Association of enamel caries lesions with oral hygiene and DMFT among adults

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Short title: Caries findings in Finnish adults

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Abstract

The aim of this study was to evaluate the prevalence of enamel caries lesions and their association with tooth brushing frequency, tooth brushing quality, and past caries experience among Finnish adults. The study population comprised 46-year-old members of the Northern Finland Birth Cohort 1966 (n=1,961). Caries lesions were examined and recorded at surface level using the International Caries Detection and Assessment System (ICDAS). Cut-off point for enamel caries was set to ICDAS score 3. Cut-off point for brushing frequency was twice daily. Visible plaque on buccal tooth surfaces represented brushing quality. Using enamel caries lesions ($ICDAS_{1-3}$) as a dependent variable, adjusted logistic regression model was conducted to investigate the association with gender, brushing frequency, visible plaque, dentin caries lesions ($ICDAS_{4-6}$), teeth with restorations, extractions and fractures. Almost all participants (99%) had enamel and 40% had dentin caries lesions; mean number of teeth with enamel caries lesions was 13.8 (SD 4.6). According to the adjusted logistic regression model, high prevalence of $ICDAS_{1-3}$ lesions was associated with having visible plaque on more than 20% of teeth and having more than 13 restored teeth. In conclusion, the prevalence of enamel caries lesions is high among Finnish adult population. The results of this study suggest that in addition to tooth brushing frequency, the presence of visible plaque seems to be critical when evaluating the association between tooth brushing and enamel caries.

Introduction

Caries is a multifactorial disease in which the undisturbed dental biofilm evolves to acidic direction leading to demineralization of the affected tooth enamel [Fejerskov and Kidd, 2008]. Globally, the proportion of untreated caries lesions of permanent teeth has remained nearly unchanged since the 1990s [Kassebaum et al., 2017], meanwhile caries experience still seems to steadily increase with age [Broadbent et al., 2008]. Means to manage caries lesions have developed over the years from extracting the affected teeth to preserving them with operative treatments [Kassebaum et al., 2015]. The protocol has shifted in the 20th century towards controlling caries and arresting the progress of early manifestations of the disease instead of concentrating on restorative care [Schulte et al., 2011], as suggested by International Caries Classification and Management System (ICCMS) [Pitts et al., 2013].

Today's adult population in Finland has received both population- and risk-based oral health promotion in their childhood, due to Primary Health Care Act in 1972 [Ministry of Social Affairs and Health, 1972] and consequent major organizational health reformation, both emphasizing health promotion [Vuorenkoski et al., 2008]. On the other hand, only few Finnish adults report having received any advice or individual demonstration for appropriate self-care at dental office in their adulthood [Suominen-Taipale et al., 2008]. Several studies suggest that oral habits are adopted at early age and that those habits persevere, yet continuous oral health promotion is required [Tolvanen et al., 2010].

Traditionally, caries experience has been measured based on the sum of decayed, missing and filled teeth (DMFT) [Klein et al., 1938]. To improve the quality of caries detection, the International Caries Detection and Assessment System (ICDAS) was developed in 2005 [Ismail et al., 2007]. It enables to record different stages of caries progression, thus producing an impression of severity of the disease [Pitts et al., 2013], especially when activity is included in estimation protocol. The outcome by ICDAS can be converted to DMFT values to provide results comparable with previous surveys [Pitts et al., 2013]. Dentin caries prevalence and restorative treatment need have been found to be relatively high among a middle-aged population in Northern Finland [Laajala et al., 2017], but the prevalence of enamel caries lesions or other lesion stages has not been examined before.

The aim of this population-based, cross-sectional clinical study was to investigate the prevalence and distribution of enamel caries lesions by tooth type among middle-aged adults. Furthermore, we aimed to evaluate the association of enamel caries lesions with oral hygiene habits and quality as well as past caries experience. The primary hypothesis was that the prevalence of enamel caries lesions is low among Finnish middle-aged population. The second hypothesis was that the prevalence of enamel caries lesions associates with high prevalence of dentin caries lesions and restorations, but also with low tooth brushing frequency and brushing quality.

Materials and Methods

The Northern Finland Birth Cohort 1966 (NFBC1966) was originally established by Professor Paula Rantakallio in 1965 [Rantakallio, 1988]. All children with the expected date of birth in the year 1966 in the two northernmost provinces of Finland (Oulu and Lapland) were invited to participate in the study (n=12,231 children). In 2012, a subgroup to participate in clinical dental examinations was formed. Cohort members living at reasonable distance (maximum of 100 km) from the city of Oulu (n=3,150) were invited to participate in a clinical oral examination as part of the 46-year follow-up study. Of those invited, 62% (n=1,964) attended the examination at dental clinic of the University of Oulu. Three participants later denied the use of their data in the study, thus a total of 1,961 participants comprised the 46-year follow-up study population [www.oulu.fi/nfbc].

