood obesity, and 20 times more common than diabetes [American Academy on Pediatric Dentistry and American Academy of Pediatrics, 2008]. Oral diseases, including caries, comprise 25 percent of the global chronic disease burden [G. B. D. Collaborators, 2016]. Poor oral health and the presence of oral diseases have a negative effect on general health and is associated with many other chronic

conditions like diabetes and cardiovascular disease [Michalowicz et al., 2013]. In addition, poor oral health affects medical care utilization and cost [Wall and Vujicic, 2015].

1.1.2 Diet and Dental Caries

The relationship between diet and caries was proposed as early as the 1880s when Millers described caries as the outcome of an action of microorganisms that adhere to the tooth surface on fermentable carbohydrates [Miller, 1883]. Later, the relationship between caries and diet, specifically sugars, was confirmed through many major observational/epidemiological studies; the World War II studies are an example. Strict food rationing in Japan during the war made sugar virtually unavailable. After the war, the mean decayed, missing, or filled teeth (dmft/DMFT) for children in 1950 was lower than before the war values. These values returned to the 1940 levels after the war when it was measured in 1957 [Takeuchi, 1961]. Similar results were seen in Norway during the German occupation in WWII [Toverud, 1957].

Human experimental studies on the effect of diet on dental caries are limited. The best-known attempt is the Vipehölm study. It was conducted in Sweden between 1945 and 1952 on mentally sick patients [Gustafsson et al., 1954]. Although considered unethical by today's standards, the study conclusions were very profound and affected the current thoughts about sugars and caries [Burt and Eklund, 2005]. The study concluded that sugar consumption increases caries activity and the risk is greatest if it is taken between meals. The study also concluded that increase in caries shows great variability between individuals and caries can still occur in the absence of sugars or high dietary carbohydrates [Gustafsson et al., 1954].

The establishment of the relationship between sugars and caries was in the pre-fluoride era. During that time, caries was widespread in high-income populations because of the availability of cariogenic food. After water fluoridation and the introduction of oral hygiene practices, the relationship between caries and sugar has changed. Many cohort studies from fluoridated countries concluded weak or no relationship between frequency and amount of sugar and caries [Burt and Pai, 2001; Rugg-Gunn et al., 1984; Szpunar et al., 1995]. They also concluded that consumption of sugars is a major factor of caries only in susceptible populations (i.e. populations with low exposure to fluoride and poor oral hygiene practices). In populations at risk, higher frequency of sugar consumption, especially when used between meals, has been associated with higher levels of caries [Garcia-Closas et al., 1997; Guido et al., 2011; Johnson et al., 2009; Vanobbergen et al., 2001].

Ecological studies on the dose-response relationship between the amount of sugar consumption and caries concluded that the relationship between sugar and caries is linear only in countries that consume 15-35 kg/year/capita and the relationship is lost in communities with lower or higher rates. As most countries consume sugars more than 35 kg/year/capita, this can explain the lost relationship between sugar and caries. Another possible explanation is that caries progression is slower with fluoride exposure from different sources and most of the old studies, which examined the relationship between caries and sugars used cavitation as a definition of caries with no stages of development [Sheiham, 2001].

Soft drinks or carbonated sugar-sweetened drinks are considered highly cariogenic. These products are acidic and contain a high concentration of sugars. Both can lower the plaque PH and enhance demineralization of tooth structure and caries formation. High soft drink consumption

was associated with greater extent and severity of dental caries [Ismail et al., 1984; Lim et al., 2008; Tahmassebi et al., 2006]. Soft drink consumption is one of the target priorities for World Health Organization (WHO) because of its impact that extends beyond dentistry as it is implicated as part of the obesity epidemic in children [World Health Organization, 2016].

1.1.3 Oral Hygiene Habits and Dental Caries

Oral hygiene can be defined as the practice of keeping the mouth clean and healthy to prevent oral diseases [Centers for Disease Control and Prevention, 2009]. The main purpose of different oral hygiene habits is to prevent plaque accumulation, reduce bacterial load, and strengthen tooth structure to prevent caries and periodontal disease. Proposed oral health habits include tooth brushing, use of fluoridated toothpaste, flossing, using of mouthrinse, and gum chewing.

Tooth brushing is a proposed individual plaque control method and a mode for delivery of fluoride through toothpaste. The evidence that supports plaque control for the prevention of caries was extracted from the Karlstad studies in the 1970s. In these studies, rigorous professional plaque control every two weeks for children was associated with 98% caries reduction [Axelsson and Lindhe, 1974, 1975]. Other studies confirmed the caries preventive effect of plaque control by health professionals [Agerbaek et al., 1978; Ashley and Sainsbury, 1981; Hamp et al., 1978]. Personal tooth brushing is an expansion of these conclusions. However, there is no evidence supporting tooth brushing as a behavior *per se* in caries prevention. The current evidence is that brushing with fluoridated toothpaste is associated with caries reduction. The frequency of toothbrushing with toothpaste was documented to be

associated with fewer new non-cavitated and cavitated caries surfaces [Chankanka et al., 2011; Lakhanpal et al., 2014; Levine et al., 2007].

Flossing is another proposed individual plaque control method that targets plaque accumulation in interproximal areas. While dental flossing has an additional benefit for prevention of gum disease, there is weak evidence of its impact on dental caries [Sambunjak et al., 2011]. Theoretically, removal or disruption of interproximal plaque should help prevent both caries and periodontal disease. However, there is no convincing evidence to support its effectiveness in caries prevention. Multiple Cochrane reviews and systematic reviews concluded that there are no quality studies that examined the effectiveness of flossing or flossing in addition to toothbrushing on proximal caries prevention [Poklepovic et al., 2013; Sambunjak et al., 2011]. Weak evidence supports that flossing plus toothbrushing may be associated with a small reduction in plaque levels [Poklepovic et al., 2013; Sambunjak et al., 2011]. Recently, the FDI World Dental Federation removed flossing as part of its recommended practices for prevention of caries due to the weak evidence supporting it [Pitts and Zero, 2016].

Toothpaste is a mode of topical fluoride delivery for caries prevention. The evidence supporting the effectiveness of using fluoridated toothpaste in preventing caries compared to non-fluoridated toothpaste is based on many high-quality trials [Marinho et al., 2003c]. A Cochrane meta-analysis of 70 studies (involving 42,300 children) showed that fluoride toothpaste use reduces the DMFS by 24% [Marinho et al., 2003c]. The caries-preventive effect of fluoride toothpaste is correlated with fluoride concentrations [Walsh et al., 2010]. Concentrations of 440/500/550 ppm fluoride and below showed no significant caries preventive

effects. Concentrations of 1000/1055/1100/1250 were associated with 23% reduction in caries while 2400/2500/2800 ppm were associated with 36% reduction [Walsh et al., 2010].

Mouthrinse is also used as a mode for the delivery of topical fluoride for caries prevention as well as antimicrobials to prevent periodontal disease. Multiple Cochrane reviews were conducted on the effectiveness of fluoride mouthrinse on caries levels [Marinho et al., 2016; Marinho et al., 2003b, a]. It has been concluded that supervised regular use of fluoride mouthrinse can reduce caries rates in children and adolescents. A metanalysis of 35 trials showed 23% reduction in DMFT and 27% reduction in DMFS in permanent teeth with fluoride mouthrinse compared with controls (i.e. placebo or no mouthrinse) [Marinho et al., 2016]. The effectiveness was seen with the use of at least 230 ppm of fluoride daily [Marinho et al., 2016]. Most of the current evidence on fluoride mouthrinse is based on permanent teeth as mouthrinse is not recommended for young children due to the risk of swallowing [Marinho et al., 2016].

Gum chewing *per se* does not affect caries experience if it does not contain xylitol as an active ingredient. A total of 6 grams of daily doses of xylitol is needed for the caries-preventive effect [Makinen, 2011; Milgrom et al., 2006; Soderling, 2009]. One study concluded that chewing sugar-free gum had shown to promote dental health only when the chewing time is 20 min long [Dodds, 2012]. Xylitol chewing gum was recommended for high-risk children to reduce *Streptococcus mutans* level as well as to stimulate salivary flow rate.

1.1.4 Oral Health-Related Quality of Life and Dental Caries

Oral health was recently defined by the FDI World Dental Federation as “multi-faceted and includes the ability to speak, smile, smell, taste, touch, chew, swallow and convey a range of

emotions through facial expressions with confidence and without pain, discomfort, and disease of the craniofacial complex" [FDI World Dental Federation, 2016]. Oral health-related quality of life (OHRQoL) is defined as a "subjective evaluation that reflects people's comfort when eating, sleeping and engaging in social interaction; their self-esteem; and their satisfaction with respect to their oral health" [Scully, 2000]. It is based on information provided by individuals and reflects the impact of oral health status on various aspects of life [Gherunpong et al., 2006]. The higher and improved quality of life is the ultimate goal of any health-related intervention or service. Measures of OHRQoL provide essential information when assessing the treatment needs of individuals and populations, as well as when making clinical decisions and evaluating interventions, services, and public health programs [Jokovic et al., 2002; Kramer et al., 2013; Krisdapong and Sheiham, 2014; Palencia et al., 2014].

Many domains are used to measure OHRQoL: oral symptoms/oral problems, functional limitations/physical functioning, social well-being/social functioning and emotional well-being/emotional functioning, and role functioning [Huntington et al., 2011; Jokovic et al., 2002]. The domains are interrelated and influence one another. Children's and adults' psychological and functional measures are related [Alsumait et al., 2015; Eccleston and Malleson, 2003; Mohlin et al., 1991]. Oral health status is thought to have a direct impact on overall children's OHRQoL [Barbosa and Gaviao, 2008].

The relationships between malocclusion and orofacial deformities and overall OHRQoL, especially in relation to emotional and social well-being domains, are well-documented [Broder and Wilson-Genderson, 2007; Foster Page et al., 2005; Gherunpong et al., 2004]. Dental aesthetics and facial appearance are also examined factors that affect OHRQoL [Broder and

Wilson-Genderson, 2007]. In addition, OHRQoL can be affected by the perceived need for dental care and poor perceived oral health [Jensen et al., 2008].

Few studies have examined how caries affects school-age children's OHRQoL. Children from low caries-level communities have all components of OHRQoL affected by caries [Robinson et al., 2005] while caries affected only oral symptom and functional components of OHRQoL in high-caries level communities [Brown and Al-Khayal, 2006]. Additionally, social and emotional well-being components were less likely to be affected by caries in very young children [Gherunpong et al., 2004]. Alsumait et al. [2015] examined the impact of different components of the dmft/DMFT on OHRQoL in a high-caries population. They found that the number of fillings was the only predictor of oral symptoms while the number of carious teeth was the main predictor for functional limitations. In addition, missing teeth was the only predictor for the emotional well-being component of OHRQoL [Alsumait et al., 2015].

1.1.5 Clinical Caries Detection and Classification

Caries detection and classification is an ongoing progressive process that has developed over time, and changes as the knowledge about caries improve. Similar to other diseases, detection and classification of caries are critical to identifying cases that need to be managed/treated. It is also important to study factors that contribute to caries formation and to examine the effectiveness of preventive approaches to caries prevention. In addition, it is important for training dentists and to describe the distribution of the caries within the oral cavity.

1.1.5.1 Establishment of caries diagnostic criteria and measurements

In mid-1800 to early 1900, G.V. Black established the fundamentals of caries detection and classification. According to Black, caries can be identified as a stickiness of the tooth surface. The exact definition is "A sharp explorer should be used with some pressure, and if a very slight pull is required to remove it, the pit should be marked for restoration even if there are no signs of decay" [Black, 1924]. Using Black's definition, teeth or surfaces are either diseased (i.e. have caries) or healthy. Black categorized carious lesions based on the type of tooth affected (anterior or posterior tooth) and the location of the lesion (e.g. lingual, buccal, occlusal, etc.). His visual-tactile detection of caries and location classification are still in use today.

1.1.5.2 World Health Organization Oral health surveys – Basic Methods

About 50 years after Black's classification, the WHO published the first edition of the WHO Oral Health Surveys – Basic Methods in 1971. This was followed by four revisions with the latest edition published in 2013. These publications aimed to provide a sound basis for assessing the oral health status and future needs of different populations. The WHO recommends that carious lesions are diagnosed by at the level of cavitation. Therefore, only cavitated lesions are considered. The exact description of caries lesions is "an unmistakable cavity, undermined enamel, or a detectably softened floor or wall" [World Health Organization, 2013]. The WHO also recommends using a community periodontal index probe during clinical examination. The rationale behind only recording obvious cavitated lesions and ignoring non-cavitated lesion was the difficulty of obtaining a reliable diagnosis of the non-cavitated caries lesions. In addition, non-surgical management of non-cavitated lesions was not available at the time that the survey methods were introduced. Although the WHO approach is the most commonly used method, it

underestimates the level of caries by excluding non-cavitated lesions [Honkala et al., 2011; Pitts, 2004]. Nor does it allow non-surgical interventions to manage non-cavitated lesions. Therefore, the WHO methods are not aligned with current advancements in caries management and prevention modalities [Fejerskov and Kidd, 2009].

1.1.5.3 D1-D3 caries progression scale

Measuring different levels of caries from a non-cavitated lesion to pulpal involvement was proposed as early as 1953 during the artificial water fluoridation Tiel-Culemborg experiment in the Netherlands [Backer Dirks et al., 1961]. Caries was classified into four grades. These grades were:

- Grade I: A minute black line at the bottom of the fissure
- Grade II: Grade I with a white zone along the margins of the fissure.
- Grade III: A small break in the continuity of the enamel with or without undermined margins.
- Grade IV: A large cavity more than 3 mm wide.

The scale and the criteria for diagnosis were further developed and first published by the WHO in 1979 as part of their guide to oral health epidemiological investigations [Burt and Eklund, 2005]. Although it consisted of four grades, it was usually referred to as the D1–D3 scale based on the diagnostic threshold of initial (D1), enamel (D2), dentinal (D3). Criteria for caries diagnosis using the D1-D3 scale are summarized in Table 1.1.

Table 1.1. Criteria for caries diagnosis using the D1-D3 scale

Code	Category	Diagnostic criteria
0	Surface Sound	No evidence of treated or untreated clinical caries (slight staining allowed in an otherwise sound fissure).
D1	Initial Caries	No clinically detectable loss of substance. For pits and fissures, there may be significant staining, discoloration or rough spots in the enamel that do not catch the explorer, but the loss of substance cannot be positively diagnosed. For smooth surfaces, these may be white, opaque areas with loss of luster.
D2	Enamel Caries	Demonstrable loss of tooth substance in pits or fissures, or on smooth surfaces, but no softened floor or wall or undermined enamel. The texture of the material within the cavity may be chalky or crumbly, but there is no evidence that cavitation has penetrated the dentin.
D3	Caries of Dentin	Detectably softened floor, undermined enamel or a softened wall, or the tooth has a temporary filling. On approximal surfaces, the explorer point must enter a lesion with certainty.
D4	Pulpal Involvement	Deep cavity with probable pulpal involvement. The pulp should not be probed. (Usually included with D3 in data analysis)

Including both cavitated and non-cavitated lesions in the classification gives a more accurate and realistic picture of the total caries experience in the examined individuals. It was shown that recording of non-cavitated lesions had increased the diagnostic accuracy by 100% [Amarante et al., 1998; Pitts and Fyffe, 1988]. It also allows non-surgical management of non-cavitated lesions. The D1-D3 recording system was used in many studies where a detailed description of caries levels was needed, especially studies evaluating caries progression. Although many studies have shown that trained and calibrated dentists can accurately diagnose non-cavitated lesions with high reliability, researchers have until recently used visual-tactile means to record caries as a dichotomous condition where caries was only noted when it reached the level of dentinal involvement D3 [Burt and Eklund, 2005]. The main limitation of this

progression scale system is that it was proposed clinically without histological confirmation. Meaning, it is a basic clinical description of lesions with no specific method to reach a diagnosis.

1.1.5.4 Ekstrand et al. caries progression classification

Ekstrand et al. (1995) developed a visual scoring system to assess the depth of caries lesions that corresponds to the histological progression of the disease. The system includes both cavitated and non-cavitated lesions and classifies caries into 5 categories [Ekstrand et al., 1995; Ekstrand et al., 1997]. These categories are

- Level 1: “No or slight change in enamel translucency after prolonged air-drying (5 s)”.
- Level 2: “Opacity or discoloration hardly visible on the wet surfaces, but distinctly visible after air-drying.”
- Level 3: “Opacity or discoloration distinctly visible without air-drying.”
- Level 4: “Localized enamel breakdown in opaque or discolored enamel and/or grayish discoloration from the underlying dentin.”
- Level 5: “Cavitation in opaque or discolored enamel exposing dentin”.

Although the classification has been evaluated histologically, it has not been used clinically, and its prognostic impact in a clinical setting has not been confirmed. Compared to the D1-D3 scale and WHO systems, Ekstrand et al. classification provides more detailed and validated information. These criteria were later incorporated into the International Caries Detection & Assessment System (ICDAS).

1.1.5.5 Nyvad et al. caries activity classification

Nyvad et al. [1999] suggested focusing on the lesion activity rather than depth. They developed different nominal diagnostic categories that included cavitation and activity. Based on their criteria, caries lesions are one of seven diagnostic categories. These categories are

- Active non-cavitated
- Active cavitated
- Inactive non-cavitated
- Inactive cavitated
- Filling
- Filling with active caries
- Filling with inactive caries

Nyvad et al. system used surface characteristics of caries lesions to reach a diagnosis regarding the activity. Activity was evaluated by surface texture and surface integrity. Active early lesions are soft or leathery. They have a whitish/yellowish opaque surface exhibiting a chalky or neon-white appearance. They are characterized by the presence of a cavity or micro-cavity on the surface. The color of an inactive lesion may vary from whitish to brownish or black. They are shiny and feel hard on gentle probing.

1.1.5.6 The International Caries Detection & Assessment System (ICDAS)

The International Caries Detection & Assessment System (ICDAS) was developed in 2002 through a collaboration of international academic centers. Later the ICDAS Foundation was established. The system incorporates a group of existing caries classification systems like

Ekstrand et al. and Nyvad et al. criteria for caries diagnosis. The system was designed as an integrated classification system that includes both assessments of lesion extent and activity. It was also validated histologically.

The ICDAS was developed as a standardized system based on the best available evidence for detecting early and later stages of carious lesions [Pitts, 2004]. The aim of developing this system was to improve the quality of collected data on caries to be used for clinical research, clinical practice, and epidemiological studies [Pitts, 2004]. Regarding its use for epidemiological research, ICDAS was designed to be practical and easy to use. The system detects cavitated and non-cavitated lesions at different stages with acceptable reliability [Ismail et al., 2007; Pitts, 2004]. ICDAS detects and categorizes early enamel lesions and dentine lesions according to their progression stage [Pitts, 2009a, b]. The validity and reliability of ICDAS have been previously reported [Agustsdottir et al., 2010].

Based on visual inspection, ICDAS records caries in combination with the type of restoration based on a six-level ordinal scale [Ismail et al., 2007; Pitts, 2004; Pitts et al., 2013]. Every surface is coded with two digits. The first digit is a nominal code of a preventive or restorative treatment and the second digit is an ordinal code of caries (Table 1.2). By measuring non-cavitated and cavitated lesions as well as recurrent carious lesions, ICDAS overcomes the shortfalls of the commonly used WHO caries examination criteria [Honkala et al., 2011; Pitts, 2004]. ICDAS is progressively gaining international acceptance for dental health surveys and clinical practice [EGOHID II, 2008; Young et al., 2015].

Table 1.2. Coding System for ICDAS (Ismail et al., 2007)

Restoration and Sealant Codes	Caries Codes
0 = Not sealed or restored 1 = Sealant (partial) 2 = Sealant (full) 3 = Tooth colored restoration 4 = Amalgam restoration 5 = Stainless steel crown 6 = Porcelain, gold, PMF crown or veneer 7 = Lost or broken restoration 8 = Temporary restoration	0 = Sound tooth surface. 1 = First visual change in enamel. 2 = Distinct visual change in enamel. 3 = Enamel break down. No dentin visible 4 = Dentinal shadow (not cavitated into dentin) 5 = Distinct cavity with visible dentin. 6 = Extensive distinct cavity with visible dentin.
	Missing Teeth
	97 = Extracted due to caries 98 = Missing for other reason 99 = Un-erupted P = Implant

1.1.6 Caries Measurement at Population Level

To study caries, its distribution, and to compare its level between different populations, caries examination measurements need to be put together in some systematic fashion. Therefore, an index is needed so that the disease in a population is precisely expressed. An index is a numerical scale with upper and lower limits, with scores on the scale that corresponds to specific criteria [Burt and Eklund, 2005]. Ideally, the index should be valid, reliable, clear, simple and objective, sensitive to small changes, and acceptable [Burt and Eklund, 2005]. As dental caries has different stages of progression (from demineralization to cavitation), it is crucial that diagnostic criteria for caries judgment to be clear.

Many indexes for measuring caries were developed over time. During the 1920s to the early 1930s, percentages and proportions of carious permanent molars were introduced as a summary measure to describe caries [Ainsworth, 1933; Hyatt, 1920]. Many of those indexes did not survive until Dean's fluoride studies in the 1930s. In Dean's studies, counts of teeth in the

mouth with obvious caries (i.e. cavities) were used [Dean et al., 1942]. Later, filled and missing teeth due to caries were added in, so that the index score reflected caries experiences and included all teeth that had been attacked by caries. This index was called the DMF (Decayed, Missing due to caries, and Filled) index and was extensively used to measure caries experience in studies among children in Hagerstown, Maryland, USA, in the 1930s [Klein et al., 1938]. Until today, the DMF index is the most used of all dental indexes as a population measure of caries.

The DMF index was originally proposed for permanent teeth. It could be applied to teeth as a whole (DMFT), or applied to all surfaces of the teeth (DMFS). The DMFT score can range from 0 to 32, in whole numbers, while the DMFS score for a group can range from 0 to 148. The original intention to score D only when there was cavitation.

Although the level of caries detection from cavitated to non-cavitated lesions has changed over time and with the wide use of the ICDAS, the dmft/DMFT or dmfs/DMFS are still the most commonly used indices [de Amorim et al., 2012; ElSalhy et al., 2013; Fontana et al., 2014; Honkala et al., 2011; Lim et al., 2015; Pinto-Sarmento et al., 2016; Runnel et al., 2013]. However, this index does not explore the full scale of collected information as it gives equal value for the different stages of caries and does not take full advantage of ordinal scales used in different systems that include different stages of caries.

Using different indices has an impact on epidemiological data and health care policy. Capturing more information using more detailed and more developed indices improve the accuracy of the evaluation of the current status and can better inform policy. Accurate capture of information is critical for designing health promotion programs and interventions. It is important

when evaluating the benefits of preventive interventions and in evaluating the performance of different oral health systems. Rich data are vital for the estimation of the resources needed to address the needs of the population. It is critical for the determination of the workforce structure. Using standardized indices allows reasonable comparisons between different patients or populations as well as monitoring progress of the different programs and polices overtime. On the other hand, using different indices has some disadvantages. Although new or different indices would provide more information, using different indices may not allow monitoring of the health status over time. If the new indices do not allow comparisons with earlier indices used in the existing epidemiological data, trends in the health status can be lost. This is very crucial and has to be examined when a change in indices use is planned. In addition, similar indices used in needs assessments before development of an intervention or a policy change have to be used later on during the evaluation of the intervention or policy changes in order to be able to identify changes in health status.

1.1.7 Assessing Caries Treatment Need

Many approaches and methods have been used to assess dental treatment needs. These approaches range from a general assessment of the need to more detailed approaches. The majority of these indices were proposed in specific studies, yet only a few have been used, and even fewer are still in use.

1.1.7.1 Numeric measures of treatment need

In addition to assessment of caries experience, the DMF indices are the most commonly used numerical measures to assess treatment needs. Dental treatment need was evaluated through

the number of teeth/surfaces with caries (the D component of DMF) [Helminen and Vehkalahti, 2003]. The total number of carious teeth/surfaces reflects the number of teeth/surfaces that need to be treated with no specification on the type of treatment needed. The unmet dental treatment need was also derived from the DMF index and is calculated as the proportion of decayed teeth to caries experience of teeth or surfaces (D/DMF) [Bolin and Jones, 2006; Mitchell et al., 2003]. The index reflects availability and access to treatments. By treating caries lesions, the unmet dental treatment need index goes toward zero.

Another proposed numerical measure of treatment need is the Oral Health Status Index (OHSI). The OHSI is an integrative index combing DMFS, gingival inflammation, calculus, and periodontal disease [Spolsky et al., 2000]. This index gives one numeric score for each individual ranging from -55 to 100 [Spolsky et al., 2000].

1.1.7.2 Proportion of specific dental treatments need

The WHO Oral Health Surveys-Basic Methods also includes assessment of normative dental treatment needs. The need is assessed individually. It includes six types of basic needs: dental caries management (extraction or restoration), traumatic dental injuries, enamel defects, periodontal, orthodontic, and prosthodontic problems. The WHO assessment is a general assessment of oral health care needs and not caries specific. The outcome of the assessment is the proportion of the population with different needs.

Some studies used the percent of people that need a specific dental treatment that is specific to caries management like the need for extractions or restorations [Dash et al., 2002; Mitchell et al., 2003].

1.1.7.3 Urgency of care need assessment

Few studies have used urgency of care to classify the population based on treatment need [Bolin and Jones, 2006]. In these studies, objective assessments and self-reports were used to determine urgency. The American Dental Association also proposed ranking treatment need based on urgency [Adegbembo et al., 2002; Council on Dental Health Planning, 1978]. The system ranks dental treatment needs into five categories. These categories are

- Class I: "No Visible Dental Problem. No problem visualized."
- Class II: "Mild Dental Problems. Small carious lesions or gingivitis, the patient is asymptomatic. The condition is not urgent."
- Class III: "Severe Dental Problems. Large carious lesions, chronic abscess, or extensive gingivitis, or a history of pain. The need for dental care is urgent."
- Class IV: "Emergency Dental Treatment Required. Acute injury, oral infection, or other painful condition. An immediate dental referral is indicated."

Another urgency-based approached defined three categories: low, moderate, and high-urgency need. Low urgency includes patients with no or early stage of the disease. Moderate urgency includes those with cavitated, asymptomatic decay, or moderate gingivitis while high-urgency need includes those with infection, tooth or jaw fracture, pulpitis, or severe periodontal conditions [Bolin and Jones, 2006].

1.1.7.4 Preventive approaches for treatment need levels

As most original approaches to examine caries and assess treatment need only considered managing caries through restoration and with the advancement of prevention and minimal

intervention approaches in managing caries, preventive-based need assessments were developed. Mann et al. classify treatment needs into six categories: 1) no treatment needed, 2) preventive treatment, 3) fissure sealants, 4) initial conservative restorations, 5) advanced conservative restorations, and 6) radical treatments [Mann et al., 1993]. Another attempt classified treatment need into preventive, restorative, and rehabilitative needs [Adewakun and Amaechi, 2005]. Preventive needs included diet modification, prophylaxis, oral hygiene instructions, and sealants. Restorative needs included restorations, pulp treatment, and crowns while rehabilitative needs included tooth removal.

1.2 PROBLEM STATEMENT

Having a reliable and reproducible measure of caries that include more information than the number of lesions will improve reporting and monitoring of caries initiation and progression, which in turn will help evaluating oral health promotion and caries prevention interventions more accurately. In addition, the classification and assessment of treatment need are essential for estimation of required workforce, efficient allocation of resources, estimation of costs of oral health care programs, and identification of treatment modalities that match the needs. Therefore, development of a summary measure that enables measuring both caries severity and treatment need at the same time should facilitate the identification of caries status among communities and oral health needs of different populations and their sub-segments. This will also facilitate more appropriate allocation of resources to community-based oral health programs and target populations or communities with greatest caries level and treatment needs as well as for policymaking. The ICDAS, as an examination system, captures rich information on caries.

However, no synthesis exists about how the information captured is being used and whether the system is being used to its full potentials or not.

1.2.1 Research Questions

1. How do different studies that employed the ICDAS report patient caries level summaries?
2. What summary measure for the ICDAS examination accurately and reliably reflect patient's caries severity in different dentitions (primary, mixed, permanent)?
3. How can the ICDAS examination be used to classify patients according to caries treatment needs?
4. What is the relationship between caries, measured by the new proposed summary measure, and oral health habits?
5. What is the relationship between caries, measured by the new proposed summary measure, and OHRQoL?

1.2.2 Objectives

The objectives of this dissertation were

1. To review how studies that employed the ICDAS system reported patient caries level summaries.
2. To identify a potential summative measure that reflects patient's overall caries level in children examined with the ICDAS.
3. To examine how specific representative surfaces (Short ICDAS) from the ICDAS examination can be used to predict caries treatment need for children by classifying them into primary, secondary and tertiary prevention.

4. To examine the relationship between oral health behaviors and caries using the total score of the full ICDAS and a short form of ICDAS as patient summary measures of caries.
5. To evaluate the association between caries measured using the total score of the full ICDAS and a short form of ICDAS and children's OHRQoL.

The next five chapters address and discuss the above objectives. Objective 1 was addressed through a systematic review of the literature in Chapter 2. Objective 2 was addressed in Chapter 3 where different measures were examined as potential summative measures for the ICDAS using original data collected from Kuwait and cross-validated using data from Spain and Brazil. Objective 3 was addressed in Chapter 3 and Chapter 4. In Chapter 3, representative surfaces were identified while the selected surfaces (Short ICDAS) were examined to predict treatment need compared to the full ICDAS in Chapter 4. Chapter 5 and Chapter 6 examined objective 4 and 5, respectively, through a cross-sectional study. In these chapters, information on oral health habits and oral health-related quality of life were collected from children in addition to clinical examination using ICDAS. Chapter 7 is a general discussion chapter on the results of all the dissertation chapters collectively.

2. Chapter Two

Caries Reporting in Studies that Used the International Caries Detection and Assessment System: A Scoping Review

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A version of this chapter has been accepted for publication in Community Dentistry and Oral Epidemiology Journal

2.1 ABSTRACT

Objective: To explore how caries was reported in studies that employed the International Caries Detection and Assessment System (ICDAS).

Methods: A systematic database search up to August 2017 was carried out using PubMed, Ovid MEDLINE, Cochrane library, and ISI Web of Science electronic databases. Only studies that used the ICDAS for dental caries examination were included. Studies were excluded if the examination was done only for the validation or the calibration of the ICDAS and/or if the examination was not done for the whole dentition. Related measures used to report caries were considered.

Results: A total of 126 papers were finally selected. Forty-four different synthesis measures were used to report caries. Most of the studies used a combination of multiple measures to report patient's caries level. These reporting measures clustered into five main groups: number of individual ICDAS scores, number of decayed surfaces/teeth, number of decayed, missing, and filled teeth/surfaces (dmft/DMFT, dmfs/DMFS), number of decayed and filled teeth/surfaces

(dft/DFT, dfs/DFS), and measures of central tendency and dispersion. The number of decayed surfaces and individual ICDAS scores were the most commonly used measures. Six different dmft/DMFT and seven different dmfs/DMFS combinations were synthesized from the ICDAS examination. Three studies used mean ICDAS score, two studies used mean ICDAS score of carious teeth and two studies used the maximum ICDAS score. The total ICDAS score was used only once.

Conclusions: There is a lack of consistency in the reporting of caries in studies using ICDAS. Most studies presented caries using categorical characteristics of the ICDAS.

2.2 INTRODUCTION

The International Caries Detection and Assessment System (ICDAS) was developed as a standardized comprehensive clinical examination system for detecting carious lesions at different stages of development [Pitts, 2004]. It was aimed to improve the quality of collected data on caries to be used for clinical practice, education, research, and public health [Pitts, 2004]. The system categorizes caries lesions according to their progression stage into six-level ordinal scale categories in combination with the type of existing restorations. Every surface is coded with two digits: a preventive or restorative treatment code and a caries code [Ismail et al., 2007; Pitts, 2004; Pitts, 2009a, b; Pitts et al., 2013]. Compared to the commonly used WHO caries examination criteria, the ICDAS measures enamel caries, non-cavitated and cavitated lesions, and recurrent carious lesions. It also records restorations and sealants [Honkala et al., 2011; Pitts, 2004].

After its development, the ICDAS was a recommended system for dental health surveys and clinical practice and was incorporated into the European Global Health Indicators Development Program [EGOHID II, 2008]. Recently, the system was adopted by the American Dental Association (ADA) as the ADA Caries Classification System (CCS) [Young et al., 2015]. The system was further developed to incorporate caries management and decisions when managing caries at both individual and public health levels by the development of the International Caries Classification and Management System (ICCMS) [Ismail et al., 2015b; Pitts et al., 2013]. Both ICDAS and ICCMS employ an evidence-based preventive-oriented approach in classifying and managing caries [Ismail et al., 2015b; Pitts et al., 2013].

The system is under continuous development to further improve the capture of caries-related information and to make the clinical examination system more practice-friendly. Yet, the system does not offer any index or summary measure to report patient's caries level or to summarize patient's caries status. Reporting caries level is important when comparing different patients or populations as well as studying factors contributing to caries development. An appropriate measure of caries should reflect most of the information captured by the ICDAS. However, little is known about how different studies have reported caries. Therefore, this scoping review aimed to explore how caries status was reported in the different published studies that examined patients using the ICDAS.

2.3 METHODS

2.3.1 Literature Search

Comprehensive systematic electronic searches of the Ovid MEDLINE, PubMed, Cochrane Library, and ISI Web of Science databases up to August 15/ 2017 were performed. PubMed and Web of Science found nearly all the selected abstracts. In addition, the reference list of relevant papers from examined articles was screened for any potentially missed papers. Repeated author's names were also specifically searched.

Search terms for both caries and ICDAS were used. For caries, the following terms were searched: decay, dental decay, tooth decay, teeth decay, surface decay, surfaces decay, coronal decay, caries, dental caries, tooth caries, teeth caries, surface caries, surfaces caries, coronal caries, carious, carious dentin, carious dentins, carious enamel, carious enamels, spot, spots, white spot, and white spots. For ICDAS, the following terms were searched: ICDAS, ICDAS I, ICDAS II, and International Caries Detection and Assessment System. Table 2.1 shows the search strategy. The search strategy was adapted to fit different databases.

Table 2.1. Basic search strategy

("decay" OR "dental decay" OR "tooth decay" OR "teeth decay" OR "surface decay" OR "surfaces decay" OR "coronal decay" OR "caries" OR "dental caries" OR "tooth caries" OR "teeth caries" OR "surface caries" OR "surfaces caries" OR "coronal caries" OR "carious" OR "carious dentin" OR "carious dentin" OR "carious enamel" OR "carious enamels" OR "spot" OR "spots" OR "white spot" OR "white spots")
AND
("ICDAS" OR "ICDAS I" OR "ICDAS II" OR "International Caries Detection and Assessment System")

2.3.2 Eligibility Criteria and Study Selection

Studies were included if patients were examined using the ICDAS criteria. Studies were excluded if the examination was done only for the validation or calibration of the ICDAS and/or if the examination was only done for specific teeth/surfaces rather than the whole dentition. No language, age, or sex/gender restrictions were applied.

Initially, titles and abstracts of all identified articles were screened to eliminate papers that did not meet the inclusion criteria by 2 independent reviewers. Full-text articles were examined when the abstract was not enough to include or exclude the studies. The studies that did not meet the inclusion criteria were excluded. When there was any doubt, the paper and the abstract were re-read and discussed by both reviewers until an agreement was reached.

2.3.3 Data extraction

Data extraction was conducted by both reviewers separately. Indices/measures used to summarize patients' caries level were evaluated in the selected studies. The index/measure of caries used and how it was calculated were extracted. Studies were grouped and summarized according to the index/measure used. Risk of bias assessment was not considered as the current study simply considered caries summary measures used in each of the included studies. Therefore, the quality of the included studies was irrelevant and not assessed.

2.4 RESULTS

Electronic search identified 320 studies. After initial screening by both reviewers, a total of 190 potential papers met the preliminary selection criteria. Following the full-text review, 126

papers were finally selected for this review. Out of the selected articles, 89 were cross-sectional studies, 22 were clinical trials, 13 were cohort studies, and 2 were case-control studies. Modified PRISMA flow diagram of the systematic searching process is shown in Figure 2.1.

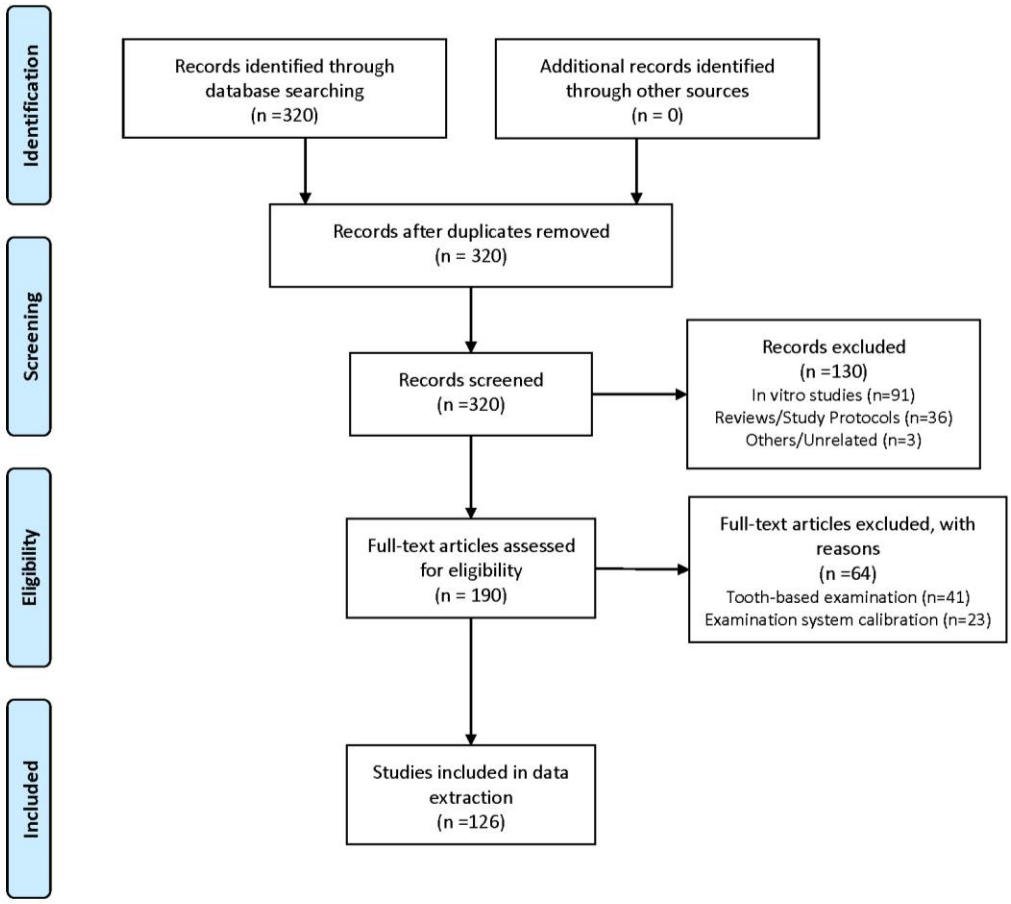

Figure 2.1. Modified PRISMA flow diagram of the systematic searching

A total of 44 different reporting measures of caries were used (Table 2.2). These reporting measures clustered into 5 main groups: number of individual ICDAS scores, number of decayed surfaces/teeth, number of decayed, missing, and filled teeth/surfaces (dmft/DMFT, dmfs/DMFS), number of decayed and filled teeth/surfaces (dft/DFT, dfs/DFS), and measures of

central tendency and dispersion. Most studies used a combination of multiple measures to summarize patient's caries status. Table 2.2 summarizes the indices/measures used and their definition in the selected studies.

Table 2.2. Summary of indices/measures used in the selected studies

Index/measure	Index definition	Studies which used the index/measure
Number of decayed surfaces/teeth		
$d_{(1-2)}s/D_{(1-2)}S$	Total counts of surfaces with ICDAS scores 1 and 2	[Agustsdottir et al., 2010; Anderson et al., 2016; Baciu et al., 2015; Calado et al., 2017; Carta et al., 2015; Chifor et al., 2014; Fernandes et al., 2017a; Fernandes et al., 2017b; Fontana et al., 2014; Gomar-Vercher et al., 2014; Guedes et al., 2016; Henry et al., 2017; Ismail et al., 2011; Ismail et al., 2015a; Ismail et al., 2008; Jurczak et al., 2017; Krzysciak et al., 2017; Lim et al., 2008; Lim et al., 2015; Martignon et al., 2010; Mendes et al., 2010; Morou-Bermudez et al., 2017; Pieper et al., 2013; Ramos-Jorge et al., 2015; Reisine et al., 2008; Samec et al., 2013; Singh et al., 2013; Sohn et al., 2007; Toutouni et al., 2015; Varma et al., 2008; Winter et al., 2016]
$d_{(1-3)}s/D_{(1-3)}S$	Total counts of surfaces with ICDAS scores 1 to 3	[Ashi et al., 2017; ElSalhy et al., 2013; ElSalhy et al., 2016; Falony et al., 2016; Garcia-Perez et al., 2017; Giacaman et al., 2015; Honkala et al., 2011; Llena et al., 2015; Majorana et al., 2014; Pitchika et al., 2016; Piva et al., 2017a; Piva et al., 2017b; Runnel et al., 2013; Sitthisettapong et al., 2015; Sitthisettapong et al., 2012; Soderling et al., 2014]
$d_{(2-3)}s/D_{(2-3)}S$	Total counts of surfaces with ICDAS scores 2 and 3	[Lozano Moraga et al., 2017; Taipale et al., 2013]
$d_{(3-4)}s/D_{(3-4)}S$	Total counts of surfaces with ICDAS scores 3 and 5	[Carta et al., 2015; Fernandes et al., 2017a; Guedes et al., 2016; Ismail et al., 2015a; Martignon et al., 2010; Ramos-Jorge et al., 2015; Varma et al., 2008]
$d_{(1-6)}s/D_{(1-6)}S$	Total counts of surfaces with ICDAS scores 1, 2, 3, 4, 5 and 6	[Anderson et al., 2016; Arangannal et al., 2016; Castro et al., 2016b; Cavallari et al., 2017; de Amorim et al., 2012; Erdemir et al., 2017; Ferreira Zandona et al., 2010; Finlayson et al., 2007; Gonzalez-Del-Castillo-McGrath et al., 2014; Goswami and Rajwar, 2015;

		Henry et al., 2017; Ismail et al., 2008; Martinez-Pabon et al., 2010; Martins Mussi et al., 2016; Muller-Bolla et al., 2015; Piovesan et al., 2013; Reisine et al., 2008; Varma et al., 2008; Volgenant et al., 2017; Wattanarat et al., 2015]
$d_{(2-6)}s/D_{(2-6)}S$	Total counts of surfaces with ICDAS scores 2, 3, 4, 5 and 6	[Cadavid et al., 2010; Castro et al., 2016b; Martins Mussi et al., 2016; Mittal et al., 2016; Pinto-Sarmento et al., 2016; Piovesan et al., 2013; Rodriguez et al., 2016; Taipale et al., 2013; Varma et al., 2008]
$d_{(3-6)}s/D_{(3-6)}S$	Total counts of surfaces with ICDAS scores 3, 4, 5 and 6	[Agustsdottir et al., 2010; Anderson et al., 2017; Anderson et al., 2016; Baciu et al., 2015; Cadavid et al., 2010; Calado et al., 2017; Castro et al., 2016b; Chifor et al., 2014; Fernandes et al., 2017b; Ferreira Zandona et al., 2010; Gomar-Vercher et al., 2014; Henry et al., 2017; Ismail et al., 2011; Ismail et al., 2008; Kamppi et al., 2016; Lim et al., 2008; Lim et al., 2015; Martins Mussi et al., 2016; Piovesan et al., 2013; Piva et al., 2017a; Reisine et al., 2008; Samec et al., 2013; Singh et al., 2013; Sohn et al., 2007; Sudhir et al., 2016; Toutouni et al., 2015; Varma et al., 2008]
$d_{(4-6)}s/D_{(4-6)}S$	Total counts of surfaces with ICDAS scores 4, 5 and 6	[Ashi et al., 2017; Castro et al., 2016b; de Amorim et al., 2012; ElSalhy et al., 2013; ElSalhy et al., 2016; Falony et al., 2016; Garcia-Perez et al., 2017; Giacaman et al., 2015; Honkala et al., 2011; Kamppi et al., 2016; Lozano Moraga et al., 2017; Martins Mussi et al., 2016; Morou-Bermudez et al., 2017; Muller-Bolla et al., 2015; Piovesan et al., 2013; Piva et al., 2017a; Piva et al., 2017b; Runnel et al., 2013; Sitthisettapong et al., 2012; Soderling et al., 2014; Taipale et al., 2013; Toutouni et al., 2015; Varma et al., 2008]
$d_{(5-6)}s/D_{(5-6)}S$	Total counts of surfaces with ICDAS scores 5 and 6	[Anderson et al., 2016; Cadavid et al., 2010; Calado et al., 2017; Carta et al., 2015; Castro et al., 2016a; Castro et al., 2016b; Fernandes et al., 2017a; Ferreira Zandona et al., 2010; Fontana et al., 2014; Guedes et al., 2016; Ismail et al., 2015a; Jurczak et al., 2017; Krzysciak et al., 2017; Leal et al., 2012; Majorana et al., 2014; Martignon et al., 2010; Martins Mussi et al., 2016; Piovesan et al., 2013; Ramos-Jorge et al., 2015; Rodriguez et al., 2016; Toutouni et al., 2015; Varma et al., 2008]

$d_{(1-6)}t/D_{(1-6)}T$	Total counts of teeth with ICDAS scores of more than 0	[Calado et al., 2017; de Amorim et al., 2012; ElSalhy et al., 2013; Ferraz et al., 2016; Melgar et al., 2016; Piovesan et al., 2013]
$d_{(2-6)}t/D_{(2-6)}T$	Total counts of teeth with ICDAS scores of 2 or more	[Melgar et al., 2016; Piovesan et al., 2013]
$d_{(3-6)}t/D_{(3-6)}T$	Total counts of teeth with ICDAS scores of 3 or more	[Agustsdottir et al., 2010; Baciu et al., 2015; Calado et al., 2017; Joseph et al., 2011; Melgar et al., 2016; Piovesan et al., 2013; Soares et al., 2017]
$d_{(1-3)}t/D_{(1-3)}T$	Total counts of teeth with ICDAS scores of 1, 2, and 3	[Falony et al., 2016; Ferraz et al., 2016; Honkala et al., 2011; Runnel et al., 2013; Sitthisettapong et al., 2015; Soderling et al., 2014]
$d_{(1-2)}t/D_{(1-2)}T$	Total counts of teeth with ICDAS scores of 1 and 2	[Agustsdottir et al., 2010; Baciu et al., 2015; Joseph et al., 2011; Melgar et al., 2016]
$d_{(4-6)}t/D_{(4-6)}T$	Total counts of teeth with ICDAS scores of 4, 5, and 6	[Alaraudanjoki et al., 2016; de Amorim et al., 2012; Falony et al., 2016; Ferraz et al., 2016; Guido et al., 2011; Honkala et al., 2011; Olak et al., 2013; Piovesan et al., 2013; Runnel et al., 2013; Silva et al., 2014; Soderling et al., 2014]
$d_{(5-6)}t/D_{(5-6)}T$	Total counts of teeth with ICDAS scores of 5 and 6	[Calado et al., 2017]
Number of decayed, missing, and filled teeth/surfaces		
$d_{(1-6)}mft/D_{(1-6)}MFT$	Total Counts of teeth with ICDAS scores of 2 or more ($d_{(1-6)}$/ $D_{(1-6)}$), teeth with fillings (F) and extracted teeth (M)	[Agustsdottir et al., 2010; Almerich-Silla et al., 2014; Almerich-Torres et al., 2016; Baciu et al., 2015; Braga et al., 2009; Cabral et al., 2014; Calado et al., 2017; de Amorim et al., 2012; Hilgert et al., 2015; Jones and Walters, 2015; Joseph et al., 2011; McGrady et al., 2012; Pieper et al., 2013; Piovesan et al., 2014; Winter et al., 2016; Wu et al., 2013; Wu et al., 2017]
$d_{(2-6)}mft/D_{(2-6)}MFT$	Total Counts of teeth with ICDAS scores of 2 or more ($d_{(2-6)}$/ $D_{(2-6)}$), teeth with fillings (F) and extracted teeth (M)	[Braga et al., 2009; Piovesan et al., 2014; Rodriguez et al., 2016; Schwendicke et al., 2015; Volgenant et al., 2017]