Before clinical examinations, the participants answered a postal questionnaire. Brushing frequency was asked as ´Do you brush your teeth´ with options: ´very rarely/sometimes within week/every now and then/once a day/twice a day/more than twice a day'? The oral examinations were performed by seven dentists using a standardized clinical examination protocol. All the examiners were introduced and trained to use the ICDAS criteria. The examiners were calibrated before the field stage, and the calibration was repeated every three months. All the examinations were carried out in a modern dental clinic by using an oral mirror, WHO ball-pointed gingival probe, and fiber-optic transillumination. The results were registered in an electronic patient file system by a dental nurse (M.Sc. Jari Päkkilä from the University of Oulu designed the patient file software for the NFBC1966 studies). [Alaraudanjoki et al., 2016]

The participants' teeth were air-dried, but not professionally cleaned, before the examination. Caries ($ICDAS_1$-$ICDAS_6$), fractures, and restorations were assessed visual-tactilely on five surfaces per tooth. The examiners were informed that the cut-off point for the restorative treatment decision was

$ICDAS_4$, and they were advised to choose the more severe option for the caries finding in borderline cases, and specifically to record active $ICDAS_3$ lesions as $ICDAS_4$. The ICDAS criteria were available for the examiners throughout the study. If the surface was both decayed and fractured, it was recorded as decayed. Restorations of any material were recorded. Plaque was examined visually and with probe from the buccal surface of each tooth, except wisdom teeth. Plaque was registered as visible plaque present/not present.

For quality assurance, ICDAS training sessions and in vitro calibrations were repeated every three months. Additionally, the examiners themselves re-examined one quadrant of the dentitions of five randomly selected participants approximately one month after the previous examination (repeated measures). An experienced clinician, a co-author of this paper (MLL), acted as the gold standard and re-examined at least ten randomly selected participants from each examiner (parallel measures). To evaluate intra- and inter-examiner agreement, kappa values were calculated (0.61, 0.64 respectively) [Alaraudanjoki et al., 2016].

Statistics

Wisdom teeth were excluded from all analyses. For the analyses, ICDAS scores 1-3 represented enamel caries lesions ($ICDAS_{1-3}$) and scores 4-6 dentin caries lesions ($ICDAS_{4-6}$). Since lesions with ICDAS score 1 were almost non-existent, they were merged with score 2 lesions ($ICDAS_{1-2}$) in the analyses. At tooth level, the stage of any caries lesion in individual tooth was determined according to the highest ICDAS score on any of its surfaces. At surface level, the distribution of $ICDAS_{1-3}$ and $ICDAS_{4-6}$ lesions in the dentitions was analyzed according to their location: occlusal, smooth (buccal and oral surfaces), and approximal (mesial and distal) surfaces. For the analyses, a tooth was considered fractured if a fracture was present on any tooth surface. Presence of plaque was determined as the proportion of teeth with visible plaque in the dentition. The individuals were then dichotomized using 20% of teeth with plaque as a cut-off. The study population was dichotomized according to their brushing frequency to those brushing once a day or less and those brushing at least twice a day.

Number of restorations and missing teeth were summed per individual. Causes of extractions were not available. The sum of $ICDAS_{4-6}$ (D), missing (M), and restored (F) teeth comprised DMFT.

Based on the distribution (normal/skewed) of the analyzed variables, the differences between the genders in the study population were analyzed with an independent-samples t-test or the Mann-

Whitney U test. The teeth were grouped as maxillary and mandibular incisors, canines, premolars, and molars. Pearson's chi-square test was used to analyze 1) the differences between the prevalence of $ICDAS_0$, $ICDAS_{1-3}$, $ICDAS_{4-6}$ within tooth groups, 2) the difference in the prevalence of $ICDAS_{4-6}$ lesions on smooth, approximal and occlusal surfaces between genders, 3) prevalence of dichotomized visible plaque in association with brushing frequency (cut-off point ≥2 daily).