$d_{(3-6)}mft/D_{(3-6)}MFT$	Total Counts of teeth with ICDAS scores of 4 or more ($d_{(3-6)}$/ $D_{(3-6)}$), teeth with fillings (F) and extracted teeth (M)	[Agustsdottir et al., 2010; Baciu et al., 2015; Braga et al., 2009; Calado et al., 2017; Ghanim et al., 2013; Joseph et al., 2011; Lim et al., 2008; Melgar et al., 2016; Muller-Bolla et al., 2016; Pieper et al., 2013; Piovesan et al., 2017; Piovesan et al., 2014; Piva et al., 2017b; Santamaria et al., 2015; Varma et al., 2008; Volgenant et al., 2017; Wang et al., 2012; Winter et al., 2017; Winter et al., 2016; Wu et al., 2017]
$d_{(4-6)}mft/D_{(4-6)}MFT$	Total Counts of teeth with ICDAS scores of 4 or more ($d_{(4-6)}$/ $D_{(4-6)}$), teeth with fillings (F) and extracted teeth (M)	[Alaraudanjoki et al., 2016; Almerich-Silla et al., 2014; Almerich-Torres et al., 2016; Braga et al., 2009; de Amorim et al., 2012; ElSalhy et al., 2013; ElSalhy et al., 2016; Falony et al., 2016; Goodwin et al., 2017; Hilgert et al., 2015; Honkala et al., 2011; McGrady et al., 2012; Olak et al., 2013; Piovesan et al., 2014; Runnel et al., 2013; Silva et al., 2014; Soderling et al., 2014]
$d_{(5-6)}mft/D_{(5-6)}MFT$	Total Counts of teeth with ICDAS scores of 5 or more ($d_{(5-6)}$/ $D_{(5-6)}$), teeth with fillings (F) and extracted teeth (M)	[Calado et al., 2017; Pieper et al., 2013; Rodriguez et al., 2016; Sitthisettapong et al., 2015; Sitthisettapong et al., 2012; Winter et al., 2016]
$d_{(3-4)}mft/D_{(3-4)}MFT$	Total Counts of teeth with ICDAS scores of 3 and 4 ($d_{(3-4)}$/ $D_{(3-4)}$), teeth with fillings (F) and extracted teeth (M)	[Toutouni et al., 2015]
$d_{(1-2)}mfs/D_{(1-2)}MFS$	Total Counts of surfaces with ICDAS scores of 3 and 4 ($d_{(1-2)}$/ $D_{(1-2)}$), surfaces with fillings (F) and surfaces of extracted teeth (M)	[Samec et al., 2013; Sundell et al., 2016]
$d_{(3-4)}mfs/D_{(3-4)}MFS$	Total Counts of surfaces with ICDAS scores of 3 and 4 ($d_{(3-4)}$/ $D_{(3-4)}$), surfaces with fillings (F) and	[Sundell et al., 2016; Toutouni et al., 2015]

	surfaces of extracted teeth (M)	
$d_{(4-6)}$mfs/$D_{(4-6)}$MFS	Total Counts of surfaces with ICDAS scores of 4, 5, and 6 ($d_{(4-6)}$/ $D_{(4-6)}$), surfaces with fillings (F) and surfaces of extracted teeth (M)	[Almerich-Silla et al., 2014; Braga et al., 2009; de Amorim et al., 2012; Ekstrand et al., 2010; ElSalhy et al., 2013; Falony et al., 2016; Honkala et al., 2011; Honkala et al., 2015; Llena et al., 2015; Piovesan et al., 2014; Runnel et al., 2013; Soderling et al., 2014]
$d_{(5-6)}$mfs/$D_{(5-6)}$MFS	Total Counts of surfaces with ICDAS scores of 5 and 6 ($d_{(5-6)}$/ $D_{(5-6)}$), surfaces with fillings (F) and surfaces of extracted teeth (M)	[Cadavid et al., 2010; Calado et al., 2017; Ferreira Zandona et al., 2012; Fontana et al., 2014; Martignon et al., 2010; Sitthisettapong et al., 2015; Sitthisettapong et al., 2012; Sundell et al., 2016]
$d_{(1-6)}$mfs/$D_{(1-6)}$MFS	Total Counts of surfaces with ICDAS scores of 1 or more ($d_{(1-6)}$/ $D_{(1-6)}$), surfaces with fillings (F) and surfaces of extracted teeth (M)	[Agustsdottir et al., 2010; Almerich-Silla et al., 2014; Baciu et al., 2015; Braga et al., 2009; Burt et al., 2006; Calado et al., 2017; Chifor et al., 2014; Cook et al., 2008; de Amorim et al., 2012; Ferreira Zandona et al., 2012; Fontana et al., 2011; Guido et al., 2011; Ismail et al., 2011; Kolker et al., 2007; Lim et al., 2008; Llena et al., 2015; Martignon et al., 2010; Mendes et al., 2010; Piovesan et al., 2014; Samec et al., 2013; Singh et al., 2013; Sohn et al., 2007; Soto-Rojas et al., 2012; Sundell et al., 2016; Sundell et al., 2015; Wu et al., 2013; Wu et al., 2017]
$d_{(2-6)}$mfs/$D_{(2-6)}$MFS	Total Counts of surfaces with ICDAS scores of 2 or more ($d_{(2-6)}$/ $D_{(2-6)}$), surfaces with fillings (F) and surfaces of extracted teeth (M)	[Braga et al., 2009; Cadavid et al., 2010; Mendes et al., 2010; Piovesan et al., 2014; Schwendicke et al., 2015]
$d_{(3-6)}$mfs/$D_{(3-6)}$MFS	Total Counts of surfaces with ICDAS scores of 3 or more ($d_{(3-6)}$/ $D_{(3-6)}$), surfaces with fillings (F) and	[Agustsdottir et al., 2010; Baciu et al., 2015; Braga et al., 2009; Cadavid et al., 2010; Calado et al., 2017; Ferreira Zandona et al., 2012; Fontana et al., 2011; Ismail et al., 2011; Mendes et al., 2010; Piovesan et al., 2014; Samec et al., 2013; Singh et al., 2013; Sundell et

	surfaces of extracted teeth (M)	al., 2015; Turska-Szybka et al., 2016; Varma et al., 2008; Wu et al., 2017]
Number of decayed and filled surfaces/teeth		
$d_{(1-2)}fs/D_{(1-2)}FS$	Total Counts of surfaces with ICDAS scores of 1 and 2 ($d_{(1-2)}$/ $D_{(1-2)}$) and surfaces with fillings (F)	[Jablonski-Momeni et al., 2014; Samec et al., 2013]
$d_{(1-3)}fs/D_{(1-3)}FS$	Total Counts of surfaces with ICDAS scores of 1, 2 and 2 ($d_{(1-3)}$/ $D_{(1-3)}$) and surfaces with fillings (F)	[Tellez et al., 2012]
$d_{(3-6)}fs/D_{(3-6)}FS$	Total Counts of surfaces with ICDAS scores of 1 and 2 ($d_{(3-6)}$/ $D_{(3-6)}$) and surfaces with fillings (F)	[Jablonski-Momeni et al., 2014; Pieper et al., 2013; Samec et al., 2013; Varma et al., 2008; Winter et al., 2016]
$d_{(1-6)}fs/D_{(1-6)}FS$	Total Counts of surfaces with ICDAS scores of 1 or more ($d_{(1-6)}$/ $D_{(1-6)}$) and surfaces with fillings (F)	[Almerich-Silla et al., 2014; Arruda et al., 2012; Jablonski-Momeni et al., 2014; Samec et al., 2013; Tellez et al., 2012]
$d_{(4-6)}fs/D_{(4-6)}FS$	Total Counts of surfaces with ICDAS scores of 4, 5 and 6 ($d_{(4-6)}$/ $D_{(4-6)}$) and surfaces with fillings (F)	[Almerich-Silla et al., 2014; Tellez et al., 2012]
$d_{(5-6)}fs/D_{(5-6)}FS$	Total Counts of surfaces with ICDAS scores of 5 and 6 ($d_{(5-6)}$/ $D_{(5-6)}$) and surfaces with fillings (F)	[Jablonski-Momeni et al., 2014]
$d_{(1-6)}ft/D_{(1-6)}FT$	Total Counts of teeth with ICDAS scores of 1 or more ($d_{(1-6)}$/ $D_{(1-6)}$)	[Almerich-Silla et al., 2014; Almerich-Torres et al., 2016]

	and teeth with fillings (F)	
$d_{(2-6)}ft/D_{(2-6)}FT$	Total Counts of teeth with ICDAS scores of 2 or more ($d_{(2-6)}$/ $D_{(2-6)}$) and teeth with fillings (F)	[Nelson et al., 2013]
$d_{(3-6)}ft/D_{3-6)}FT$	Total Counts of teeth with ICDAS scores of 3 or more ($d_{(3-6)}$/ $D_{(3-6)}$) and teeth with fillings (F)	[Varma et al., 2008]
$d_{(4-6)}ft/D_{(4-6)}FT$	Total Counts of teeth with ICDAS scores of 4 or more ($d_{(4-6)}$/ $D_{(4-6)}$) and teeth with fillings (F)	[Almerich-Silla et al., 2014; Almerich-Torres et al., 2016]
Individual ICDAS Scores		
Individual ICDAS Scores	Total Counts of ICADS 0 surfaces Total Counts of ICADS 1 surfaces Total Counts of ICADS 2 surfaces Total Counts of ICADS 3 surfaces Total Counts of ICADS 4 surfaces Total Counts of ICADS 5 surfaces Total Counts of ICADS 6 surfaces	[Anderson et al., 2017; Andrade et al., 2017; Arangannal et al., 2016; Cadavid et al., 2010; de Amorim et al., 2012; Diaz-Cardenas and Gonzalez-Martinez, 2010; Fakhruddin and El Batawi, 2017; Ferreira Zandona et al., 2010; Garcia-Perez et al., 2017; Ismail et al., 2008; Kamppi et al., 2016; Kirschneck et al., 2016; Majorana et al., 2014; Maxim et al., 2013; Mendes et al., 2010; Mittal et al., 2016; Morou-Bermudez et al., 2017; Nazir et al., 2011; Pieper et al., 2013; Piovesan et al., 2013; Pitchika et al., 2016; Ramos-Jorge et al., 2014; Sim et al., 2015; Sudhir et al., 2016; Toutouni et al., 2015; Winter et al., 2016]
Measures of central tendency and dispersion		
Mean ICDAS	Total ICDAS scores dived by the total number of teeth/surfaces	[Chen et al., 2014; Kirschneck et al., 2016; Wang et al., 2012]
Mean ICDAS in carious teeth	Total ICDAS scores dived by the total	[ElSalhy et al., 2013; ElSalhy et al., 2016]

	number of carious teeth	
Maximum ICDAS	Maximum ICDAS score was used to categorized subjects in groups	[Abreu-Placeres et al., 2017; Nazir et al., 2011]
Total ICDAS	Total of ICDAS scores	[Kulkarni et al., 2013]
Caries Activity		[Agustsdottir et al., 2010; Chifor et al., 2014; Ferreira Zandona et al., 2012; Henne et al., 2016; Kamppi et al., 2016; Pinto-Sarmento et al., 2016; Piovesan et al., 2013; Ramos-Jorge et al., 2014; Taipale et al., 2013; Turska-Szybka et al., 2016; Varma et al., 2008]

Nine different reporting for the number of decayed surfaces and six different reporting for the number of decayed teeth were used (Table 2.2). Surfaces with ICDAS scores 3 or more, 4 or more, and 5 or more, were commonly used to describe the number of surfaces/teeth with caries extending into dentin. For the number of enamel lesions, ICDAS scores of 2 or less and 3 or less were frequently used (Table 2.2).

Many studies synthesized the WHO decayed, missing, and filled teeth/surfaces indices or their decayed and filled teeth/surfaces derivatives from the ICDAS examination. As different studies defined the d/D component of the dmf/DMF differently, a total of six different dmft/DMFT and seven different dmfs/DMFS combinations were used (Table 2.2). The most commonly used were $d_{(1-6)}mf/D_{(1-6)}MF$, $d_{(3-6)}mfs/D_{(3-6)}MFS$, and $d_{(4-6)}mf/D_{(4-6)}MF$ teeth/surfaces. Similarly, six different DFS and four DFT were synthesized.

Three studies used mean ICDAS and two studies used mean ICDAS in carious teeth. The maximum ICDAS score was used twice while the total ICDAS was used only once. In the

selected studies, caries activity was only reported in 11 studies [Agustsdottir et al., 2010; Chifor et al., 2014; Ferreira Zandona et al., 2012; Henne et al., 2016; Kamppi et al., 2016; Pinto-Sarmento et al., 2016; Piovesan et al., 2013; Ramos-Jorge et al., 2014; Taipale et al., 2013; Turska-Szybka et al., 2016; Varma et al., 2008]. Most of these studies reported caries activity as the proportion of active lesions to the total number of lesions according to different ICDAS scores (Table 2.2).

2.5 DISCUSSION

This scoping review aimed to explore how patient caries status was reported in different studies using the ICDAS. There is a significant variation in the presentation of caries in studies employing ICDAS. Many of the published studies used the ICDAS categorical characteristics of the recorded caries scores either in the form of a number of decayed surfaces/teeth or the dmf/DMF index at different caries cut-off points to define caries. Only a few studies calculated summative measures.

Categorical characteristics of the recorded ICDAS caries scores were the most used measure in the selected studies. The problem is that using the ICDAS categorical characteristics does not explore the full scale of the collected information. Using total counts of lesions or grouping different scores into groups give equal value for lesions at different stages of caries and does not take full advantage of the 6-ordinal scale used. In addition, different studies used a different grouping of caries scores. For example, nine different caries surfaces' measures were identified in the present review. Some studies grouped the ICDAS scores to classify caries as dentine and enamel lesions while others classified them as initial/early, moderate/established and

severe/extensive lesions [Carta et al., 2015; Guedes et al., 2016; Majorana et al., 2014; Ramos-Jorge et al., 2015]. In addition, some studies combined all scores of caries into one group. Such variations and inconsistencies are very disconcerting as comparisons between these studies are not possible. Therefore, a unified representative index is needed. An overall valid summative measure can provide a better summary evaluation of caries for each patient considering both the number and the stage of caries lesions.

Few attempts tried to use summative measures to report caries [Chen et al., 2014; ElSalhy et al., 2013; ElSalhy et al., 2016; Kirschneck et al., 2016; Kulkarni et al., 2013; Wang et al., 2012]. These attempts used mean ICDAS, mean ICDAS in carious teeth and total ICDAS. These measures can be more representative of caries level than the categorical measures commonly used as they represent both the number of lesions and their stage of progression. However, these indices need to be examined in relation to the number of lesions at different stages of disease progression to be representative. To be a valid summative summary measure of patients' caries level, the measure should be reflective of caries in patients with different levels of caries as well as different type of dentition. A longitudinal evaluation of the measures as the level of caries progresses is the ideal approach for examining these indices.

This study highlighted that different cut-off points were used when calculating dmf/DMF and its different derivatives. Caries or d/D in the WHO criteria is recorded when a lesion has an obvious cavity, undermined enamel lesion, or a detectably softened floor or wall [World Health Organization, 2013]. By definition, this is coincident with ICDAS caries scores of 4, 5 and 6. Iranzo-Cortes et al. [2013] examined the equivalence between WHO caries diagnosis criteria and the ICDAS caries classification scale and concluded that possible errors could be reduced by

locating this equivalence at cut-off point 3 rather than 4; that is $d_{3\text{-}6}mf$ /$D_{3\text{-}6}MF$ to be equivalent to the WHO dmf/DMF. This was confirmed by Braga et al. [2009] conclusion that ICDAS was comparable to the standard WHO criteria when the cut-off point was score 3. However, this review identified a few studies reported caries corresponding to WHO's d/D at ICDAS levels of 5 and 6 [Pieper et al., 2013; Rodriguez et al., 2016; Schwendicke et al., 2015; Sitthisettapong et al., 2015; Sitthisettapong et al., 2012; Winter et al., 2016]. Again, such inconsistency makes comparisons of data difficult, especially against prevalence data presented using the dmf/DMF index. This makes using the dmf/DMF index not suitable for the system without verifying the diagnosis threshold before comparing values between different studies. Moreover, calculating the dmft/DMFT or dmfs/DMFS reflects patients' caries experience and may not reflect their current caries status.

Assessment of caries activity can provide vital information when studying oral hygiene behaviors, dietary behaviors, use of fluoride, and oral microbiology. In addition, it is important for caries diagnosis and management. However, only few studies reporting lesion activity were identified in the present scoping review. Many of these studies reported the percentage of active lesions for the patient or for every ICDAS stage of caries. A possible explanation of low reporting is the difficulty of using tooth level's lesion activity when reporting patient or population caries level in addition to the gained value in reporting caries activity at the population level compared to individual level. Few studies that used lesion activity aimed to examine factors associated with lesion activity or the impact of a specific intervention on lesion activity [Henne et al., 2016; Pinto-Sarmento et al., 2016; Turska-Szybka et al., 2016]. Some studies that assessed caries activity were excluded from this review because they examined only specific surfaces rather than the whole dentition [Guedes et al., 2014; Santos et al., 2014].

Since the development of the ICDAS, many studies were conducted for the purpose of validation or calibration of ICDAS. Many of these studies reported caries as individual ICDAS surface scores to examine intra- and inter-examiner reliability. Studies that were solely conducted for the calibration with no aim to describe patient's caries were excluded. Including these studies would inflate the use of individual ICDAS scores in reporting subjects with caries. Studies that described patient or population caries level as part of the study were included even if they reported details about their validation process.

The ICDAS was developed as a standardized examination system to improve the quality of collected data on caries [Pitts, 2004]. However, the system cannot achieve its goal without the ability to compare epidemiological data. The current inconsistencies in the presentation of caries can prevent researchers from using it and taking advantage of its rich information. Therefore, a summary measure that reflects caries is needed to be part of the system's guide or recommendations. In addition, the proposed index should be reflective of both the number of caries lesions and their stage of progression.

In conclusion, most studies presented caries using categorical characteristics of the ICDAS. There are variations in the utilization of the system in summarizing caries between the studies. These inconstancies do not allow comparison between different studies. A consistent summary measure that reflects patient caries level is therefore needed.

3. Chapter Three

Identifying a potential summary measure for overall caries level in children examined with the International Caries Detection and Assessment System

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A version of this chapter was published in Caries Research Journal a ElSalhy M, Alsumait A, Lai H, Almerich-Silla JM, Piovesan C, Flores-Mir C, Amin M: Identifying a Potential Summary Measure for Overall Caries Level in Children Examined with the International Caries Detection and Assessment System. Caries Res 2017; 51:568-575.

3.1 ABSTRACT

Objective: To identify a potential summative measure that reflects patient's overall caries level in children examined with the International Caries Detection and Assessment System (ICDAS).

Methods: Participants were 1 to 15-year-old children from Kuwait, Brazil, and Spain. Children's teeth were examined using the ICDAS. Multiples measures of central tendency and dentition specific indices were considered as potential summative measures. The relationship between the summative measures and number of caries lesions were evaluated considering degrees of caries severity using Spearman's correlation analysis. The results were generated using Kuwait sample and were cross-validated using Brazil and Spain samples.

Results: A total of 3,076 children participated in the present study. Total ICDAS score and mean ICDAS score showed a strong correlation with the number of caries lesions at different caries severity levels in both primary, mixed and permanent dentitions (lowest ρ value was 0.866). The total ICDAS of 51 Buccal (B), 61B, 54 Occlusal (O), 55O, 64O, 65O, 74O, 75O, 84O, 85O surfaces in primary dentition and total ICDAS of 14O, 16L, 16O, 24O, 26L, 26O, 36B, 36O, 37O, 46O, 46B, 47O surfaces in permanent dentition or mixed dentition (if present) showed strong correlations with the number of caries lesions at different caries severity levels (lowest ρ value was 0.713).

Conclusions: Total ICDAS score and mean ICDAS score were the best summary measures of caries levels at different dental stages to describe patient's overall caries level in children examined with ICDAS. They strongly correlated with the number of caries lesions with all correlation coefficient values equal or more than 0.86. A short version of ICDAS that include selectively examined 10 surfaces in primary dentition and 12 surfaces in permanent dentition can give an excellent summary measurement for patient's overall caries status with a high level of accuracy (ROC > 0.9) while simultaneously diminishing the time involved in completing the assessment.

3.2 INTRODUCTION

The International Caries Detection and Assessment System (ICDAS) was developed as a standardized system based on the available evidence for detecting early and later stages of carious lesions [Pitts, 2004]. The aim of developing this system was to improve the quality of collected data on caries to be used for clinical research, clinical practice, and epidemiological

studies [Pitts, 2004]. Regarding its use for epidemiological research, ICDAS was designed to be practical and easy to use. It was also intended to detect cavitated and non-cavitated lesions at different stages with acceptable reliability [Ismail et al., 2007]. ICDAS detects and categorizes early enamel lesions and dentine lesions according to their progression stage [Pitts, 2009a, b]. The validity and reproducibility of ICDAS have been previously reported [Agustsdottir et al., 2010; Ismail et al., 2007].

Based on visual inspection, ICDAS records caries in combination with the type of restoration based on a six-level ordinal scale [Ismail et al., 2007; Pitts, 2004; Pitts et al., 2013]. Every surface is coded with two digits. The first digit is preventive or restorative treatment code and the second digit is caries code. By measuring non-cavitated and cavitated lesions as well as recurrent carious lesions, ICDAS overcomes the shortfalls of the commonly used WHO caries examination criteria [Honkala et al., 2011; Pitts, 2004]. ICDAS is progressively gaining international acceptance for dental health surveys and clinical practice [EGOHID II, 2008; Young et al., 2015].

Most of the published studies used the ICDAS categorical characteristics of the recorded caries scores [Chapter 2]. In these studies, the total number of enamel and/or dentine caries lesions or the number of decayed, missed and filled teeth or surfaces (dmft/DMFT or dmfs/DMFS) were used [Chapter 2]. Such usage does not explore the full scale of collected information. Using the total number of lesions gives equal value for the different stages of caries and does not take full advantage of the six-ordinal scale used. Therefore, an overall measure is needed to present a summative evaluation of caries for each patient considering both the number and the stage of caries lesions.

Ordinal data are a type of data generated from ordered observations. The distance between each category on the ordinal scale is not equal. Therefore, the difference between the categories is not absolute but relative. The most suitable center measure for such ordinal scale data is positional statistic such as median or mode [Manikandan, 2011]. In addition, nonparametric tests, based on ranks, are the most appropriate measures for inferential analyses [Manikandan, 2011]. The ICDAS categorizes caries on a six-level ordinal scale based on the histological extent and progression [Pitts et al., 2013]. ICDAS scores within the patients are unique as they are not independent observations as they are affected by the individual's habits, and they differ between individuals. In addition, the probability of having caries are not equal between surfaces as some surfaces are more susceptible to caries than others and caries progression differs between surfaces. Since the majority of surfaces are caries-free in most children [Honkala et al., 2011; Runnel et al., 2013], using a non-conditional positional statistic may not be the best measures to represent caries. Because all of the above reasons, any potential measure of central tendency has to be examined if it actually represents caries scores.

Unlocking the full potential of the ICDAS can improve our current knowledge about caries. Using a summative measure allows reasonable comparisons between different patients or populations. This is crucial when studying and analyzing factors contributing to caries development. Accurate identification of factors contributing to caries development may improve health promotion programs and interventions. It is also important when analyzing the benefits of preventive interventions and in evaluating the performance of different oral health systems. To be a valid summative summary measure of patients' overall caries level, the measure has to be reflective of caries status in patients with different levels of caries. Therefore, the objective of

this study was to identify a potential summative measure that adequately reflects patient's overall caries level in children examined with the ICDAS.

3.3 METHODS

3.3.1 Study design

This was a cross-sectional study based on oral examinations of participating children. The study protocol was approved by the University of Alberta Research Ethics Board (Protocol no. 00050417). Informed consent from parents/guardians of every participating child was collected, and the study was conducted in accordance with the Helsinki Declaration.

3.3.2 Study setting and participants

Participants in the present study were from three countries: Kuwait, Brazil, and Spain. Original data were collected in Kuwait and cross-validated with the data from the other two countries.

In Kuwait, the study was conducted in the Capital Education/Health Region, where more than 85% of Kuwaiti children attend public schools. The research procedures were carried out for 3 months during the 2014-2015 academic year. Participants were 3 to 15 years-old children attending public kindergartens and schools in the Kuwait Capital Region. Two Kindergartens, 2 primary schools, and 4 intermediate schools were randomly selected from a list provided by the Ministry of Education Research Department. A letter of information describing the study procedure was sent to the selected schools. It was coupled with an additional information package to be sent to the parents. All children at these schools were approached for participation.

Children were grouped according to their dental stage into primary, permanent, and mixed dentition groups.

For the cross-validation of primary dentition results, data of a representative sample of 639 children aged 12-59 months examined in Santa Maria, Brazil was used. Data collection procedure and population demographics were previously described [Piovesan et al., 2014].

For children with mixed and permanent dentitions, data of a representative sample of the entire schoolchild population of the Valencia region of Spain was used. From seventy schools, 1373 pupils aged 6-15 years were examined. Data collection procedure and population demographics were previously described [Almerich-Silla et al., 2014].

The sample size was calculated based on an estimated type I error of 0.05, expected power of 0.8, and minimum expected correlation of 0.20 [ElSalhy et al., 2013] was estimated to be 194 children with caries for each dentition [Hulley et al., 2013]. As caries-free children can range from 30-50% in different populations, 338 children in each dentition were targeted. A 75% positive response rate was expected. Therefore, a total of 518 consents were aimed for distribution for every dental age group.

3.3.3 Procedure

A 5-minute presentation about the study was presented to children in the classrooms. Information letter along with a consent form were sent home for their parents to sign. Child's assent was obtained prior to the dental examination.

3.3.4 Clinical examination

Dental examinations were performed by one trained dentist using a mobile dental chair, artificial spotlight, and a mobile dental unit at the school clinics. Before the dental examinations, students were asked to brush their teeth. The ICDAS criteria were employed by the examiner who has been already trained and calibrated with high inter-and intra-examiner reliability (both weighted kappa > 0.9).

3.3.5 Data analysis

Data were managed and analyzed using SPSS 21.0 software (IBM Corp., Armonk, N.Y., USA). Frequencies of ICDAS caries scores were used for data description. The following measures of central tendency and dispersion were calculated from the ICDAS caries scores:

- Total ICDAS: Total counts of ICDAS scores of all surfaces.
- Mean ICDAS: Total counts of ICDAS scores divided by the number of all teeth.
- Mean ICDAS in carious teeth: Total number of ICDAS scores divided by the number carious teeth.
- Median ICDAS in carious teeth: The median ICDAS score of the range of scores from all carious surfaces.
- Mode ICDAS in carious teeth: The most frequently repeated ICDAS score in all carious surfaces. If more than one mode exists, the largest was used.
- Maximum ICDAS: The maximum ICDAS score of all surfaces.

A two-way ANOVA was used to examine the influence of specific teeth and surfaces on the ICDAS caries scores. As it was significant in all dentitions, dentition specific indices were calculated by summing the ICDAS scores of teeth surfaces with highest caries frequency. To do so, total scores of every surface and its contralateral side were summed starting from teeth with the highest frequency and adding surfaces gradually until the area under the receiver operating characteristic (ROC) curve of more than 0.9 for the measure caries detection accuracy (i.e., the child has caries or not) was reached. An area under the ROC curve of 0.9 or more indicates an excellent diagnostic accuracy [Zhu et al., 2010]. The sensitivity and specificity measures were also calculated. The total with the best summary measurement was used as a dentition specific index. For mixed dentition, teeth chosen in primary and permanent dentitions were used if present.

The relationship between the summary measures and the number of lesions were evaluated gradually by increasing lesion severity using Spearman's correlation analysis. The correlations were done in children with only ICDAS scores of 1, children with ICDAS 1 and 2, children with ICDAS 1-3, children with ICDAS 1-4, children with ICDAS 1-5, and children with ICDAS 1-6. To accommodate for multiple comparisons, the level of significance was set at 0.001 after Bonferroni-Holm correction.

3.4 RESULTS

3.4.1 Original Analysis Results

A total of 294 children (53 % female) with primary dentition, 266 children with mixed dentition (51 % female), and 505 children (51 % female) with permanent dentition from Kuwait

participated in the present study. Caries-free children with primary dentition were 72 (24.5 %), and caries-free children with mixed permanent dentitions were 61 (22.9%) and 115 (22.8 %), respectively.

3.4.1.1 Primary Dentition

In children with carious primary dentition, the occlusal surface of tooth 75 was the most commonly carious surface (70.3%) followed by the occlusal surface of 85 (67.6%), occlusal surface of 65 (56.8%), and occlusal surface of 74 (55.9%).

Out of the 88 surfaces examined in primary teeth, 10 surfaces with the highest frequency of caries were selected to represent patient overall caries severity. These surfaces were 51 Buccal (B), 61B, 54 Occlusal (O), 55O, 64O, 65O, 74O, 75O, 84O, 85O. Examining only these 10 surfaces combined had an excellent diagnostic accuracy to detect caries in these children with an area under the ROC of 0.95 (SE: 0.02, 95 % CI: 0.91-0.99). The sensitivity and specificity of examining these surfaces were 96.40% (95% CI: 93.02-98.43%) and 100% (95% CI: 95.01-100.00%), respectively. The total ICDAS caries score of these surfaces was used as one of the summary measurement.

In primary dentition, the total ICDAS score, the mean ICDAS score, and the total ICDAS score of the selected 10 surfaces showed a strong correlation with the number of caries lesions at different severity levels (Table 3.1). All the other examined indices showed weak correlation with the number of caries lesions in children with low caries level, but they were moderately correlated with the number of caries lesions when children with severe caries lesions were

included. Correlations between the measures and the number of caries lesions with increasing caries severity in primary dentition are summarized in Table 3.1.

Table 3.1. Correlations between the indices and the number of lesions evaluated in children with increasing caries severity by Spearman's correlation test -Primary Dentition.

	No. of ICDAS 1 lesions N= 18	No. of 1-2 ICDAS lesions N= 36	No. of 1-3 ICDAS lesions N= 52	No. of 1-4 ICDAS lesions N= 72	No. of 1-5 ICDAS lesions N= 136	No. of 1-6 ICDAS lesions N= 222
Total ICDAS	1.000*	0.879*	0.804*	0.845*	0.958*	0.981*
Mean ICDAS score	1.000*	0.879*	0.804*	0.845*	0.958*	0.981*
Mean ICDAS score in caries teeth	0.0	0.048	0.288	0.443*	0.741*	0.841*
Median ICDAS score of caries surfaces	0.290	0.021	0.178	0.228	0.488*	0.679*
Mode ICDAS score (largest if more than 1 mode)	0.290	0.072	0.223	0.167	0.455*	0.606*
Maximum ICDAS score	0.0	0.111	0.307	0.545*	0.781*	0.816*
Total ICDAS of 51B, 52B, 54O, 55O, 64O, 65O, 74O, 75O, 84O, 85O	1.000*	0.842*	0.791*	0.713*	0.862*	0.921*
N is the number of children * Significant at 0.001 level						

3.4.1.2 Permanent Dentition

In children with carious permanent dentition, the occlusal surface of tooth 16 was the most commonly carious surface (60.3%) followed by the occlusal surface of 36 and 46 (58.9% each), and occlusal surface of 26 (56.1%).

Out of the 124 surfaces examined in permanent teeth, 12 surfaces with the highest frequency of caries were selected to represent patient's overall caries level. These surfaces were 14O, 16L, 16O, 24O, 26L, 26O, 36B, 36O, 37O, 46O, 46B, 47O. The total ICDAS caries score of these surfaces was used as one of the summary indices. The combined selected 12 surfaces had an excellent diagnostic accuracy with an area under the ROC of 0.94 (SE: 0.02, 95 % CI: 0.91-0.97). Examining only these surfaces had a sensitivity of 95.90 % (95% CI: 93.42-97.64%) specificity of 100 % (95% CI: 96.85-100.00%) to detect caries in these children. The total ICDAS caries score of these surfaces was used as one of the summary measurements.

The total ICDAS scores, the mean ICDAS score, and the total ICDAS score of the combined selected 12 surfaces showed a strong correlation with the number of caries lesions at different levels of severity in permanent dentition (Table 3.2). All the other examined indices showed weak correlation with the number of caries lesions in children with low caries level, but they were moderately correlated with the number of caries lesions when children with severe caries lesions were included. Correlations between the measures and the number of caries lesions with increasing caries severity in permanent dentition were summarized in Table 3.2.

Table 3.2. Correlations between the indices and the number of lesions evaluated in children with increasing caries severity by Spearman's correlation test -Permanent Dentition.

	No. of ICDAS 1 lesions N= 34	No. of 1-2 ICDAS lesions N= 237	No. of 1-3 ICDAS lesions N= 342	No. of 1-4 ICDAS lesions N= 386	No. of 1-5 ICDAS lesions N= 431	No. of 1-6 ICDAS lesions N= 505
Total ICDAS	1.000*	0.941*	0.929*	0.925*	0.923*	0.963*
Mean ICDAS score	0.942*	0.932*	0.917*	0.912*	0.911*	0.957*
Mean ICDAS score in caries teeth	0.272	0.615*	0.563*	0.541*	0.537*	0.782*
Median ICDAS score of caries surfaces	0.0	0.371*	0.211*	0.189*	0.165	0.620*
Mode ICDAS score (largest if more than 1 mode)	0.0	0.221*	0.078	0.062	0.042	0.567*
Maximum ICDAS score	0.0	0.655*	0.575*	0.561*	0.544*	0.788*
Total ICDAS of 14O, 16L, 16O, 24O, 26L, 26O, 36B, 36O, 37O, 46O, 46B, 47O	0.700*	0.842*	0.819*	0.818*	0.816*	0.906*

N is the number of children
* Significant at 0.001 level

3.4.1.3 Mixed Dentition

The total ICDAS score, the mean ICDAS score and the total ICDAS of 51B, 52B, 54/14O, 55O, 64/24O, 65O, 74O, 75O, 84O, 85O, 16L, 16O, 26L, 26O, 36B, 36O, 37O, 46O, 46B, 47O surfaces, if present, showed strong correlation with the number of caries lesions at different level of severity (Table 3.3). The combined selected 22 surfaces had an excellent diagnostic accuracy with an area under the ROC of 0.95 (SE: 0.01, 95% CI: 0.93-0.97). The

sensitivity and specificity of these surfaces (if present) to detect caries in these children were 94.39% (95% CI: 92.13-96.27%) and 100% (95% CI: 98.90-100.00%). All the other indices showed moderate correlation with the number of caries lesions only when children with severe caries lesions were included. Correlations between the measures and the number of lesions with increasing caries severity in mixed dentition are summarized in Table 3.3.

Table 3.3. Correlations between the indices and the number of lesions evaluated in children with increasing caries severity by Spearman's correlation test -Mixed Dentition.

	No. of ICDAS 1 lesions N= 12	No. of 1-2 ICDAS lesions N= 39	No. of 1-3 ICDAS lesions N= 91	No. of 1-4 ICDAS lesions N= 130	No. of 1-5 ICDAS lesions N= 168	No. of 1-6 ICDAS lesions N= 205
Total ICDAS	1.000*	0.926*	0.940*	0.931*	0.913*	0.970*
Mean ICDAS score	0.866*	0.880*	0.931*	0.925*	0.901*	0.961*
Mean ICDAS score in caries teeth	0.0	0.222	0.412*	0.314*	0.313*	0.774*
Median ICDAS score of caries surfaces	0.0	0.136	0.085*	0.046	0.074	0.701*
Mode ICDAS score (largest if more than 1 mode)	0.0	0.133	0.240	0.137	0.065	0.681*
Maximum ICDAS score	0.0	0.363*	0.517*	0.428*	0.441*	0.804*
Total ICDAS of 51B, 52B, 54/14O, 55O, 64/24O, 65O, 74O, 75O, 84O, 85O, 16L, 16O, 26L, 26O, 36B, 36O, 37O, 46O, 46B, 47O (if present).	0.866*	0.803*	0.832*	0.820*	0.786*	0.905*
N is the number of children * Significant at 0.001 level						

3.4.2 Cross-Validation Results

3.4.2.1.1 Primary dentition

Similar trends to the original data were observed using the Brazilian sample of children with primary dentition. The total ICDAS score, the mean ICDAS score, and the total ICDAS score of the selected 10 surfaces showed a strong correlation with the number of caries lesions at different severity levels (Table 3.4). The selected combined 10 surfaces had an excellent diagnostic accuracy with an area under the ROC of 0.91 (SE: 0.02, 95% CI: 0.88-0.94). The sensitivity and specificity of the selected 10 surfaces to detect caries in these children were 91% (95% CI: 88.87-95.23%) and 100% (95% CI: 99.08-100.00%) respectively. All the other indices showed moderate correlation with the number of caries lesions only when children with severe caries lesions were included. Correlations between the measures and the number of caries lesions with increasing caries severity in primary dentition are summarized in Table 3.4.

3.4.2.2 Permanent Dentition

Similar trends to the original data were observed using the Spanish sample of children with permanent dentition. The total ICDAS score, the mean ICDAS score, and the total ICDAS score of the selected 12 surfaces showed a strong correlation with the number of caries lesions at different levels of severity (Table 3.5). The selected 12 surfaces had an excellent diagnostic accuracy with an area under the ROC of 0.98 (SE: 0.01, 95% CI: 0.96-0.99). The sensitivity and specificity of the selected 10 surfaces to detect caries in these children were 95.1% (95% CI: 92.27-97.12%) and 100% (95% CI: 95.80-100.00%). All the other indices showed moderate correlation with the number of caries lesions only when children with severe caries lesions were

included. Correlations between the indices and the number of lesions with increasing caries severity in permanent dentition are summarized in Table 3.5.

Table 3.4. Correlations between the indices and the number of lesions evaluated in children with increasing caries severity by Spearman's correlation test in cross-validation sample -Primary Dentition.

	No. of ICDAS 1 lesions N= 26	No. of 1-2 ICDAS lesions N= 323	No. of 1-3 ICDAS lesions N= 403	No. of 1-4 ICDAS lesions N= 434	No. of 1-5 ICDAS lesions N= 443	No. of 1-6 ICDAS lesions N= 444
Total ICDAS	1.000*	0.983*	0.974*	0.970*	0.969*	0.969*
Mean ICDAS score	0.935*	0.973*	0.965*	0.962*	0.962*	0.962*
Median ICDAS score of caries surfaces	0.0	0.403*	0.388*	0.349*	0.349*	0.349*
Mode ICDAS score (largest if more than 1 mode)	0.0	0.312*	0.298*	0.263*	0.263*	0.263*
Maximum ICDAS score	0.0	0.722*	0.700*	0.674*	0.674*	0.674*
Total ICDAS of 51B, 52B, 54O, 55O, 64O, 65O, 74O, 75O, 84O, 85O	0.935*	0.864*	0.861*	0.860*	0.860*	0.860*
N is the number of children * Significant at 0.001 level						

Table 3.5. Correlations between the indices and the number of lesions evaluated in children with increasing caries severity by Spearman's correlation test in cross-validation sample -Permanent Dentition.

	No. of ICDAS 1 lesions N= 27	No. of 1-2 ICDAS lesions N= 245	No. of 1-3 ICDAS lesions N= 303	No. of 1-4 ICDAS lesions N= 335	No. of 1-5 ICDAS lesions N= 347	No. of 1-6 ICDAS lesions N= 347
Total ICDAS	1.000*	0.979*	0.966*	0.964*	0.963*	0.963*
Mean ICDAS score	0.922*	0.977*	0.964*	0.963*	0.962*	0.962*
Mean ICDAS score in caries teeth	0.516*	0.585*	0.456*	0.454*	0.446*	0.446*
Median ICDAS score of caries surfaces	0.0	0.331*	0.180*	0.185*	0.176*	0.176*
Mode ICDAS score (largest if more than 1 mode)	0.0	0.272*	0.096	0.099	0.094	0.094
Maximum ICDAS score	0.0	0.612*	0.488*	0.487*	0.478*	0.478*
Total ICDAS of 14O, 16L, 16O, 24O, 26L, 26O, 36B, 36O, 37O, 46O, 46B, 47O	0.813*	0.882*	0.849*	0.848*	0.840*	0.840*
N is the number of children * Significant at 0.001 level						

3.4.2.3 Mixed Dentition

The total ICDAS score, the mean ICDAS score and the total ICDAS of 51B, 52B, 54/14O, 55O, 64/24O, 65O, 74O, 75O, 84O, 85O, 16L, 16O, 26L, 26O, 36B, 36O, 37O, 46O, 46B, 47O surfaces, if present, showed strong correlation with the number of caries lesions at different level of severity (Table 3.6). The combined selected 22 surfaces had an excellent diagnostic accuracy with an area under the ROC of 0.96 (SE: 0.01, 95% CI: 0.94-0.97). The sensitivity and specificity of these surfaces (if present) to detect caries in these children were 94.74% (95% CI: 92.63-96.36%) and 100% (95% CI: 98.90-100.00%). All the other indices showed moderate

correlation with the number of caries lesions only when children with severe caries lesions were included. Correlations between the measures and the number of lesions with increasing caries severity in mixed dentition are summarized in Table 3.6.

Table 3.6. Correlations between the indices and the number of lesions evaluated in children with increasing caries severity by Spearman's correlation test in cross-validation sample-Mixed Dentition.

	No. of ICDAS 1 lesions N= 37	No. of 1-2 ICDAS lesions N= 332	No. of 1-3 ICDAS lesions N= 501	No. of 1-4 ICDAS lesions N= 552	No. of 1-5 ICDAS lesions N= 581	No. of 1-6 ICDAS lesions N= 606
Total ICDAS	1.000*	0.966*	0.962*	0.957*	0.948*	0.946*
Mean ICDAS score	0.879*	0.944*	0.946*	0.938*	0.929*	0.926*
Mean ICDAS score in caries teeth	0.321	0.476*	0.572*	0.558*	0.507*	0.496*
Median ICDAS score of caries surfaces	0.0	0.246*	0.292*	0.288*	0.242*	0.233*
Mode ICDAS score (largest if more than 1 mode)	0.0	0.194*	0.199*	0.202*	0.166*	0.16*
Maximum ICDAS score	0.0	0.565*	0.623*	0.609*	0.565*	0.553*
Total ICDAS of 51B, 52B, 54/14O, 55O, 64/24O, 65O, 74O, 75O, 84O, 85O, 16L, 16O, 26L, 26O, 36B, 36O, 37O, 46O, 46B, 47O (if present).	0.894*	0.897*	0.891*	0.883*	0.875*	0.874*
N is the number of children * Significant at 0.001 level						

3.5 DISCUSSION

This study aimed to identify potential summary measurements to describe patient's overall caries level in children examined with the ICDAS. Out of the examined synthesis measurements,

total ICDAS score and mean ICDAS score were the best summary measures of caries level at different dental stages. In addition, selectively examining of 10 combined surfaces in primary dentition and 12 combined surfaces in permanent dentition were shown to be an excellent summary measure for patient's overall caries level with high diagnostic accuracy. Most of the examined indices were moderately correlated with caries when children with high caries level were included but weakly correlated in children with a low level of caries. These results were also confirmed in different populations.

The ICDAS categorizes caries on a six-level ordinal scale. Although the ICDAS categorizes the stages of the caries process on the basis of histological extent and progression, the degree of difference between the categories is not absolute but relative [Pitts et al., 2013]. Ideally, a positional statistic such as median or mode can be used to give a center measure for such ordinal scale data [Manikandan, 2011]. However, this may not be very applicable in measuring caries in children as the majority of surfaces are caries-free [Honkala et al., 2011; Runnel et al., 2013], and a zero score will be the non-conditional median or mode in the majority of children. For this reason, median and mode caries scores were used as potential summary measures in the present study. Based on our results, none of the examined positional statistics seemed to be a good summary measure of individual patient's caries level.

Both the total ICDAS and mean ICDAS were very strongly correlated with the number of caries lesions in low caries children, as well as in children with a high level of caries. In addition, they had very similar trends. As the mean is calculated by dividing the total score by the number of teeth, the overall low number of extracted teeth due to caries in these children can be a possible explanation for the trends. Mean ICDAS score in carious teeth was moderately

correlated with caries only when children with high caries level were included. The mean ICDAS in carious teeth was previously suggested as a new overall caries index for the ICDAS that reflects patient's caries status and caries severity [ElSalhy et al., 2013]. This index showed a strong correlation with the number of decayed teeth, the number of enamel carious surfaces, the number of dentine carious surfaces, DMFT/dmft and DMFS/dmfs in children with mixed dentition. In our study, the index had similar trends in all stages of dentition, but these trends only existed in children with high levels of caries. In addition, the population of children included in ElSalhy et al. [2013] study was overall a high caries risk population. For these reasons, the mean ICDAS in carious teeth is not an adequate index to be a universal index to reflect caries in children examined with the ICDAS in different populations with different caries levels.

Although the ICDAS system has existed for almost a decade and is the internationally recommended system for dental health surveys, its adoption remains limited [Aidara et al., 2011]. It has been shown that practitioners perceived the ICDAS as a time-consuming method. This has an impact on its adoption as well as the accuracy of its recordings. Aidara et al. [2011] showed that mistakes originate from dentists' attempts to simplify the completion of ICDAS record charts. Identifying specific teeth or surfaces that can reflect overall caries level of the patient can simplify the examination system and makes it more adaptable. In the present study, 10 surfaces (51B, 61B, 54 O, 55O, 64O, 65O, 74O, 75O, 84O, 85O) in primary dentition and 12 surfaces (14O, 16L, 16O, 24O, 26L, 26O, 36B, 36O, 37O, 46O,46B, 47O) in permanent dentition showed a strong correlation with number of caries lesions in children with different caries levels. They also showed high sensitivity to identify children with caries and high specificity to identify children without caries. These surfaces can be used as a short version of

ICDAS. As less than 12% of the surfaces need to be examined without compromising the accuracy of the examination, the short version can reduce the total examination time and make the ICDAS a more efficient and manageable examination system.

In the present study, the proposed indices were evaluated against the number of caries lesions in children with a gradual increase in the caries level rather than against the number of different caries scores. As caries is a progressive disease process, directly correlating the indices with the ICDAS scores will not give an accurate picture of the relationship between caries level and the summary measure. For example, in children with low caries levels, high caries scores (i.e., 4, 5, or 6) will correlate negatively with the indices and vice versa in children with very high caries level. Gradual evaluation of the correlation between the proposed indices and number of caries lesions in children with different levels of caries gives a more realistic picture of how the indices reflect the caries level in these children. A longitudinal evaluation of the indices as the level of caries progress is the ideal approach for examining these indices. However, this may not be ethically and practically achievable as ignoring caries lesions without intervention is not an acceptable clinical approach. Therefore, the cross-sectional approach used in the present study is the next best assessment.

Difficulty in detecting proximal lesions is an inherent limitation of clinical examinations without using radiographs. This limitation exists in the ICDAS as well as all other clinical examination systems. Our data, as well as the data used for the cross-validation, demonstrated a low level of interproximal caries. However, this limitation should not affect how the indices are summarizing caries level as they reflect the examination system outcome. In addition, examining the relationship of the proposed indices and socioeconomic variables can confirm the validity of

these indices. As the strength of association between caries level and socioeconomic variables tends to vary by socioeconomic status, evaluating how the indices behave can help further validate these indices. One limitation of the proposed indices is that caries activity was not part of the measurements. The indices reflect the number of caries lesions and the level of progression but give equal values for active and inactive lesions. It is difficult to assign a value to caries activity other than a dichotomous option (active/inactive) without longitudinally evaluating lesions' progression so that information on the speed of progression can be developed, scaled and validated.

In conclusion, total ICDAS score and mean ICDAS score were the best summary measures of caries levels at different dental stages to describe patient's overall caries level in children examined with ICDAS. A short version of ICDAS that include selectively examined 10 surfaces in primary dentition and 12 surfaces in permanent dentition can give an excellent summary measurement for patient's overall caries status with a high level of accuracy while simultaneously diminishing the time involved in completing the assessment.

4. Chapter Four

A Proposed Community Caries Index of Treatment Need Derived from the International Caries Detection and Assessment System

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4.1 ABSTRACT

Objective: To examine the accuracy of a short version of the International Caries Detection and Assessment System (ICDAS) compared to the full ICDAS in predicting caries treatment need for children by classifying them into primary, secondary, and tertiary prevention.

Methods: Participants were children with different dentitions from Kuwait, Brazil, and Spain. Children were clinically examined using ICDAS criteria. Children were classified into primary, secondary, and tertiary prevention categories using the full ICDAS (Gold Standard) and the short ICDAS. Kappa score was used to assess the agreement between the short ICDAS and the full ICDAS in classifying children according to caries treatment needs. Sensitivity and specificity, predictive values, likelihood ratios, and the area under the receiver operating characteristic (ROC) curve were used to measure the discriminative and diagnostic accuracy of the proposed short version of ICDAS compared to the full ICDAS. Initial analysis was conducted with Kuwait sample, and the results were cross-validated using Brazil and Spain samples.

Results: Clinical dental examination data from a total 3,076 children were used. The proposed short ICDAS and the full ICDAS showed a very good agreement on caries treatment need determination with Kappa scores of more than 0.833 in all dentitions. The short ICDAS showed excellent operating characteristics in all types of dentitions. The area under the ROC was more than 0.9 in primary dentition, 0.89 in permanent dentition, and 0.86 in mixed dentition. Lowest area under ROC and sensitivity values were observed when discriminating between secondary and tertiary prevention.

Conclusions: The proposed short version of the ICDAS showed good diagnostic accuracy in classifying children according to their caries treatment need into primary, secondary, and tertiary prevention groups. The area under the ROC values were 0.86 or more. Sensitivity values were more than 82% and specificity values were 100% in all dentitions. Positive predictive values were 100% and negative predictive values were at least 85% in different dentitions. By reducing the number of surfaces needed to be examined and the time involved in completing the clinical assessment, the short version of the ICDAS is a convenient alternative to the full ICDAS to be used in community settings.

4.2 INTRODUCTION

"Dental needs" or "Unmet dental needs" is a measure of the extent of unsatisfactory level of dental diagnosis, prevention, or treatment in the community [Committee for Medicinal Products for Human Use, 2006]. Identifying and measuring dental needs are crucial when designing oral health programs, anticipating workforce requirements, allocating resources for health care, and estimating costs of these programs [Aleksejūnienė and Brukienė, 2009]. It is also important for evaluating current programs and comparing different communities and

populations [Aleksejūnienė and Brukienė, 2009; Petersen, 2009]. As dental caries is the most common oral health condition and hence the most costly to treat, identifying and monitoring dental caries-related needs are crucial [Petersen, 2009; Pitts and Zero, 2016]. Assessing dental caries-related treatment needs require screening of the population for caries and summarizing the needs to present it to stakeholders for decision making [Pitts and Zero, 2016].

Determining caries treatment need is dependent on the information captured through caries examination. For years, caries treatment need was evaluated through the number of teeth/surfaces with caries [Helminen and Vehkalahti, 2003]. The total number of carious teeth/surfaces reflects the number of teeth/surfaces that need to be treated. It can identify only patients who need conventional dental treatment from those who do not need any treatment. However, this assessment does not evaluate the intermediate stage between no treatment and conventional treatment where an intervention is needed to arrest or reverse early-stage carious lesions before it reaches the treatment stage [Fisher et al., 2012]. This is mainly because caries is often detected at cavitation stage, which limits the knowledge captured on the intermediate caries stages [Pitts and Zero, 2016].

The International Caries Detection and Assessment System (ICDAS) was developed to detect early and established stages of caries [Pitts, 2004]. The system detects cavitated and non-cavitated lesions and categorized caries into six categories based on the level of caries progression [Ismail et al., 2007; Pitts, 2004]. Although the ICDAS was designed to be practical and easy to use for epidemiological studies, the ICDAS examination system is time-consuming, and this could limit its use for caries screening [Aidara et al., 2011]. The system requires examining 88 surfaces in primary dentition and 128 surfaces in permanent dentition (excluding

third molars) [Ismail et al., 2007; Pitts, 2004]. Instead, less than 12 % of the surfaces (twelve surfaces in permanent dentition and ten surfaces in primary dentition) were proposed to detect more than 90% of children with caries [Chapter three]. A shorter version of the examination system to be used in a community setting for screening of treatment need would expedite the process, reduce cost, and expand the use of the system and would ultimately improve the captured information on the needs of the population. However, the short version should be examined for accuracy in classifying caries according to the treatment need.

Recently, the FDI World Dental Federation released a caries management guideline with emphasis on prevention [Pitts and Zero, 2016]. FDI World Dental Federation suggested the use of primary (preventing disease in the absence of disease), secondary (early detection and control of initial-stage disease), and tertiary prevention (control of an established disease) concepts as the basis for caries management [Pitts and Zero, 2016]. Therefore, the aim of this study was to examine the accuracy of a short version of the ICDAS in predicting treatment need for children by classifying them into primary, secondary, and tertiary prevention stages compared to the full ICDAS.

4.3 METHODS

4.3.1 Study design

This was a cross-sectional study based on clinical oral examination of participating children. The study protocol was approved by the University of Alberta Research Ethics Board (Protocol no. 00050417). Informed consent from parents/guardians of every participating child was collected, and child's assent was attained for the dental examination.

4.3.2 Study setting and participants

Participants were from Kuwait, Brazil, and Spain. Participants from Kuwait were 3 to15-year-old children attending public kindergartens and schools in the Capital Education/Health Region. Data collection procedure were previously described [Chapter three]. Children were grouped according to their dental stage into primary, mixed, and permanent dentition groups.

Participants from Brazil were 12-59 months old. They were examined in Santa Maria, Brazil. Data collection procedure and population demographics were previously described [Piovesan et al., 2014]. All Brazilian children were at the primary dentition stage.

Participants from Spain were the entire school-children population of the Valencia region of Spain. They aged 6-15 years. Data collection procedure and population demographics were previously described [Almerich-Silla et al., 2014]. Spanish children were grouped according to their dental stage into mixed and permanent dentition groups.

The sample size was calculated based on an estimated type I error of 0.05, expected power of 0.8, and minimum expected correlation of 0.20 [ElSalhy et al., 2013] was estimated to be 194 children with caries for each dentition [Hulley et al., 2013]. As caries-free children can range from 30-50% in different populations, 338 children in each dentition were targeted. A 75% positive response rate was expected. Therefore, a total of 518 consents were aimed for distribution for every dental age group.

4.3.3 Clinical examination

Dental examinations were performed by one trained dentist using a mobile dental chair, artificial spotlight, and a mobile dental unit at the school clinics. Before the dental examinations, students were asked to brush their teeth. The ICDAS criteria were employed by the examiner who has been already trained and calibrated with high inter-and intra-examiner reliability (both weighted kappa > 0.9).

4.3.4 Data analysis

Data were managed and analyzed using SPSS 21.0 software (IBM Corp., Armonk, N.Y., USA). Based on FDI World Dental Federation guideline [Pitts and Zero, 2016] and the ICDAS Caries Management System^{TM} recommendations [Pitts and Ekstrand, 2013], children were classified into three caries treatment need categories based on the levels of prevention using both the full ICDAS (Gold Standard) and the short ICDAS. These categories were

1. Primary prevention: children with no caries (all ICDAS caries codes were 0).
2. Secondary prevention: children with ICDAS caries scores of 1, 2, and/or 3.
3. Tertiary prevention: children with an ICDAS caries score of more than 3.

Weighted Kappa scores were used to evaluate the agreement between the short and the full ICDAS in classifying treatment needs in different dentitions. Ordinal regression analysis was conducted to evaluate how much variance in caries treatment need can be explained by the ICDAS scores of the selected 10 surfaces in primary dentition and 12 surfaces in permanent dentition. Caries scores of the surfaces from the short version of ICDAS were used as

independent variables and the patient caries treatment need, based on the full ICDAS (Gold Standard), were used as the dependent variable.

Sensitivity and specificity, positive and negative predictive values (PPV and NPV), positive and negative likelihood ratios (LR+ and LR-), and the area under the receiver operating characteristic (ROC) curve were used to measure the diagnostic accuracy of the short ICDAS compare to the full ICDAS while discrimination between different categories of caries treatment needs. Initial analysis was conducted with Kuwaiti sample, and the results were cross-validated using Brazilian and Spanish samples.

4.4 RESULTS

Clinical dental examination data of a total 3,076 children were used in the present study. The data included 933 children with primary dentition [Kuwait: n=294, 47% male; Brazil: n=639, 50.2% male], 1,205 children with mixed dentition [Kuwait: n=266, 49% male; Spain: n=939, 49% male], and 938 children with permanent dentition [Kuwait: n=505, 49% male; Spain: n=433, 47.8% male]. About 24.5 % of Kuwait children and 30.6% of Brazil children with primary dentition were caries-free. Caries-free children with mixed dentition from Kuwait were 22.9 % and from Spain were 35.5%. Caries-free children with permanent dentition from Kuwait and Spain were 22.8% and 19.9%, respectively.

The proposed short ICDAS and the full ICDAS showed very good agreement on caries treatment need determination. Kappa scores for primary dentition were 0.946 (0.918 - 0.973) for Kuwait sample and 0.891 (0.874 - 0.932) for Brazil sample. For mixed dentition, Kuwait and Spain Kappa scores were 0.833 (0.753 - 0.913) and 0.865 (0.836 - 0.894), respectively. Kappa

scores for permanent dentition were 0.870 (0.834 - 0.905) for Kuwait sample and 0.891 (0.848 - 0.933) for Spain sample.

Ordinal regression analysis showed that 70% of the variance in patient caries treatment need could be explained by the short ICDAS score of the 10 proposed surfaces in primary dentition (Table 4.1). In permanent dentition, 53.5% of the variance in patient overall caries treatment need can be explained by the short ICDAS score of the 12 proposed surfaces (Table 4.2). About 58.1% of the variance in caries treatment need in mixed dentition can be explained by the 20 surfaces in primary/permanent teeth surfaces (Table 4.3). High correlation in the ICDAS scores between most of the surfaces was observed (Spearman correlation coefficients range from 0.4 to 0.9).

Table 4.1. Ordinal regression analysis model of short ICDAS scores of the selected 10 surfaces as predictors of patient's treatment need in primary dentition.

		Estimate	Std. Error	Wald	P-value	95% CI	
						Lower	Upper
Threshold	Primary Prevention	.523	.115	20.561	<0.001	.297	.749
	Secondary Prevention	4.663	.309	227.427	<0.001	4.057	5.269
Surface	51B	.397	.158	6.277	0.012	.086	.708
	61B	.808	.170	22.664	<0.001	.475	1.140
	54O	.472	.136	12.062	0.001	.206	.738
	55O	.267	.141	3.597	0.58	-.009	.543
	64O	.093	.142	.433	0.11	-.185	.372
	65O	.411	.145	8.006	0.005	.126	.696
	74O	.469	.112	17.597	<0.001	.250	.688
	75O	.480	.119	16.192	<0.001	.246	.714
	84O	.429	.112	14.697	<0.001	.210	.649
	85O	.620	.120	26.567	<0.001	.384	.855
Nagelkerke Pseudo $R^2 = 0.700$							

Table 4.2. Ordinal regression analysis final model of ICDAS scores of the selected 12 surfaces as predictors of patient's treatment need in permanent dentition.

		Estimate	Std. Error	Wald	P-value	95% CI	
						Lower	Upper
Threshold	Primary Prevention	-.071	.152	.218	0.640	-.369	.227
	Secondary Prevention	5.177	.407	161.860	<0.001	4.379	5.974
Surface	14O	-.133	.244	.296	0.586	-.610	.345
	16L	.072	.176	.166	0.683	-.274	.418
	16O	.739	.130	32.396	<0.001	.484	.993
	24O	-.095	.240	.158	0.691	-.565	.374
	26L	.082	.176	.215	0.643	-.263	.427
	26O	.397	.125	10.136	0.001	.153	.642
	36B	.038	.162	.054	0.816	-.281	.356
	36O	.370	.126	8.616	0.003	.123	.617
	37O	.481	.128	14.016	<0.001	.229	.733
	46O	.579	.130	19.910	<0.001	.325	.833
	46B	-.027	.174	.024	0.876	-.368	.314
	47O	.323	.128	6.375	0.012	.072	.573
Nagelkerke Pseudo R^2 = 0.535							

Table 0.3. Ordinal regression analysis final model of ICDAS scores of teeth surfaces as predictors of patient's treatment need in mixed dentition.

		Estimate	Std. Error	Wald	P-value	95% CI	
						Lower	Upper
Threshold	Primary Prevention	.574	.090	40.327	.000	.397	.752
	Secondary Prevention	3.741	.186	403.031	.000	3.376	4.106
Surface	37O	.401	.155	6.639	.010	.096	.705
	47O	.067	.161	.176	.675	-.248	.382
	16O	.575	.102	32.017	.000	.376	.775
	16L	-.299	.171	3.051	.081	-.634	.036
	55O	.559	.096	34.185	.000	.371	.746
	54/14O	-.122	.131	.859	.354	-.379	.136
	51B	.749	.445	2.833	.092	-.123	1.620
	26O	.275	.095	8.316	.004	.088	.462
	26L	-.099	.152	.425	.514	-.397	.199
	65O	.292	.101	8.343	.004	.094	.491
	64/24O	.148	.119	1.534	.215	-.086	.381
	61B	.236	.400	.349	.555	-.547	1.019
	36O	.522	.106	24.367	.000	.315	.729
	36B	-.045	.160	.080	.777	-.358	.268
	75O	.531	.097	30.048	.000	.341	.721
	74O	.170	.144	1.410	.235	-.111	.452
	46O	.201	.112	3.205	.073	-.019	.420
	46B	.258	.168	2.350	.125	-.072	.587
	85O	.580	.101	33.000	.000	.382	.778
	84O	.241	.149	2.626	.105	-.050	.532
Nagelkerke Pseudo R^2 = 0.581							

The short ICDAS showed excellent operating characteristics in all types of dentitions. In primary dentition, the index has an area under the ROC of 0.9 or more when discrimination between different types of treatment needs. The lowest ROC measure was seen in discriminating between secondary and tertiary prevention with ROC of 0.9. The lowest sensitivity measure was found to be 81.92% when discriminating between secondary and tertiary prevention. The short ICDAS has a specificity of 100% in all treatment need comparisons. In addition, the PPV was 100% in discriminating between different types of treatment needs with the lowest NPV of 88%

was seen in discriminating between secondary and tertiary prevention. Tables 4.4 and 4.5 summarize the operating characteristics of the selected surfaces to classify treatment need in primary dentition in the Kuwaiti and Brazilian samples, respectively.

Table 4.4. Operating characteristics of the selected surfaces to classify treatment need in primary dentition- Kuwait sample.

Measure	Primary and secondary	Primary and tertiary	Secondary and tertiary
Area Under ROC	0.923 (0.864 – 0.982)	1 (1 – 1)	0.985 (0.971 – 0.999)
Sensitivity (95%CI)	84.62 (71.92 - 93.12)	100 (97.78 – 100)	96.47 (92.48 – 98.69)
Specificity (95%CI)	100 (95.01 – 100)	100 (95.01 – 100)	100 (91.96 – 100)
PPV (95%CI)	100 (100 – 100)	100 (100 – 100)	100 (100 – 100)
NPV (95%CI)	90.0 (82.63 – 94.45)	100 (100 – 100)	88.0 (76.97 – 94.15)
LR+	∞	∞	∞
LR-	0.15 (0.08 – 0.29)	0	0.04 (0.02 – 0.08)

Table 4.5. Operating Characteristics of the selected surfaces to classify treatment need in primary dentition- Brazil sample.

Measure	Primary and Secondary	Primary and tertiary	Secondary and tertiary
Area Under ROC	0.935 (0.911 – 0.960)	0.986 (0.972 – 1)	0.898 (0.862 – 0.935)
Sensitivity (95%CI)	87.02 (82.34 - 90.84)	96.67 (92.39 - 98.91)	81.92 (75.45 - 87.29)
Specificity (95%CI)	100 (98.13 – 100)	100 (98.13 – 100)	100 (98.40 – 100)
PPV (95%CI)	100 (100 – 100)	100 (100 – 100)	100 (100 – 100)
NPV (95%CI)	85.15 (80.74 - 88.70)	97.50 (94.28 - 98.93)	87.69 (83.89 - 90.70)
LR+	∞	∞	∞
LR-	0.13 (0.09 - 0.18)	0.03 (0.01 - 0.08)	0.18 (0.13 - 0.25)

In permanent dentition, the short ICDAS had an area under the ROC of 0.89 or more with the lowest measure seen in the discrimination between secondary and tertiary prevention. The lowest sensitivity measure was found to be 87.69% when discriminating between secondary and tertiary prevention. The short ICDAS has a specificity of 100% in all treatment need comparisons. In addition, the PPV was 100% in discriminating between different types of treatment needs with the lowest NPV of 85% was seen in discriminating between primary and

secondary prevention. Tables 4.6 and 4.7 summarizes the operating characteristics of the selected surfaces to classify caries treatment need in children with permanent dentition.

Table 4.6. Operating characteristics of the selected surfaces to classify treatment need in permanent dentition- Kuwait sample.

Measure	Primary and Secondary	Primary and tertiary	Secondary and tertiary
Area Under ROC	0.969 (0.950 – 0.988)	1 (1 – 1)	0.895 (0.859 – 0.932)
Sensitivity (95%CI)	93.81 (89.65 - 96.66)	97.95 (94.11 - 99.57)	89.38 (83.53 – 93.69)
Specificity (95%CI)	100 (96.84 – 100)	100 (96.84 – 100)	100 (98.14 – 100)
PPV (95%CI)	100 (100 – 100)	100 (100 – 100)	100 (100 – 100)
NPV (95%CI)	89.84 (83.94 - 93.74)	97.46 (92.60 – 99.16)	92.06 (88.09 - 94.78)
LR+	∞	∞	∞
LR-	0.06 (0.04 - 0.10)	0.02 (0.01 - 0.06)	0.11 (0.07 - 0.17)

Table 4.7. Operating characteristics of the selected surfaces to classify treatment need in permanent dentition- Spain sample.

Measure	Primary and Secondary	Primary and tertiary	Secondary and tertiary
Area Under ROC	0.980 (0.966 – 0.994)	0.986 (0.964 – 1)	0.886 (0.825 – 0.947)
Sensitivity (95%CI)	96.0 (92.96 - 97.99)	96.61 (88.29 - 99.59)	87.69 (77.18 – 95.53)
Specificity (95%CI)	100 (98.80 – 100)	100 (95.80 – 100)	100 (98.61 – 100)
PPV (95%CI)	100 (100 – 100)	100 (100 – 100)	100 (100 – 100)
NPV (95%CI)	88.66 (81.42 - 93.31)	97.73 (91.67 – 99.41)	97.06 (94.52 - 98.44)
LR+	∞	∞	∞
LR-	0.04 (0.02 - 0. 07)	0.03 (0.01 - 0.13)	0.12 (0.06 - 0.24)

In mixed dentition, the short ICDAS had an area under the ROC of 0.86 or more when discrimination between different types of treatment needs with the lowest ROC measure was seen in the discrimination between secondary and tertiary prevention. The lowest sensitivity measure was found to be 85.42% when discriminating between secondary and tertiary prevention. The short ICDAS has a specificity of 100% in all treatment need comparisons. In addition, the PPV was 100% in discriminating between different types of treatment needs with the lowest NPV of 85% was seen in discriminating between secondary and tertiary prevention.

Tables 4.8 and 4.9 summarize the operating characteristics of the selected surfaces to classify treatment need in children with mixed dentition in the Kuwaiti and Spanish samples, respectively.

Table 4.8. Operating characteristics of the selected surfaces to classify treatment need in Mixed dentition- Kuwait sample.

Measure	Primary and Secondary	Primary and tertiary	Secondary and tertiary
Area Under ROC	0.961 (90.95– 100)	0.986 (96.40 – 100)	0.860 (77.85– 94.21)
Sensitivity (95%CI)	92.11 (78.62 – 98.34)	94.87 (82.68 - 99.37)	86.05 (72.07 – 94.70)
Specificity (95%CI)	100 (89.72 – 100)	100 (89.75 – 100)	100 (90.0 – 100)
PPV (95%CI)	100 (100 – 100)	100 (100 – 100)	100 (100 – 100)
NPV (95%CI)	91.89 (79.28 - 97.11)	94.44 (81.51 – 98.50)	85.37 (73.52 - 92.45)
LR+	∞	∞	∞
LR-	0.08 (0.03 - 0. 23)	0.05 (0.01 - 0.20)	0.14 (0.07 - 0.29)

Table 4.9. Operating characteristics of the selected surfaces to classify treatment need in Mixed dentition- Spain sample.

Measure	Primary and Secondary	Primary and tertiary	Secondary and tertiary
Area Under ROC	0.980 (96.77– 99.19)	0.921 (89.95– 94.21)	0.913 (88.90– 93.63)
Sensitivity (95%CI)	96.24 (93.77– 97.93)	90.11 (84.82 – 94.03)	85.42 (79.62 – 90.09)
Specificity (95%CI)	100 (98.90 – 100)	100 (98.90 – 100)	100 (98.97 – 100)
PPV (95%CI)	100 (100 – 100)	100 (100 – 100)	100 (100 – 100)
NPV (95%CI)	95.97 (93.43 - 97.55)	94.87 (92.27 – 96.63)	92.75 (90.08 - 94.74)
LR+	∞	∞	∞
LR-	0.04 (0.02 - 0.06)	0.1 (0.06 - 0.15)	0.15 (0.10 - 0.21)

4.5 DISCUSSION

This study aimed to examine the accuracy of a short version of the ICDAS in predicting caries treatment need for children. The shortened ICDAS showed very good agreement with the full ICDAS in classifying children into primary, secondary and tertiary prevention categories. It also showed good operating characteristics and high level of diagnostic accuracy to discriminate different categories of treatment need in different dentitions.

Although this was the first attempt to use specific surfaces to describe the full dentitions and classify patients based on caries treatment need, such concept has been used previously for the assessment of periodontal treatment needs. Most commonly used systems are the Community Periodontal Index of Treatment Need (CPITN), Periodontal Treatment Need System (PTNS), Basic Periodontal Examination (BPE), and Periodontal Screening and Recording (PSR)[Cole et al., 2014; Cutress et al., 1987; Landry and Jean, 2002; Mann et al., 1980]. In all these indices, specific surfaces/teeth are examined in every quadrant/sextant, and these surfaces/teeth are used to identify periodontal treatment need. All of these indices aimed to identify the worse condition rather than reflecting the average condition of the individual examined [Gjermo, 1994]. A similar principle was applied in this study. Children were classified based on the highest ICDAS score they had. The assumption behind this approach is that these patients have to be managed by a dentist who will also be able to take care of less severe stages of the disease that are present in the mouth. The target of such approach is to identify the population who can be managed through community approaches and those who needs to see a dentist. This may make the management of caries more cost-effective as a large portion of the population can be managed through community-based prevention programs.

Both the selected ten surfaces in primary dentitions and the twelve surfaces in permanent dentition showed excellent diagnostic accuracy to classify children with different dentitions based on treatment need. The surfaces had lower sensitivity (less than 10% difference) in discriminating between secondary prevention and tertiary prevention in primary dentition than other dentitions. This can be explained by the fact that caries in primary dentition is generally deep and more spread in the mouth [Baginska et al., 2014], which increases the probability of having false negative results by not examining all the surfaces. However, the lowest values

achieved in the present study are considered good values for a screening test [Warner, 2004] and much higher than the commonly used periodontal indices of treatment need [Bassani et al., 2006]. Since the total score of these surfaces showed a strong correlation with the number of caries lesions at different severity levels and had a high diagnostic accuracy to identify children with caries [Chapter 3], the short ICDAS can be used to measure the prevalence, severity, and treatment need of caries in children.

Classifying caries treatment need into primary, secondary, and tertiary prevention categories highlights the importance of prevention in the management of caries [Pitts and Zero, 2016]. Primary prevention approaches aim to reduce the exposure caries risk factors by changing unhealthy behaviors and by increasing resistance to caries through promoting caries prevention modalities like fluoride and fissure sealant. Secondary prevention aims to early detect and manage non-cavitated lesions by reversing and arresting them; thus, preventing further tooth destruction. Tertiary prevention aims to reduce the impact of cavitated lesions by preventing pulpal involvement and tooth loss as well as restoring function and aesthetics [Pitts and Zero, 2016]. Another advantage of classifying children according to prevention stages is that it fits the expansion of the dental workforce and incorporate the role of mid-level dental providers in managing caries. Both the primary and secondary prevention stages can be fully managed by dental therapists and dental hygienists. Therefore, using the proposed classification will help in a more accurate estimation of the needed dental workforce rather than overestimation of the number of dentists needed.

In this study, commonly used measures of diagnostic accuracy including sensitivity and specificity, predictive values, likelihood ratios, the area under the receiver operating

characteristic (ROC) curve were used to evaluate the performance of the short ICDAS. These measures assess the discriminative property of the test/cutoff point as well as its predictive ability [Eusebi, 2013; Simundic, 2009]. Sensitivity and specificity are measures of discriminative ability. Both sensitivity and specificity are transferable measures that can be used in different populations and settings as they are not dependent on disease prevalence [Eusebi, 2013; Simundic, 2009]. The likelihood ratio is the ratio of expected test results in subjects with a certain condition to the subjects without the condition. Both positive and negative likelihood ratios are calculated from specificity and sensitivity. Therefore, they are not dependent on disease prevalence. The PPV and NPP describe the probability of having/not having the condition for a subject with a positive/negative result [Eusebi, 2013; Simundic, 2009]. Both PPV and NPV are affected by disease prevalence in the evaluated population. The shape of a ROC curve and the area under the ROC curve reflects the discriminative power of a test or a cutoff point. The area under the ROC curve is a measure of diagnostic accuracy, and it is an indicator of the goodness of the test [Eusebi, 2013; Simundic, 2009].

An inherent limitation in all clinical examination systems is the difficulty in detecting proximal lesions without using radiographs. This limitation exists in the full ICDAS as well as the proposed short form. However, this limitation should not affect how the short ICDAS can classify treatment need compared to the full ICDAS. The short version of ICDAS showed very good agreement with the full ICDAS.

A limitation of the proposed short version is that caries activity was not part of the classification. However, this should not affect the classification. Non-cavitated lesions, either active or inactive, need to be managed through secondary prevention to arrest active lesions or

maintain the inactivity of inactive lesions. On the other hand, cavitated lesions need to be evaluated by a dentist to determine the appropriate management and therefore has to be classified into tertiary prevention categories. The surfaces in the short ICDAS were selected because they were the most commonly carious surfaces in children and showed excellent diagnostic accuracy in identifying children with caries [Chapter 3].

In conclusion, a short version of the ICDAS that is based on selectively examining ten surfaces in primary dentition and twelve surfaces in permanent dentition showed good to excellent diagnostic accuracy in classifying children according to their caries treatment need into primary, secondary, and tertiary prevention categories. By reducing the number of surfaces needed to be examined and the time involved in completing the clinical assessment, the short version of the ICDAS is a convenient alternative to the full ICDAS to be used in community settings.

5. Chapter Five

The Relationship between Children's Oral Health Behaviors and Caries Measured Using the International Caries Detection and Assessment System

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5.1 ABSTRACT

Objective: To examine the relationship between oral health behaviors and caries using the total International Caries Detection and Assessment (ICDAS) score and the total score of a short form of ICDAS as patient summary measures of caries.

Methods: Participants were 13-14 years-old children attending public schools in the Kuwait Capital Region. Dental examinations were performed using the ICDAS criteria and children completed a previously validated oral health behaviors questionnaire. Linear regression analysis was used to examine behaviors as predictors of caries level.

Results: Total of 424 children (61.6% males and 38.4% female) participated in the present study. The total score of the full ICDAS and the short ICDAS were highly correlated (ρ=0.901, $p<0.001$). Both the full and the short form of ICDAS showed similar relationships with oral health behaviors. Children who visited the dentist due to pain had significantly higher level of caries (full ICDAS p=0.004; short ICDAS p=0.001) with no significant difference between children who visited the dentist for a regular check-up or other reasons ($p>0.05$). Children who brushed their teeth once a day or less had significantly higher levels of caries compared to

children who brushed their teeth more than once a day (full ICDAS p=0.008; short ICDAS p=0.02). Having adjusted for other behaviors, every unit increase in the sugar consumption frequency was associated with an increase in the total score of the full ICDAS of 4 units (B=3.92, 95% CI: 1.53-6.31, p=0.001) and the short ICDAS of 2 units (B=2.01, 95% CI: 0.85-3.17, p=0.001). No significant association between flossing, use of mouthrinse, chewing gum and caries level was found (all p>0.05).

Conclusions: Both the frequency of brushing and sugar consumption were associated with caries level. The frequency of sugar consumption was the only predictor of caries level, measured by the total score of the full and the short forms of ICDAS, after controlling for all behaviors. Other measured oral health behaviors were not impactful. The short ICDAS showed similar relationships with oral health behaviors as the full ICDAS.

5.2 INTRODUCTION

Dental caries is the most common behavior-associated chronic disease in children [Petersen, 2009]. It is considered one of the main determinants of individuals' oral health-related quality of life [Gherunpong et al., 2006]. Multiple oral health behaviors have been proposed to be associated with caries formation or its prevention. These behaviors include dental attendance, sugar consumption, tooth brushing, use of dental floss, use of fluoridated toothpaste, chewing gums and/or use of mouthrinse [Gherunpong et al., 2006]. Some of these behaviors like sugar consumption, use of fluoridated toothpaste, and use of fluoride mouthrinse have shown to be consistently associated with caries presence or absence while others like use of dental floss and gum chewing have shown inconsistency in their relationship [Chankanka et al., 2011; Lakhanpal

et al., 2014; Levine et al., 2007; Marinho et al., 2016; Sambunjak et al., 2011; Soderling, 2009]. One of the reasons behind the inconstancies maybe how caries was measured when studying these associations. Traditional studies, which identified behaviors associated with caries, measured caries using the WHO criteria which detect only cavitated caries lesions [World Health Organization, 2013]. However, more recent studies attempted to include early caries lesions, which can be more reflective of the impact or effect of these oral health behaviors [Chankanka et al., 2011; ElSalhy et al., 2013].

Identifying behaviors that affect caries formation or prevent its occurrence is important when designing oral health education and promotion programs. Targeting limited but most critical behaviors should be easier for patients to modify rather than giving a large number of recommended behaviors to change [Institute of Medicine, 2001]. Hence, improved compliance with positively linked oral health behaviors should improve the oral health status of children and, consequently, their oral health-related quality of life.

The International Caries Detection and Assessment System (ICDAS) is a standardized comprehensive clinical examination system for detecting carious lesions at different stages of development [Pitts, 2004]. The system categorizes enamel and dentine lesions according to their progression stage and includes both non-cavitated and cavitated lesions as well as recurrent carious lesions [Ismail et al., 2007; Pitts, 2004; Pitts, 2009a, b; Pitts et al., 2013]. Compared to the commonly used WHO caries examination criteria, the ICDAS system includes more information about patients' caries status. In Chapter 3, the total ICDAS score was proposed to be a comprehensive summary measure that reflects patient overall caries level. In addition, a short version of ICDAS was proposed to be a good measure of caries level, and a good predictor of

treatment need in children [Chapter 3; Chapter 4]. Examining oral health behaviors using measures that includes more information about dental caries can help to better understand how these behaviors relate to caries.

For these reasons, this study aimed to examine the relationship between oral health behaviors and caries using the total ICDAS score of the full ICDAS and the short ICDAS as a patient summary measure of caries.

5.3 METHODS

5.3.1 Study design

This was a cross-sectional study based on oral examinations of participating children and a self-administrated questionnaire. The study protocol was permitted by the University of Alberta Research Ethics Board (Protocol no. 00050417). Parents/guardians informed consent of every participating child was collected, and child's assent was obtained prior to the dental examination.

5.3.2 Study setting and participants

The study was conducted in the Capital Education/Health Region of Kuwait. The data collection was carried out for 3 months during the 2014-2015 academic year. Participants were grade 7 and 8 (13-14 years-old) children attending public schools in the Kuwait Capital Region. Four intermediate schools were randomly selected from a list provided by the Ministry of Education Research Department. All children at these schools were approached for participation.

The required sample size was calculated based on the number of 13-14 years old children in the capital region, a type I error of 0.05, margin of error of 0.05, and estimated proportion of children with adequate behaviors of 0.5 to be 370 surveys as a target. As 70% response rate was expected, a total of 500 consents were distributed.

5.3.3 Clinical examination

Dental examinations were performed by one trained dentist using a mobile dental chair, artificial spotlight, and a mobile dental unit at the school clinics. Before the dental examinations, students were asked to brush their teeth. The ICDAS criteria were employed by the examiner who has been already trained and calibrated with high inter- and intra-examiner reliability (both weighted kappa > 0.9). Both the total score of the full ICDAS and a short form of ICDAS (using ten primary dentition surfaces and twelve permanent dentition surfaces) were calculated as previously described [Chapter 3].

5.3.4 Oral health behaviors questionnaire

A previously validated Arabic oral health behaviors questionnaire consisting of 12 questions was used [ElSalhy et al., 2015]. Two questions were asked about dental attendance: When was your last visit to a dentist? (Less than a year ago/One to two years ago/ More than two years ago), and reason for the last dental visit? (Pain/Regular check-up/Others). Four questions on the frequency of brushing, flossing, use of mouthrinse and gum chewing (Less than once a day/Once a day/More than once a day) were used. Two questions about toothpaste use: Do you use fluoride-containing toothpaste to clean your teeth? (Yes, No, Sometimes) were used. Five questions were adapted from the validated Health Behaviors in School-Aged Children (HBSC)

survey [Currie et al., 2009] asked about the consumption of candies, ice cream, chocolate, cake, biscuit, juices, and soft drinks per day to evaluate the frequency of sugary food/drink intakes per day. Answers to the questions were “Never,” “Once a week or less,” “2-4 times a week”, “5-6 times a week”, “Once a day, every day,” “Twice a day, every day,” “More than twice, every day.” Scores of 0 was given for “Never” and “Once a week or less”; 0.5 for “2-4 times a week”, 0.75 for “5-6 a week”; 1 for “Once a day, every day”; 2 for “Twice a day, every day”; and 3 for “More than 2 every day”. For data description, participants were grouped into 3 categories of sugar consumption: 0-3, 4-5, and 6 or more [Gherunpong et al., 2006].

5.3.5 Data analysis

Data were managed and analyzed using SPSS 21.0 software (IBM Corp., Armonk, N.Y., USA). Shapiro-Wilk test was used to examine data normality. As total ICDAS score of the full ICDAS and the short ICDAS was not normally distributed, frequencies and medians (25^{th} percentile, 75^{th} percentile) were used for data description. Associations between sex (Dichotomous variable) and different habits (Categorical variables) were evaluated by Chi-square test. Kruskal-Wallis analysis was used to examine the relationship between caries level measured as total ICDAS scores of the full ICDAS and the short ICDAS (Continuous variables) and different habits (Categorical variables). Linear regression analysis was used to evaluate habits as predictors of caries level. All habits were used as independent variables. All behaviors were used as categorical variables in the regression analysis except for sugar consumption which was used as a continuous variable. The level of significance was set at a p-value of 0.05.

5.4 RESULTS

Of the 533 children approached at the selected four schools, 424 were finally assessed with respective parent authorizations (response rate 79.5%). All the 424 children (61.6 % males and 38.4 % females) completed the questionnaire.

Two-thirds of children (63.3%) visited the dentist within the last year with pain as the main reason for the dental visit for half of them. About 85.9% of children brushed their teeth once a day or more and the majority used fluoridated toothpaste. More than half of the children (55.4%) consumed sugary foods/drinks 6 times or more per day. Only 8.3% reported 3 times or less sugar intake per day. Only one-fourth of children used dental floss once a day or more. About 40% of children used chewing gum more than once a day and used a mouthrinse at least once a day. Brushing, flossing, use of mouthrinse, and gum chewing behaviors were significantly different between male and female children. Participants' behaviors are summarized in Table 5.1.

Table 5.1. Participants' oral health behaviors according to sex.

Behaviors	Male N=261		Female N=163		p-value*	Total N=424	%
	N	%	N	%			
Last dental visit							
Less than a year	159	60.9	105	64.4	0.399	264	63.3
One to two years	55	21.1	36	22.1		91	21.8
More than two years	43	16.5	19	11.7		62	14.9
Reason for last dental visit							
Pain	131	50.2	72	44.2	0.547	203	47.9
Regular check-up	75	28.7	52	31.9		127	30.0
Other reason	55	21.1	39	23.9		94	22.2
Brushing							
More than once a day	123	47.1	111	68.1	<0.001	234	55.2
Once a day	91	34.9	39	23.9		130	30.7
Less than once a day	46	17.6	13	8.0		59	13.9
Use of toothpaste							
Always	241	92.3	154	94.5	0.333	395	93.2
No/sometimes	19	7.7	8	5.5		27	6.8
Dental flossing							
More than once a day	26	10.0	6	3.7	0.013	32	7.5
Once a day	47	18.0	25	15.3		72	17.0
Less than once a day	188	72.0	131	80.4		319	75.2
Use of mouthrinse							
More than once a day	56	21.5	17	10.4	<0.001	73	17.2
Once a day	69	26.4	22	13.5		91	21.5
Less than once a day	135	51.7	124	76.1		259	61.1
Use of chewing gum							
More than once a day	92	35.2	77	47.2	0.009	169	39.9
Once a day	69	26.4	39	23.9		108	25.5
Less than once a day	99	37.9	45	27.6		144	34.0
Frequency of sugar intake							
0-3	26	10.1	12	7.5	0.628	38	9.0
4-5	91	34.9	60	36.7		151	35.6
6 or more	144	55.0	91	55.8		235	55.4
* Chi-square test							

The total score of the full ICDAS and the short ICDAS were highly correlated ($\rho = 0.901$, $p<0.001$). Comparable relationships between caries level are different behavior were measured using both the total full and the total short ICDAS as measures of caries level (Tables 5.2 and 5.3). Children who visited the dentist due to pain had significantly higher median total ICDAS scores (full ICDAS $p=0.004$; short ICDAS $p=0.001$) with no significant difference between children who visited the dentist for a regular check-up or other reasons ($p>0.05$). Children who brushed their teeth once a day or less had significantly higher median total ICDAS score compared to children who brushed their teeth more than once a day (full ICDAS $p=0.008$; short ICDAS $p=0.02$). Different frequencies of sugar consumption were significantly associated with caries level (full ICDAS $p=0.002$; short ICDAS $p=0.001$). Children who consumed sugary foods and drinks 6 times a day had significantly higher median total ICDAS score than children who consumed sugars less than 6 times a day ($p<0.05$). In addition, children who consumed sugars 4-5 times a day had significantly higher median total ICDAS score than children who consumed sugars three times or less ($p<0.05$). Participants' median total ICDAS scores of the full ICDAS and the short ICDAS according to oral health behaviors are summarized in Table 5.2 and Table 5.3, respectively.

Table 5.2. Participants' median (25th percentile, 75th percentile) total score of the full ICDAS according to oral health behaviors.

Behavior	Male			Female			Total			p-value*
	25th	Median total ICDAS	75th	25th	Median total ICDAS	75th	25th	Median total ICDAS	75th	
Last dental visit										
Less than a year	4.0	10.0	20.0	5.0	12.0	20.0	4.5	10.0	20.0	0.460
One to two years	5.0	11.0	23.0	4.0	9.0	25.0	4.0	9.5	24.5	
More than two years	5.0	12.0	25.0	7.0	13.5	26.5	5.0	12.0	26.5	
Reason for last dental visit										
Pain	6.0	14.0	24.5	5.5	13.0	25.0	6.0	14.0[a]	25.0	0.004
Regular check-up	3.0	7.5	17.0	3.5	10.0	17.5	3.0	9.0[b]	18.0	
Other reason	4.0	8.0	11.5	2.0	13.0	25.0	3.8	9.0[b]	17.5	
Brushing										
More than once a day	3.0	8.0	14.0	5.0	11.0	19.5	4.0	9.5[a]	18.0	0.003
Once a day	7.0	14.5	23.0	5.0	13.5	22.0	6.0	14.0[b]	22.5	
Less than once a day	4.0	10.0	21.0	5.0	16.0	25.0	4.0	11.0[b]	24.0	
Use of toothpaste										
Always	4.0	10.0	20.0	5.0	11.5	20.0	5.0	10.0	20.0	0.201
No	10.0	12.0	29.0	16.0	20.0	25.0	10.0	17.0	28.0	
Sometimes	2.0	6.0	19.0	19.0	21.0	23.0	4.0	17.0	21.0	
Dental flossing										
More than once a day	4.0	10.0	16.0	2.0	5.5	8.0	3.0	8.5	14.5	0.560
Once a day	3.0	9.5	22.0	9.0	16.0	25.5	4.5	11.0	22.5	
Less than once a day	5.0	10.0	22.0	5.0	12.0	20.0	5.0	11.0	22.0	
Use of mouthrinse										
More than once a day	2.0	7.0	15.0	6.0	24.0	27.0	2.5	8.0	22.5	0.218
Once a day	5.0	14.0	22.0	7.5	12.0	19.5	5.5	12.0	21.5	
Less than once a day	5.0	11.5	22.5	4.0	10.0	19.5	5.0	11.0	21.5	
Use of chewing gum										
More than once a day	5.0	10.0	22.0	5.0	12.0	21.5	5.0	11.0	22.0	0.748
Once a day	3.0	9.5	18.0	4.0	12.0	25.0	4.0	10.0	21.5	
Less than once a day	4.5	12.0	23.0	6.0	10.0	19.0	5.0	11.5	22.0	
Frequency of sugar intake										
0-3	0.5	7.0	13.0	5.5	8.0	14.5	4.0	7.0[a]	14.0	0.002
4-5	4.0	8.0	15.5	3.0	10.5	22.0	4.0	9.0[b]	17.0	
6 or more	5.0	13.0	23.0	6.0	13.0	24.0	5.0	13.0[c]	23.0	

*Kruskal-Wallis Test
Within columns, medians with different superscript are significantly different with Mann-Whitney test ($p<0.05$).

Table 5.3. Participants' median (25th percentile, 75th percentile) total score of the short ICDAS according to oral health behaviors.

Behavior	Male			Female			Total			p-value*
	25th	Median total ICDAS	75th	25th	Median total ICDAS	75th	25th	Median total ICDAS	75th	
Last dental visit										
Less than a year	2.0	6.5	12.5	3.0	8.0	12.0	2.0	7.5	12.0	0.530
One to two years	3.0	7.0	15.0	2.0	5.5	16.0	3.0	7.0	15.0	
More than two years	3.0	8.0	16.0	3.5	9.0	17.5	3.0	9.0	17.0	
Reason for last dental visit										
Pain	3.0	9.0	15.0	4.0	10.0	15.5	4.0	9.0[a]	15.0	0.001
Regular check-up	1.0	5.0	10.0	2.0	5.5	10.0	2.0	6.0[b]	10.0	
Other reason	3.5	5.0	9.5	1.0	10.0	19.0	2.25	6.5[b]	11.0	
Brushing										
More than once a day	1.0	5.0	12.0	2.5	8.0	13.0	2.0	7.0[a]	12.0	0.02
Once a day	4.0	9.0	14.0	3.0	8.0	12.0	3.75	9.0[b]	14.0	
Less than once a day	3.0	6.0	13.0	4.0	10.0	18.5	3.0	8.0[b]	14.0	
Use of toothpaste										
Always	2.0	7.0	13.0	3.0	8.0	13.0	3.0	7.0	13.0	0.163
No	7.0	10.0	12.0	7.0	9.0	13.5	7.25	10.5	13.75	
Sometimes	4.5	11.0	17.0	10.0	14.5	19.0	3.0	10.0	17.0	
Dental flossing										
More than once a day	4.0	9.0	12.0	1.5	5.5	8.0	3.0	8.0	10.0	0.768
Once a day	1.0	8.0	14.0	7.0	10	18.5	2.25	9.0	15.0	
Less than once a day	2.0	7.0	14.0	3.0	9.5	16.5	3.0	9.0	15.0	
Use of mouthrinse										
More than once a day	1.0	5.0	9.0	2.0	16.0	22.0	1.5	7.0	13.0	0.179
Once a day	4.0	10.0	15.0	5.5	10.0	16.5	4.0	10.0	15.0	
Less than once a day	2.0	7.0	13.0	3.0	7.5	12.0	2.0	7.0	13.0	
Use of chewing gum										
More than once a day	3.0	8.5	14.5	2.5	9.0	12.0	3.0	9.0	14.0	0.286
Once a day	1.0	6.0	12.0	2.0	8.0	17.0	1.25	7.0	14.0	
Less than once a day	2.0	7.0	13.0	3.0	7.0	11.0	3.0	7.0	12.0	
Frequency of sugar intake										
0-3	0.0	5.0	9.0	3.0	5.0	10.0	0.0	5.0[a]	9.0	0.001
4-5	2.0	6.0	11.0	2.0	7.0	12.5	2.0	6.0[b]	12.0	
6 or more	3.0	9.0	15.0	4.0	9.0	14.0	3.5	9.0[c]	15.0	

*Kruskal-Wallis Test
Within columns, medians with different superscript are significantly different with Mann-Whitney test ($p<0.05$).

After adjusting for sex and other oral health behaviors (frequency of dental visit, frequency of brushing, use of mouthrinse, and chewing gum) during the linear regression analysis, the frequency of sugar consumption was the only predictor of caries level measured using the total ICDAS score of the full ICDAS (Table 5.4) and the short ICDAS (Table 5.5). Every unit increase in the sugar consumption frequency was associated with an increase in the total score of the full ICDAS of 4 units (B=3.92, 95% CI: 1.53-6.31, p=0.001) and the short ICDAS of 2 units (B=2.01, 95% CI: 0.85-3.17, p=0.001). About 16% of the variance in the full ICDAS scores and 21% of the short ICDAS can be explained by the frequency of sugar consumption (R^2=0.16; 0.21, respectively).

Table 5.4. Final model of linear regression analysis of oral health habits as predictors of caries level measured using the full ICDAS*

Independent Variables	B	SE	P-value	95% CI	
				Lower limit	Upper limit
Constant	5.49	3.09	0.076	-0.59	11.56
Frequency of sugar consumption	3.92	1.21	0.001	1.53	6.31
R^2= 0.16 *Only significant variables (p<0.05) were kept in the final model. Ratios were adjusted for gender and other behaviors as covariates in the model.					

Table 5.5. Final model of linear regression analysis of oral health habits as predictors of caries level using the short ICDAS*

Independent Variables	B	SE	P-value	95% CI	
				Lower limit	Upper limit
Constant	2.80	1.81	0.112	-0.75	6.36
Frequency of sugar consumption	2.01	0.59	0.001	0.85	3.17
R^2= 0.21 *Only significant variables (p<0.05) were kept in the final model. Ratios were adjusted for gender and other behaviors as covariates in the model.					

5.5 DISCUSSION

Identifying oral health behaviors that affect caries formation or prevent its occurrence is important when designing oral health education and promotion programs. In this study, the association between children's oral health behaviors and their caries level was examined using the total score of the full ICDAS and a short form of ICDAS. Both the full ICDAS and the short ICDAS showed similar relationships with oral health behaviors. The majority of children brushed their teeth at least once a day using fluoridated toothpaste. However, a large percentage of children had a high frequency of sugar consumption. After the statistical analysis, it was determined that brushing and sugar consumption were the oral health behaviors significantly associated with caries level. After controlling for sex and other oral health behaviors, the frequency of sugar consumption was the only significant predictor of caries level measured as the total ICDAS score.

Higher frequency of sugar consumption, especially when used between meals, has been associated with higher levels of caries [Garcia-Closas et al., 1997; Guido et al., 2011; Johnson et al., 2009; Vanobbergen et al., 2001]. In the present study, caries level significantly increased as the frequency of sugar consumption increased. In addition, it was the single predictor of caries level, as determined by total ICDAS, in the final regression model. Children's frequency of sugar consumption was high as more than half of them would be considered high consumers based on Gherunpong et al. classification [Gherunpong et al., 2006]. These results were similar to previous studies done on school children in Kuwait [ElSalhy et al., 2015; ElSalhy et al., 2013]. Previous reports for the same population have shown that forty percent of children consumed soft drinks more than once a day, which was significantly associated with caries level [ElSalhy et

al., 2013; Honkala et al., 2012]. Therefore, health promotion approaches need to target the frequency of consumption of soft drinks. A more comprehensive model like a common risk factor approach may achieve more success in changing the sugar consumption behavior in children than a conventional oral health education approach [Sheiham and Watt, 2000]. The common risk factor approach targets the high sugar consumption behavior through its impact on multiple chronic diseases like diabetes and obesity in addition to caries. This might be more successful than implementing oral health programs in isolation [Sheiham and Watt, 2000]. Another approach is to target policy level change such as the taxation of sugary drinks and banning the sale of sugary products at schools [Nakhimovsky et al., 2016].

The frequency of tooth brushing was documented to be associated with fewer new non-cavitated and cavitated caries surfaces [Chankanka et al., 2011]. In this study, children who brushed their teeth more than once a day had significantly lower median total ICDAS scores compared to children who brushed once a day or less. A previous report from the same age group showed lower levels of caries measured by different indices in children who brushed at least once a day [ElSalhy et al., 2013]. However, after adjusting for other oral health behaviors, brushing was not in the final regression model, and only frequency of sugar consumption remained as the single predictor of caries level. High sugar consumption can impede the preventive effects of brushing even if it is performed as recommended [Moynihan and Petersen, 2004].

While dental flossing has an additional benefit for prevention of gum disease, there is weak evidence on its impact on dental caries [Sambunjak et al., 2011]. In the present study, only a small percentage of children reported flossing every day, and flossing was not associated with

caries level. This was also documented in a previous report on the same children population [ElSalhy et al., 2013]. Theoretically, removal or disruption of interproximal plaque should help prevent both caries and periodontal disease. However, there is no evidence to support its effectiveness in caries prevention. It has to be noted that because of the relatively small proportion of children in this sample that did use interproximal floss, the influence of that oral health behavior could not be properly assessed. A couple of Cochrane reviews and systematic reviews [Poklepovic et al., 2013; Sambunjak et al., 2011] concluded that no quality studies that examined the effectiveness of flossing or flossing in addition to toothbrushing on proximal caries prevention. Weak evidence supports that flossing plus toothbrushing may be associated with a small reduction in plaque levels [Poklepovic et al., 2013; Sambunjak et al., 2011]. Recently, the FDI World Dental Federation removed flossing as part of its recommended practices for prevention of caries due to the weak evidence supporting it [Pitts and Zero, 2016].

Mouthrinse has been proposed as a mode of the delivery for topical fluoride for caries prevention as well as antimicrobials to prevent periodontal disease. Although the effectiveness of fluoride mouthrinse is well-documented, no significant association between the use of mouthrinse and caries level was seen in our study as well as a previous study [ElSalhy et al., 2013]. It was documented that use of at least 230 ppm of fluoride daily can results in 27% reduction in caries experience in permanent teeth compared with placebo or no mouthrinse use [Marinho et al., 2016]. As no information was collected about the fluoride content of used mouthrinse or the content of different brands in the market, this discrepancy cannot be fully explained.

Similar to a previous report [ElSalhy et al., 2013], chewing gum was a common habit in our study participants as two-thirds of children chewed gum at least once a day. However, no significant association was found between caries level and chewing gum in the present study. It was evident that chewing gum *per se* does not affect caries experience if it does not contain xylitol as an active ingredient. Alanzi et al. [2016] recently tracked xylitol gums in the Gulf Cooperation Council Countries and concluded that none of the chewing gums sold in the GCC market provide the consumers with the recommended effective daily dose of xylitol for caries prevention [Alanzi et al., 2016]. A total of 6 grams of daily doses of xylitol is needed for the caries-preventive effect [Makinen, 2011; Milgrom et al., 2006; Soderling, 2009]. One study concluded that chewing sugar-free gum had been shown to promote oral health only when the chewing time is at least 20 minutes long [Dodds, 2012].

A short form of ICDAS was proposed to simplify the examination system and makes it more adaptable and less time-consuming [Chapter 3]. The short form, calculated using less than 12% of the teeth surfaces, showed a strong correlation with the number of caries lesions in children with different caries levels [Chapter 3]. Using only these surfaces has an excellent diagnostic accuracy to identify children with caries and to classify children according to their treatment need [Chapter 3; Chapter 4]. The short ICDAS presented similar relationships with oral health behaviors as the full ICDAS. This further validates the short form to be a good alternative to the full ICDAS to be used in community settings as it reduces the time needed for the examination without compromising the quality of the information captured on caries.

Cross-sectional studies, including this study, have inherent investigative limitations in their design. Although identifying cause-effect relations cannot be achieved by cross-sectional

design, it would show valuable associations. Another limitation of this study was the use of a self-administered questionnaire. However, the questionnaire used in the present study had been previously validated and used in the same population [ElSalhy et al., 2015].

In this study, participants were 61.6 % males and 38.4 % females. This does not reflect the actual sex distribution of children in Kuwait public schools. Even though the schools were randomly selected and all children were invited, more positive consents were received from male students than females. Nevertheless, the number of participants of both genders was enough to conduct the analysis, and the results were consistent with previous reports [ElSalhy et al., 2015; ElSalhy et al., 2013].

In conclusion, both the total ICDAS score of the full and the short forms of ICDAS showed similar relationships with oral health behaviors. Among several factors studied, only toothbrushing and sugar consumption were associated with caries level in our participants. However, the frequency of sugar consumption was the only predictor of caries level measured by the total ICDAS score of both the full and the short forms. Targeting sugar consumption could help reduce the incidence of caries in children. A more comprehensive model like a common risk factor approach may achieve more success in changing the sugar consumption behavior in children than a conventional oral health education approach. In addition, targeting sugar consumption through policy changes may have more predictable and long-lasting impact than simple oral health promotion approaches.

6. Chapter Six

Association between Caries Level Measured Using the International Caries Detection and Assessment System and Oral Health-Related Quality of Life in Children: A Cross-Sectional Study

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6.1 ABSTRACT

Objective: To evaluate the association between caries measured using the total score of the full ICDAS and a short form of ICDAS and children's oral health-related Quality of life (OHRQoL).

Methods: Participants were 13-14 years-old children attending public schools in the Kuwait Capital Region. Dental examinations were performed using the ICDAS criteria. Several domains of OHRQoL were measured using the Child Perceptions Questionnaire. Linear regression analysis was used to examine caries as a predictor of children's OHRQoL.

Results: Total of 424 children participated. Two-thirds of children evaluated their oral health as excellent or very good while less than 10% evaluated their oral health as fair or poor. Majority of children indicated that their oral health condition barely affected their overall life. Both the total score of the full ICDAS and the short ICDAS were significantly and moderately correlated with total CPQ_{11-14} (ρ=0.435, R^2=0.189, p<0.001; ρ=0.393, R^2=0.131, p<0.001, respectively), oral symptoms (ρ=0.519, R^2=0.269, p<0.001; ρ=0.472, R^2=0.199, p<0.001, respectively), and functional limitations (ρ=0.539, R^2=0.291, p<0.001; ρ=0.490, R^2=0.219, p<0.001, respectively).

The total score of the full ICDAS was weakly correlated with emotional well-being score (ρ=0.161, R^2=0.026, p=0.001) and was not significantly correlated with social well-being (ρ=0.089, R^2=0.008, p=0.069). After controlling for sex in the regression analysis, a one-unit increase in total score of the full ICDAS was associated with 0.500-unit increase in the total CPQ_{11-14} score, 0.22-unit increase in oral symptoms and functional limitations scores, and 0.069-unit increase in the emotional well-being score. Regarding the short ICDAS, a one-unit increase in total score of the short ICDAS was associated with 0.854-unit increase in the total CPQ_{11-14} score, and 0.35-unit increase in oral symptoms and functional limitations scores.

Conclusions: Caries was mainly affecting children through oral symptoms and functional limitations. The impact of caries on children's emotional well-being score and social well-being was limited. The short ICDAS showed similar relationships with OHRQoL as the full ICDAS.

6.2 INTRODUCTION

Oral health describes the health of the oral cavity and its surrounding tissues [FDI World Dental Federation, 2016]. It is reflected by the absence of active disease, discomfort, or embarrassment and allows an individual to eat, speak, and socialize. Oral health is also essential to the general health and the overall well-being [FDI World Dental Federation, 2016]. Objectively, oral health status is evaluated by measuring caries, fluorosis, malocclusion, hypodontia, periodontal diseases, and developmental deformities [Mohlin et al., 1991]. Oral health-related quality of life (OHRQoL) is a subjective indicator of oral health status. It is based on information provided by individuals and reflects the impact of oral health status on various aspects of life [Gherunpong et al., 2006]. Higher and improved quality of life is the ultimate goal

of any health-related interventions or services. These indicators, including OHRQoL, can be used when assessing the treatment needs of individuals and populations. It can guide clinical decisions and public health program evaluations [Jokovic et al., 2002; Kramer et al., 2013; Krisdapong and Sheiham, 2014].

Many domains are used to measure OHRQoL: oral symptoms/oral problems, functional limitations/physical functioning, social well-being/social functioning and emotional well-being/emotional functioning, and role functioning [Huntington et al., 2011; Jokovic et al., 2002]. These domains are interconnected and influence one another. For instance, psychological and functional measures have been documented to be related in both children and adults [Alsumait et al., 2015; Eccleston and Malleson, 2003; Mohlin et al., 1991].

Few studies examined how caries affects school-age children's OHRQoL [Alsumait et al., 2015; Brown and Al-Khayal, 2006; Jokovic et al., 2002]. It was reported that children from a low-caries population have all components of OHRQoL affected by caries [Robinson et al., 2005] while only oral symptom and functional components of OHRQoL are affected in high caries level population [Brown and Al-Khayal, 2006]. Additionally, social and emotional well-being components are less likely to be affected by caries in very young children [Gherunpong et al., 2004]. Most previous studies used the total decayed, missing, and filled teeth/surfaces (dmft/DMFT, dmfs/DMFS) to measure dental caries [Broder and Wilson-Genderson, 2007; Brown and Al-Khayal, 2006; Foster Page et al., 2005; Kramer et al., 2013; Locker, 2007; Martins-Junior et al., 2013; Scarpelli et al., 2013]. Alsumait et al. [2015] tried to determine the component of the dmft/DMFT responsible for the impact on OHRQoL in a high-caries population. They found that the number of filled teeth was the only predictor of oral symptoms

while the number of carious teeth was the main predictor for functional limitations. The number of missing teeth was the only predictor for the emotional well-being component of OHRQoL [Alsumait et al., 2015].

The dmft/DMFT and dmfs/DMFS indices measure caries experience and give equal values for decayed, missing, and filled teeth/surfaces and do not reflect the level of caries. Using a more accurate measure that reflects both the number of caries lesions and their level of progression will better suggest the impact of caries on each component of OHRQoL. In Chapter 3, the total ICDAS score was proposed to be a comprehensive summary measure that reflects patient overall caries level. In addition, a short version of ICDAS was proposed to be a good measure of caries level, and a good predictor of treatment need in children [Chapter 3; Chapter 4]. Therefore, the aim of this study was to evaluate the association between caries measured as the total ICDAS and children's OHRQoL.

6.3 METHODS

6.3.1 Study design

This was a cross-sectional study based on dental examinations of participating children and a self-administrated questionnaire. The study protocol was approved by the University of Alberta Research Ethics Board (Protocol no. 00050417). Informed consent was collected from parents/guardians of every participating child prior to data collection, and the study was conducted in accordance with the Helsinki Declaration. In addition, child's assent was obtained prior to the dental examination.

6.3.2 Study setting and participants

The study was conducted in the Capital Education/Health Region in Kuwait. Data collection was carried out for 3 months during the 2014-2015 academic year. Participants were grade 7 and 8 (13-14 years-old) children attending public schools in the Kuwait Capital Region. Four intermediate schools were randomly selected from a list provided by the Ministry of Education Research Department. All grade 7 and 8 children at these schools were approached for participation.

The required sample size was calculated based on the number of 13-14 years old children in the capital region, type I error of 0.05, a margin of error of 0.05, and estimated proportion of affected children of 0.5 to be 370 surveys as a target. As 70% response rate was expected, a total of 500 consents were distributed.

6.3.3 Clinical examination

Dental examinations were performed by one trained dentist using a mobile dental chair, artificial spotlight, and a mobile dental unit at the school clinics. Before the dental examinations, students were asked to brush their teeth. The ICDAS criteria [Ismail et al., 2007] were employed by the examiner who has been already trained and calibrated with high inter- and intra-examiner reliability (both weighted kappa > 0.9). Both the total score of the full ICDAS and a short form of ICDAS (using ten primary dentition surfaces and twelve permanent dentition surfaces) were calculated as previously described [Chapter 3].

6.3.4 OHRQoL Child Perceptions Questionnaire

The self-administered Child Perceptions Questionnaire among 11- to 14-year-old (CPQ_{11-14}) was used to assess children's OHRQoL [Jokovic et al., 2002]. The items of the questionnaire were grouped into four domains: oral symptoms (6 questions), functional limitations (9 questions), emotional well-being (9 questions), and social well-being (12 questions). The recall period for the questions was 3 months (i.e. evaluating events within the last three months). The CPQ_{11-14} questionnaire used Likert-type scales with "Never," "Once or twice," "Sometimes," "Often," and "Every day or almost every day" responses.

The questionnaire also had two global self-rating questions. One question was about perceived oral health with Likert-type scale responses of "Excellent," "Very good," "Good," "Acceptable," and "Poor." The second question was about the impact of oral health on overall well-being with responses of "Not at all," "Very little," "Somewhat," "A lot" and "Very much."

The Arabic version of this questionnaire that had been previously translated and validated [Brown and Al-Khayal, 2006] was recently re-validated again and modified in Kuwait with students of the same age group [Alsumait et al., 2015]. During the re-validation, the kappa scores for the test/re-test questionnaires were more than 0.87 [Alsumait et al., 2015].

6.3.5 Data analysis

Data were managed and analyzed using SPSS 21.0 software (IBM Corp., Armonk, N.Y., USA). Data normality was tested using the Shapiro-Wilk test. The CPQ_{11-14} responses were coded from 0 to 4; ranging from no impact to an extreme impact. Domain and overall OHRQoL scores of the CPQ_{11-14} were calculated by summing all responses either for the domains or for the

whole questionnaire. Lower scores indicate a better OHRQoL. The internal consistency for the whole questionnaire as well as each domain was examined using Cronbach's alpha. Frequencies were used to describe the global rating questions. Median, 25th percentile, 75th percentile, minimum, and maximum were used to describe the total score of the full ICDAS, the short ICDAS, and OHRQoL as data were not normally distributed. The maximum possible score for the for the total OHRQoL is 144 while the maximum scores for the domains are 24 for oral symptoms, 36 for functional limitations, 36 for emotional well-being, and 48 for social well-being. Sex differences in total ICDAS and OHRQoL were examined using Mann-Whitney test. The correlation between the total ICDAS scores of the full ICDAS the short ICDAS and domains as well as overall CPQ_{11-14} scores were evaluated using Spearman's correlation. Linear regression analyses were performed to examine total ICDAS (both the full and the short forms) (as a continuous independent variable) as a predictor of domains and overall CPQ_{11-14} (as continuous dependent variables). Results were adjusted for sex. The level of significance was set at 0.05.

6.4 RESULTS

Of the 533 children at the selected four schools, 424 were returned with positive consents to participate (response rate 79.5%). All the 424 children (61.6% males and 38.4% female) completed the questionnaire. The internal consistency, evaluated using Cronbach's alpha coefficient, was excellent for the overall CPQ_{11-14} (0.919), emotional well-being domain (0.859) and social well-being domain (0.821). The alpha coefficient was acceptable for the functional limitation and oral symptoms components (0.748, 0.696, respectively).

The median (25th percentile, 75th percentile) of total full ICDAS, total short ICDAS, and total CPQ_{11-14} scores were 10 (5, 20), 8 (3, 13), and 20 (9, 34), respectively (Table 1). The median scores for the OHRQoL domains were 5 (3, 10) for oral symptoms, 5 (2, 11) for functional limitations, 3 (1, 7) for social well-being, and 3 (1, 7.75) for emotional well-being (Table 6.1). No significant difference in total full ICDAS, short ICDAS, total CPQ_{11-14}, and all OHRQoL domain scores between male and females ($p>0.05$). Descriptive statistics of caries and OHRQoL according to sex are summarized in Table 6.2.

Table 6.1. Descriptive Statistics of Caries and OHRQoL

	Minimum	25th percentile	Median	75th percentile	Maximum
Total full ICDAS	0	5	10	20	91
Total short ICDAS	0	3	8	13	47
Oral Symptoms	0	3	5	10	82
Functional Limitations	0	2	5	11	27
Social well-being	0	1	3	7	36
Emotional well-being	0	1	3	7.75	35
Total CPQ_{11-14}	0	9	20	34	104

Table 6.2. Descriptive Statistics Caries and OHRQoL According to Sex

	Male			Female			p-value
	25th percentile	Median	75th percentile	25th percentile	Median	75th percentile	
Total full ICDAS	4	10	20	5	12	21.25	0.175
Total short ICDAS	2	7	14	3	8	14	0.136
Oral Symptoms	3	5	10	3	5	9	0.189
Functional Limitations	2	6	10.5	2	5	11	0.959
Social well-being	1	3	7	1	2	6	0.667
Emotional well-being	1	3	7	1	3	9	0.162
Total CPQ_{11-14}	9	20	34.5	9	20	34	0.975

Two-thirds of children evaluated their oral health as excellent or very good while less than 10% evaluated their oral health as fair or poor (Table 3). Majority of children indicated that

their oral health condition barely affected their overall life and only 3.3% reported that their oral health conditions were severely affecting their overall life. Participants' global self-rating responses are summarized in Table 6.3.

Table 6.3. Participants' Global Self-Rating Responses

1. Would you say the health of your teeth, lips, jaws, and mouth is:					
	Excellent	Very Good	Good	Fair	Poor
N (%)	127 (30.0)	154 (36.3)	105 (24.8)	23 (5.4)	15 (3.5)
2. How much does the condition of your teeth, lips, jaws or mouth affect your life overall?					
	Not at all	Very little	Sometimes	A lot	Very much
N (%)	241 (56.8)	106 (25.0)	63 (14.9)	8 (1.9)	6 (1.4)

Both the total score of the full ICDAS and the short ICDAS were significantly and moderately correlated with total CPQ_{11-14} (ρ=0.435, R^2=0.189, p<0.001; ρ=0.393, R^2=0.131, p<0.001, respectively), oral symptoms (ρ=0.519, R^2=0.269, p<0.001; ρ=0.472, R^2=0.199, p<0.001, respectively), and functional limitations (ρ=0.539, R^2=0.291, p<0.001; ρ=0.490, R^2=0.219, p<0.001, respectively). The total score of the full ICDAS was weakly correlated with emotional well-being score (ρ=0.161, R^2=0.026, p=0.001) and was not significantly correlated with social well-being (ρ=0.089, R^2=0.008, p=0.069) (Table 6.4).

Table 6.4. Correlation between total ICDAS and OHRQoL

	Oral Symptoms	Functional Limitations	Emotional well-being	Social well-being	Total CPQ_{11-14}
Total full ICDAS	0.519	0.539	0.161	0.089	0.435
P-value	<0.001	<0.001	0.001	0.069	<0.001
Total short ICDAS	0.472	4.90	0.048	0.053	0.393
P-value	<0.001	<0.001	0.086	0.273	<0.001

After controlling for sex in the regression analysis, a one-unit increase in total score of the full ICDAS was associated with 0.500-unit increase in the total CPQ_{11-14} score, 0.22-unit increase in oral symptoms scores and functional limitations scores, and 0.069-unit increase in the

emotional well-being score. Regarding the short form of ICDAS, a one-unit increase in total score of the short ICDAS was associated with 0.854-unit increase in the total CPQ11-14 score, 0.35-unit increase in oral symptoms scores and functional limitations scores. Linear regression analyses of the full ICDAS and the short ICDAS as a predictor of OHRQoL are shown in Tables 6.5 and 6.6.

Table 6.5. Linear regression analysis of total score of the full ICDAS as predictors of OHRQoL models*

Dependent Variable: Oral symptoms score					
Independent Variables	B	SE	P-value	95% CI	
				Lower limit	Upper limit
Constant	3.610	0.360	<0.001	2.902	4.318
Total full ICDAS	0.217	0.017	<0.001	0.183	0.251
R^2= 0.269 *Ratios were adjusted for sex.					
Dependent Variable: Functional Limitations score					
Independent Variables	B	SE	P-value	95% CI	
				Lower limit	Upper limit
Constant	3.58	0.340	<0.001	2.915	4.251
Total full ICDAS	0.216	0.016	<0.001	0.184	0.248
R^2= 0.291 *Ratios were adjusted for sex.					
Dependent Variable: Emotional Well-being score					
Independent Variables	B	SE	P-value	95% CI	
				Lower limit	Upper limit
Constant	4.375	0.480	<0.001	3.533	5.217
Total full ICDAS	0.069	0.021	0.001	0.029	0.110
R^2= 0.024 *Ratios were adjusted for sex.					
Dependent Variable: Total CPQ_{11-14} score					
Independent Variables	B	SE	P-value	95% CI	
				Lower limit	Upper limit
Constant	16.021	1.124	<0.001	13.811	18.230
Total full ICDAS	0.538	0.054	<0.001	0.431	0.645
R^2= 0.189 * Ratios were adjusted for sex.					

Table 6.6. Linear regression analysis of total score of the short ICDAS as predictors of OHRQoL models*

Dependent Variable: Oral symptoms score					
Independent Variables	B	SE	P-value	95% CI	
				Lower limit	Upper limit
Constant	5.567	0.83	<0.001	3.936	7.199
Total short ICDAS	0.352	0.035	<0.001	0.284	0.420
R^2= 0.199 *Ratios were adjusted for sex.					
Dependent Variable: Functional Limitations score					
Independent Variables	B	SE	P-value	95% CI	
				Lower limit	Upper limit
Constant	4.174	0.785	<0.001	2.630	5.718
Total short ICDAS	0.357	0.033	<0.001	0.293	0.422
R^2= 0.219 *Ratios were adjusted for sex.					
Dependent Variable: Total CPQ_{11-14} score					
Independent Variables	B	SE	P-value	95% CI	
				Lower limit	Upper limit
Constant	19.166	2.563	<0.001	14.128	24.205
Total short ICDAS	0.854	0.107	<0.001	0.643	1.065
R^2= 0.131 * Ratios were adjusted for sex.					

6.5 DISCUSSION

Understanding the relationship between caries and OHRQoL is important when assessing the caries treatment needs and can guide clinical decisions for individuals and populations. In our study, the total scores of both the full and the short ICDAS score were significantly correlated with oral symptoms and functional limitations. The full ICDAS was weakly correlated with emotional well-being score while both the full and the short ICDAS were not correlated with social well-being.

The overall CPQ_{11-14} score of children in the present study was similar to a previous report from Kuwait [Alsumait et al., 2015]. The majority of children perceived their oral health as good and indicated that it did not affect their overall life. This could be due to the presence of a school-based program in Kuwait that provides treatment, education, and prevention services to all school-age children [Alsumait et al., 2015]. Children in Kuwait showed better OHRQoL compared to other countries in the region [Brown and Al-Khayal, 2006; Foster Page et al., 2005].

Previous reports have suggested an association between children's caries level and their OHRQoL [Broder and Wilson-Genderson, 2007; Brown and Al-Khayal, 2006; Foster Page et al., 2005; Kramer et al., 2013; Locker, 2007; Martins-Junior et al., 2013; Scarpelli et al., 2013]. They found that the OHRQoL was affected in children with 4 or more dmft/DMFT or dmfs/DMFS. However, there was a discrepancy in reporting the components of OHRQoL that were mainly affected. Foster Page et al. [2005] found that a dmft/DMFS score of 4 or more was associated with oral symptoms and social well-being [Foster Page et al., 2005], while Brown and Al-Khayal [2006] reported that the dmft/DMFT was significantly correlated with oral symptoms only [Brown and Al-Khayal, 2006]. A further analysis was conducted to find which components of the dmft/DMFT affected each OHRQoL component. It revealed that the number of carious and filled teeth was associated with oral symptoms and functional limitation, while the number of missing teeth mainly affected children's emotional well-being [Alsumait et al., 2015]. In the present study, the level of caries was correlated with overall OHRQoL scores mainly through oral symptoms and functional limitation, which supports Alsumait et al. [2015] conclusions.

In this study, similar to many previous reports [Alsumait et al., 2015; Wong et al., 2006], a weak or no relationship was found between caries and emotional and social well-being. An

explanation for this weak relationship is that most caries lesions were in posterior teeth in this age group as well as the majority of lesions cannot be identified by children if they were asymptomatic. Other oral health conditions such as malocclusion and orofacial deformities have been shown to be main predictors of emotional and social well-being domains [Broder and Wilson-Genderson, 2007; Foster Page et al., 2005; Gherunpong et al., 2004]. Such conditions directly affect children's social interactions and how they perceived themselves.

The short form of ICDAS showed similar relationships with OHRQoL and its components compared to the full ICDAS. This further validates the short form to be a good alternative to the full ICDAS when evaluating OHRQoL. In addition, the short ICDAS was strongly correlated with the total score of the full ICDAS. This proposed short ICDAS was examined to identify children with caries and to classify children according to their treatment need [Chapter 3; Chapter 4]. Moreover, the short form presented similar relationships with oral health behaviors as the full ICDAS [Chapter 5].

One limitation of the present study was the use of a self-administered questionnaire. The used CPQ_{11-14} questionnaire was validated with the same population [Alsumait et al., 2015] and showed good measures of internal consistency. The questionnaire overall internal consistency was high with lower domain scores recorded in the oral symptoms and the functional limitations components compared to the emotional and social well-being components. These lower scores were consistent with studies which used the CPQ_{11-14} questionnaire [Alsumait et al., 2015; Brown and Al-Khayal, 2006; Jokovic et al., 2002]. The questionnaire examined six different oral symptoms and nine functional limitations. The oral symptoms were pain, gum bleeding, soreness, bad breath and food impaction between teeth and in the palate. These symptoms are

specific and can happen individually or in combination but rarely all of them together. Similarly, the examined functional limitations may occur in combinations but rarely most of them in the same patient. In contrast, emotional and social impacts are not specific and affect the individual as a whole. This can explain the strength of the internal consistency measures in the emotional and social well-being components compare to oral symptoms and functional limitations. In addition, the questionnaire was designed to examine different oral health conditions, and some of the questions might not be related to caries especially in oral symptoms and functional limitations sections. Shortening the questionnaire with only items that reflect the specific oral condition in-study would produce higher internal consistency scores but not reflect the overall perceived situation.

In this study, participants were 61.6% males and 38.4% females. This does not reflect the actual sex distribution of children in Kuwait public schools. Even though the schools were randomly selected and all children were invited, more positive consents were received from male students than females. Nevertheless, the number of participants of both genders was enough to conduct the analysis.

In conclusion, the total ICDAS score was significantly associated with children's overall OHRQoL. Caries, measured as the total ICDAS score, was mainly affecting children through oral symptoms and functional limitations. The impact of caries on children's emotional well-being score and social well-being was limited.

7. Chapter Seven

Discussion and Conclusions

In this dissertation, we aimed identify a potential summative measure that reflects patient's caries level in children examined with the ICDAS. Different summative measures were examined to reflect the number of caries lesions in children with different levels of caries. Values captured on specific surfaces from the ICDAS examination were also examined as a short form of ICDAS. The relationship between oral health habits and OHRQoL and the identified summative measures from both the full ICDAS and the short ICDAS were further evaluated. In addition, the identified short ICDAS was examined to predict caries treatment need for children by classifying them into primary, secondary and tertiary prevention categories compared to the full ICDAS.

7.1 DISCUSSION

The ICDAS was developed to fill gaps in the commonly used WHO criteria for detecting caries with an aim to improve the quality of collected data on caries. Improved quality of data is achieved through the use of evidence-based criteria to detect both enamel and dentine caries. This comprehensive system was proposed for use in clinical research, clinical practice, and epidemiological studies [Ismail et al., 2007; Pitts, 2004]. In the second chapter, a significant variation was noted in the reporting of caries was found in studies that used the ICDAS. Such variation can be an indication that the system is very adaptable so that researchers can use different reporting of caries depending on the type of study and the targeted outcome. However,

this variation in the reporting makes comparing different studies difficult, especially epidemiological studies. In addition, most of the studies that used the ICDAS did not take advantage of the most information captured during the examination as the majority of the studies used the categorical characteristics of the system. These studies used counts of surfaces/teeth or a group of surfaces/teeth affected by caries, giving an equal value for lesions at different stages of caries and not taking full advantage of the 6-ordinal scale used. Moreover, many of these studies tried to synthesize the dmf/DMF indices to allow comparability with studies that used the WHO criteria.

An important issue identified while reviewing studies that used the ICDAS was a huge variation in the definition for the d/D component of the synthesized dmf/DMF index. This can defeat the purpose of calculating the dmf/DMF index to allow comparisons with previous studies that used the WHO criteria. Considering ICDAS score 3 or more to be WHO's caries equivalent have shown the least difference, and the greatest agreement between the WHO and ICDAS criteria were calculating dmft/DMFT and dmfs/DMFS as well as caries prevalence [Iranzo-Cortes et al., 2013]. Using ICDAS cut-offs at scores 1 and 2 overestimates caries compared to WHO criteria, while ICDAS score 4 cut-off underestimates caries prevalence compared to WHO criteria [Braga et al., 2009].

In the third chapter, multiple summative measures for patient's caries level or status were examined as potential summary measures to improve the ability to better capture and summarize caries information collected by the ICDAS. Most of these measures were previously used to summarize caries in published studies. Out of the examined indices, total ICDAS and mean ICDAS showed high correlation with the number of caries lesions. They were very strongly

correlated with the number of caries lesions in low and high caries children. Both measures capture the number of caries lesions and their level of progression, and they would be a good summative measure to report caries in future studies that use ICDAS. Using a single measure that reflects patient's caries rather than multiple measures would provide better knowledge when examining factors contributing to caries formation or examining the impact of an intervention on caries progression. Both the total and the mean reflects the gradual increase in caries level. In addition, using the total ICDAS or the mean ICDAS would allow direct comparison between patients as well as between populations.

One of the highlighted barriers related to the feasibility of the ICDAS to be used in epidemiological surveys is the time it takes to examine all surfaces and make a decision on the stage of caries level compared to the WHO criteria where researchers need only to identify obvious caries [Braga et al., 2009]. It was estimated that the ICDAS mean examination time is twice as long as the WHO (3.7±1.8 min vs. 1.9±0.7 min) [Braga et al., 2009]. In the third chapter, surfaces with the highest frequency of caries to be potential representative surfaces to identify children with caries were examined. Ten surfaces in primary dentition and 12 surfaces in permanent dentition showed a good diagnostic accuracy to identify children with caries. In addition, the total ICDAS of these surfaces gave a good summary measure for patient's caries level. These surfaces had a high correlation with the number of caries lesions in children with both high and low level of caries. Using only these surfaces can capture information about caries closer to the whole dentition examined using ICDAS and can shorten the examination time to even less than the WHO examination time, as less than 12% of the surfaces are examined. This would make the ICDAS a more efficient and practical examination system when the examination time is a concern in epidemiological studies or in community settings.

In the fourth chapter, the potential use of the selected ten surfaces in primary dentition and 12 surfaces in permanent dentition as a short version of the ICDAS was examined to be used to predict children's treatment need. The ability to use the surfaces to classify children according to their treatment needs into primary, secondary and tertiary prevention groups was examined. The proposed short ICDAS showed a good agreement on treatment needs determination with the full ICDAS with excellent operating characteristics in all dentitions. This adds to the time-saving and convenience characteristics of examining only a limited number of surfaces to measure overall caries level and determine treatment needs. By reducing the number of surfaces needed to be examined and the time involved in completing the clinical assessment, the short version of the ICDAS is a convenient alternative to the full ICDAS for use in community settings.

The relationship between the total score of the full and the short ICDAS with oral health habits and oral health-related quality of life were examined for two purposes. The first purpose was to further validate the indices proposed as the strength of association between the total scores and oral health behaviors or oral health-related quality of life is an evaluation of how the proposed indices behaves. The second purpose was to examine if capturing more information about caries would improve the current understating of the relationship between caries and oral health habits or oral health-related quality of life.

The full and the short ICDAS showed similar relationships with oral health behaviors and OHRQoL. The total scores of the full and the short ICDAS score were significantly associated with both the frequency of brushing and sugar consumption. In addition, they were significantly correlated with children's overall OHRQoL. They were mainly correlated with oral symptoms and functional limitations domains with a weak correlation with children's emotional well-being

and social well-being domains. These relationships with oral health habits and OHRQoL would also support the validity of the full and the short ICDAS as measures of caries.

Using the total ICDAS as a measure of caries in chapter five, the frequency of sugar consumption was the only predictor of caries level after adjusting for all other behaviors. The impact of the frequency of sugar intake on caries level was quantified. Every one-unit increase in the sugar consumption frequency was associated with a 4-unit increase in the total ICDAS. As total ICDAS combines both enamel and dentin caries, these conclusions highlight the association between sugar consumption and both the number of caries lesions and their level of progression. Such information is richer than previous attempts that classified children as with/without caries [Vanobbergen et al., 2001] or those that used the number of lesions regardless of their level of progression [Guido et al., 2011].

The impact of a one-unit increase in the total ICDAS on the CPQ_{11-14} score of OHRQoL was also quantified in chapter six. A one-unit increase in total ICDAS caries score was associated with 0.5-unit increase in the total OHRQoL score with 0.2-unit increase in both oral symptoms and functional limitations scores. Enamel lesions (low scores of caries) generally have a very low impact on OHRQoL measured using the CPQ_{11-14} which has a wide scale range of 144 points. Certainly, enamel lesions are generally asymptomatic and are not associated with oral symptoms or functional limitations. For caries to affect the quality of life, the total ICDAS scores need to be high. This explains why previous studies that measured the relationship between caries and OHRQoL identified the impact of caries in children with DMFT/S of four or more [Brown and Al-Khayal, 2006; Foster Page et al., 2005].

7.2 LIMITATIONS

One of the limitations of the present study is the inherent investigative limitations in its cross-sectional design. As an approach to reduce the impact of the study design on the evaluation of different summative measures, the indices were evaluated against the number of caries lesions in children with a gradual increase in the caries level rather than against the number of different caries scores. This approach is the closest to the longitudinal evaluation of the indices as caries progress, which is the ideal approach for examining these indices. Therefore, the approach used in the present study is the next best assessment.

One limitation of clinical examinations without using radiographs is the difficulty in detecting proximal lesions. This limitation exists in all clinical examination systems including the ICDAS. The data, as well as data used for cross-validation, demonstrated a low level of interproximal caries. However, this limitation should not affect how the indices are summarizing caries level as they reflect the examination system outcome or how the short form of the ICDAS can classify treatment need compared to the full ICDAS. Yet, it may have a minimal impact when studying the relationship between oral health behaviors and caries as well as when studying the relationship between caries and oral health-related quality of life. This limitation cannot be avoided, as exposing children to unnecessary radiation for research purposes is not ethically acceptable. An approach to overcome this limitation is to examine oral health habits and oral health-related quality of life of patients attending routine dental care where having radiographs are part of their routine dental appointment. Nevertheless, such an approach adversely affects the random sample selection and the generalizability of the results.

Another limitation related to the clinical examination in the present dissertation is that caries activity was not measured. The proposed indices reflect the number of caries lesions and the level of progression but give equal values for active and inactive lesions. It is difficult to assign a value to caries activity other than a dichotomous option (active/inactive) without longitudinally evaluating lesions' progression so that information on the speed of progression can be developed, scaled and validated. Therefore, the summary measures proposed do not account for caries activity. However, lack of activity measure should not affect the treatment need classification based on the short form of ICDAS. Non-cavitated lesions, either active or inactive, need to be managed through secondary prevention to arrest active lesions or maintain the inactivity of inactive lesions, while cavitated lesions need to be evaluated by the dentist to determine the appropriate management and therefore has to be classified into tertiary prevention categories.

Another limitation of the present dissertation was the use of self-administered questionnaires. The used CPQ_{11-14} and the oral health habits questionnaires were validated with the same population [Alsumait et al., 2015; ElSalhy et al., 2015] and showed good measures of internal consistency and validity.

7.3 CONCLUSIONS AND FUTURE RESEARCH RECOMMENDATIONS

The following conclusions were drawn from the results of the present dissertation:

1. There are variations in summarizing caries among the studies that used the ICDAS with most studies presented caries using categorical characteristics of the system.

2. Total ICDAS and mean ICDAS scores were the best summary measures of overall caries level at different dental stages.
3. Total ICDAS of selectively examined 10 surfaces in primary dentition and 12 surfaces in permanent dentition can give an excellent summary measure for patient's caries level with high diagnostic accuracy. These surfaces can be used as a short version of the ICDAS.
4. The relationship between the total ICDAS score, mean ICDAS score, and the total ICDAS of selective surfaces and the number of caries lesions were consistent across different dentitions and populations.
5. The proposed short version of the ICDAS showed good diagnostic accuracy in classifying children according to their treatment need into primary, secondary and tertiary prevention groups.
6. The proposed short version of the ICDAS demonstrated similar relationships with oral health behaviors and OHRQoL compared to the full ICDAS.
7. The frequency of brushing and sugar consumption were the only examined behaviors associated with caries level. The frequency of sugar consumption was the only predictor of caries level, measured by the total ICDAS score, after adjusting for all other behaviors.
8. The total ICDAS caries score was significantly correlated with children's overall OHRQoL. Caries was mainly affecting children through oral symptoms and functional limitations. The impact of caries on children's emotional well-being score and social well-being was limited.

Future research recommendation includes

1. Examining the relationship between caries measured by total ICDAS/mean ICDAS and socioeconomic status to further validate the proposed indices.
2. Assessment of the total ICDAS/mean ICDAS measures in a longitudinal cohort study to examine how these indices reflect caries progression and/or regression.
3. Evaluation of the total ICDAS/mean ICDAS in an adult population as caries pattern in adults maybe different from that in children.
4. Assessment of the proposed short version of ICDAS in a longitudinal cohort study to examine how these surfaces reflect caries progression and/or regression.
5. Evaluation of the short version of ICDAS as a predictor of treatment needs in adults.
6. Identify a method to assign a quantitative value to lesion activity to be added to the patient summative caries score.

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Appendices

Appendix I

Ethics Approval

UNIVERSITY OF ALBERTA

RESEARCH ETHICS OFFICE

308 Campus Tower
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Notification of Approval

Date:	September 11, 2014
Study ID:	Pro00050417
Principal Investigator:	Maryam Sharifzadeh-Amin
Study Title:	ICDAS Caries Index: An Index Of Caries Severity and Treatment Need and Its Relationship with Oral Health Habits and Oral Health Related Quality Of Life
Approval Expiry Date:	September-10-15

	Approval Date	Approved Document
Approved Consent Form:	09/11/2014	Arabic-Letter of Information
	09/11/2014	Arabic- Parent Consent Form
	09/11/2014	Information Letter
	09/11/2014	Parent Consent Form

Thank you for submitting the above study to the Research Ethics Board 2. Your application has been reviewed and approved on behalf of the committee.

A renewal report must be submitted next year prior to the expiry of this approval if your study still requires ethics approval. If you do not renew on or before the renewal expiry date, you will have to re-submit an ethics application.

Approval by the Research Ethics Board does not encompass authorization to access the staff, students, facilities or resources of local institutions for the purposes of the research.

Sincerely,

Stanley Varnhagen, PhD
Chair, Research Ethics Board 2

Note: This correspondence includes an electronic signature (validation and approval via an online system).

Appendix II

ICDAS Examination Form

Date of Examination: _____ School Name: _____ Participant ID:_____

			55	54	53	52	51	61	62	63	64	65		
	17	16	15	14	13	12	11	21	22	23	24	25	26	27
D														
O														
M														
B														
L														

			85	84	83	82	81	71	72	73	74	75		
	47	46	45	44	43	42	41	31	32	33	34	35	36	37
D														
O														
M														
B														
L														

Restoration and Sealant Codes:	**Caries Codes**
0 = Not sealed or restored 1 = Sealant (partial) 2 = Sealant (full) 3 = Tooth colored restoration 4 = Amalgam restoration 5 = Stainless steel crown 6 = Porcelain, gold, PMF crown or veneer 7 = Lost or broken restoration 8 = Temporary restoration	0 = Sound tooth surface. 1 = First visual change in enamel. 2 = Distinct visual change in enamel. 3 = Enamel break down. No dentin visible 4 = Dentinal shadow (not cavitated into dentin) 5 = Distinct cavity with visible dentin. 6 = Extensive distinct cavity with visible dentin. **Missing Teeth** 97 = Extracted due to caries 98 = Missing for other reason 99 = Un-erupted P = Implant

Appendix III

Oral Health Habits Questionnaire

Participant ID: _____ School Name: _____

The next 12 questions are about your daily habits. There are no "right" or "wrong" answer

1. How long time ago did you visit a dentist?

   - ☐ Less than a year ago
   - ☐ 1-2 years ago
   - ☐ More than 2 years ago

2. What is the reason for your last visit?
   - ☐ Pain
   - ☐ Regular check-up
   - ☐ Other reason

3. How often do you brush your teeth?

   - ☐ More than once a day
   - ☐ Once a Day
   - ☐ Less than once a day

4. How often do you use dental floss?

   - ☐ More than once a day
   - ☐ Once a Day
   - ☐ Less than once a day

5. Do you use a mouth rinse?

   - ☐ More than once a day
   - ☐ Once a Day
   - ☐ Less than once a day

6. Do you use chewing gum?

   - ☐ More than once a day
   - ☐ Once a Day
   - ☐ Less than once a day

7. How often do you eat candies?

- Never
- Once a week or Less
- 2-4 a week
- 5-6 a week
- Once a day, every day
- Twice a day, every day
- Every day, more than two

8. How often do you eat Ice cream?

- Never
- Once a week or Less
- 2-4 a week
- 5-6 a week
- Once a day, every day
- Twice a day, every day
- Every day, more than two

9. How often do you drink Juices?

- Never
- Once a week or Less
- 2-4 a week
- 5-6 a week
- Once a day, every day
- Twice a day, every day
- Every day, more than two

10. How often do you drink soft drinks (Like Coka-Cola, Pepsi, 7-Up, Mirinda, Sprite, Mountain Dew, Crush)? Do not count diet drinks.

- Never
- Once a week or Less
- 2-4 a week
- 5-6 a week
- Once a day, every day
- Twice a day, every day
- Every day, more than two

11. How often do you eat Cake and cookie, and Biscuit?

- Never
- Once a week or Less
- 2-4 a week
- 5-6 a week
- Once a day, every day
- Twice a day, every day
- Every day, more than two

Appendix IV

Oral Health-Related Quality of Life (CPQ_{11-14}) Questionnaire

Participant ID: _____ School Name: _____

These next few questions are about how you feel about your teeth. There are no "right" or "wrong"

1. Would you say the health of your teeth, lips, jaws and mouth is:

☐ Excellent ☐ Very Good ☐ Good ☐ Fair ☐ Poor

2. How much does the condition of your teeth, lips, jaws or mouth affect your life overall?

☐ Not at all ☐ Very little ☐ Sometime ☐ A lot ☐ Very much

In the past 3 months, how often have you had:

3. Pain in your teeth, lips, jaws or mouth?

☐ Never ☐ Once or twice ☐ Sometimes ☐ Often ☐ Every day or almost every day

4. Bleeding gums?

☐ Never ☐ Once or twice ☐ Sometimes ☐ Often ☐ Every day or almost every day

5. Sores in your mouth?

☐ Never ☐ Once or twice ☐ Sometimes ☐ Often ☐ Every day or almost every day

6. Bad Breath?

☐ Never ☐ Once or twice ☐ Sometimes ☐ Often ☐ Every day or almost every day

7. Food stuck in between your teeth?

☐ Never ☐ Once or twice ☐ Sometimes ☐ Often ☐ Every day or almost every day

8. Food stuck in the top of your mouth

☐ Never ☐ Once or twice ☐ Sometimes ☐ Often ☐ Every day or almost every day

For the next questions, has this happened because of your teeth, lips or mouth?

In the past 3 months, how often have you had?

9. Breathed through your mouth?

☐ Never ☐ Once or twice ☐ Sometimes ☐ Often ☐ Every day or almost every day

10. Taken longer than others to eat a meal?

☐ Never ☐ Once or twice ☐ Sometimes ☐ Often ☐ Every day or almost every day

11. Had trouble sleeping?

☐ Never ☐ Once or twice ☐ Sometimes ☐ Often ☐ Every day or almost every day

In the past 3 months, because of your teeth, lips, mouth or jaws, how often has it been:

12. Difficulty to bite or chew food like apples, corn on the cob or steak?

☐ Never ☐ Once or twice ☐ Sometimes ☐ Often ☐ Every day or almost every day

13. Difficult to open your mouth wide?

☐ Never ☐ Once or twice ☐ Sometimes ☐ Often ☐ Every day or almost every day

14. Difficulty to say any words?

☐ Never ☐ Once or twice ☐ Sometimes ☐ Often ☐ Every day or almost every day

15. Difficult to eat foods you would like to eat?

☐ Never ☐ Once or twice ☐ Sometimes ☐ Often ☐ Every day or almost every day

16. Difficult to drink with a straw?

☐ Never ☐ Once or twice ☐ Sometimes ☐ Often ☐ Every day or almost every day

17. Difficult to drink or eat hot or cold foods?

☐ Never ☐ Once or twice ☐ Sometimes ☐ Often ☐ Every day or almost every day

QUESTIONS ABOUT FEELINGS

Have you had feelings because of your teeth, lips or mouth? If you felt this way for another reason, answer 'Never'.

In the past 3 months, how often have you had:

18. Felt irritable or frustrated?

☐ Never ☐ Once or twice ☐ Sometimes ☐ Often ☐ Every day or almost every day

19. Felt unsure of yourself?

☐ Never ☐ Once or twice ☐ Sometimes ☐ Often ☐ Every day or almost every day

20. Felt shy or embarrassed?

☐ Never ☐ Once or twice ☐ Sometimes ☐ Often ☐ Every day or almost every day

21. Been concerned what other people think about your teeth, lips, mouth or jaws?

☐ Never ☐ Once or twice ☐ Sometimes ☐ Often ☐ Every day or almost every day

22. Worried that you are not as good-looking as others?

☐ Never ☐ Once or twice ☐ Sometimes ☐ Often ☐ Every day or almost every day

23. Been upset?

☐ Never ☐ Once or twice ☐ Sometimes ☐ Often ☐ Every day or almost every day

24. Felt nervous or afraid?

☐ Never ☐ Once or twice ☐ Sometimes ☐ Often ☐ Every day or almost every day

25. Worried that you are not as healthy as others?

☐ Never ☐ Once or twice ☐ Sometimes ☐ Often ☐ Every day or almost every day

26. Worried that you are different than other people?

☐ Never ☐ Once or twice ☐ Sometimes ☐ Often ☐ Every day or almost every day

QUESTIONS ABOUT SCHOOL

Have you had these experiences because of your teeth, lips or mouth? If it was for another reason, answer 'Never'.

In the past 3 months, how often have you had:

27. Missed school because of pain, appointments or surgery?

☐ Never ☐ Once or twice ☐ Sometimes ☐ Often ☐ Every day or almost every day

28. Had a hard time paying attention in school?

☐ Never ☐ Once or twice ☐ Sometimes ☐ Often ☐ Every day or almost every day

29. Had difficulty doing your homework?

☐ Never ☐ Once or twice ☐ Sometimes ☐ Often ☐ Every day or almost every day

30. Not wanted to speak or read out loud in class**?**

☐ Never ☐ Once or twice ☐ Sometimes ☐ Often ☐ Every day or almost every day

QUESTIONS ABOUT YOUR SPARE-TIME ACTIVITIES AND BEING WITH OTHER PEOPLE

In the past 3 months, how often have you had:

31. Avoided taking part in activities like sports, clubs, drama, music, school trips?

☐ Never ☐ Once or twice ☐ Sometimes ☐ Often ☐ Every day or almost every day

32. Not wanted to talk to other children?

☐ Never ☐ Once or twice ☐ Sometimes ☐ Often ☐ Every day or almost every day

33. Avoided smiling or laughing when around other children?

☐ Never ☐ Once or twice ☐ Sometimes ☐ Often ☐ Every day or almost every day

34. Not wanted to spend time with other people?

☐ Never ☐ Once or twice ☐ Sometimes ☐ Often ☐ Every day or almost every day

35. Argued with other children or your family?

☐ Never ☐ Once or twice ☐ Sometimes ☐ Often ☐ Every day or almost every day

In the past 3 months, because of your teeth, lips, mouth or jaws, how often have:

36. Other children teased you or called you names?

☐ Never ☐ Once or twice ☐ Sometimes ☐ Often ☐ Every day or almost every day

37. Other children made you feel left out?

☐ Never ☐ Once or twice ☐ Sometimes ☐ Often ☐ Every day or almost every day

38. Other children ask you questions about your teeth, lips, jaws or mouth?

☐ Never ☐ Once or twice ☐ Sometimes ☐ Often ☐ Every day or almost every day

Thank you