An adjusted logistic regression model was conducted, where prevalence of $ICDAS_{1-3}$ (cut-off point >10) was used as the dependent variable, and gender, number of restored teeth (cut-off point >13), brushing frequency (cut-off point ≥2 times daily), proportion of teeth with visible plaque (cut-off point >20% of teeth), prevalence of $ICDAS_{4-6}$ (cut-off point >1), number of fractured (cut-off point >1) and extracted (cut-off point >1) teeth, and their statistically most significant two-way interaction terms were used as independent variables. The cut-off point was chosen according to the mean of the variable prevalence ($ICDAS_{4-6}$, restored teeth, visible plaque, extractions) or according to the peak point of prevalence ($ICDAS_{1-3}$, brushing, fractures).

The data were analyzed with SPSS (version 24.0, Illinois, USA). The distribution of $ICDAS_{4-6}$ was illustrated using the Lorenz curve composed with the R-program (version 3.2.5, a language and environment for statistical computing; R Foundation for Statistical Computing, Vienna, Austria, URL: http://www.R-project.org).

Results

The study population was slightly dominated by females (males 47%, n=911; females 53%, n=1,050). The complete cariological status was available for 1,944 participants, who all were dentate. The data on tooth brushing was available for 1877 participants. Excluding wisdom teeth, the mean number of teeth per individual was 27 (SD 2.1); there was no significant difference between the genders. The details concerning the distribution of the stages of caries lesions and caries experience are presented in Table 1.

Teeth with $ICDAS_{1-3}$ lesions were prevalent almost in the entire study population (99%). Caries lesions needing restorative treatment ($ICDAS_{4-6}$) were prevalent in 40% of the participants (n=773), while the least prevalent single ICDAS score was 6 (5% of the study population). $ICDAS_{4-6}$ were most often found in upper premolars and lower molars, whereas $ICDAS_{1-3}$ affected mostly molars in

both jaws (Fig. 1). The difference in caries prevalence between the tooth groups was statistically significant ($p < 0.001$).

The analysis of tooth surfaces revealed that both enamel and dentin caries affected most often approximal surfaces, followed by smooth and occlusal surfaces. In terms of gender, males had more enamel caries lesions on smooth surfaces than females ($p = 0.003$), whereas the difference on occlusal and approximal surfaces was non-significant. The majority of those participants who had at least two $ICDAS_{4-6}$ lesions on smooth or approximal surfaces were males (63%, $p = 0.001$ and 58%, $p < 0.001$, respectively).

The prevalence of $ICDAS_{4-6}$ lesions was polarized (Fig. 2). The range of the teeth with $ICDAS_{4-6}$ lesions varied between 0-19, and the proportion of those with at least two teeth with $ICDAS_{4-6}$ lesions was 21% (n =408 males 26%, females 17%, $p < 0.001$). Contrary to the $ICDAS_{4-6}$ lesions, the prevalence of $ICDAS_{1-3}$ lesions was not polarized.

More than two thirds of the participants (n = 1,270, 65%) reported to brush their teeth at least twice a day, whereas the proportion of those who reported to brush even less than once daily was 3%. Brushing frequency alone was not associated with either $ICDAS_{1-3}$ or $ICDAS_{4-6}$. Of those who reported brushing at least twice a day, 40% had visible plaque on ≥20% of teeth. They had more often enamel caries lesions compared to other frequent brushers who had <20% teeth covered with visible plaque ($p < 0.001$).

According to the adjusted logistic regression model, high prevalence of enamel caries lesions was significantly associated with high number of restorations and presence of visible plaque on ≥20% of the teeth and suggestively associated with high number of teeth with $ICDAS_{4-6}$, brushing at least twice a day and a low number of missing teeth (Table 2).

Discussion

This study gives evidence that practically all in this middle-aged study population have enamel caries lesions. High prevalence of enamel caries lesions associates with notable prevalence of visible plaque and high prevalence of past caries experience. The proportion of teeth with visible plaque in dentition was high even though majority of the participants reported to brush their teeth twice daily. Visible plaque was examined on buccal surfaces of the teeth, which can be considered as easily cleanable.

The results indicate insufficient quality of oral hygiene in this study population. Polarization of dentin caries lesions was obvious but it was not found to exist concerning for enamel caries lesions.

The NFBC1966 is representative of the middle-aged population in Northern Finland, including both urban and rural areas [http://www.oulu.fi/nfbc]. However, the oral health of those not participating this study is impossible to estimate. Possible regional differences in middle-aged population could be examined in the future, since for young Finnish adults, existence of regional differences has been found (Kämppi et al., 2015).

To our knowledge, this is the first study analyzing enamel caries lesions of Finnish adults and confirms the proposal of Manji [2018] of the ubiquitous nature of caries. Contradictory to previous studies from other countries, prevalence of enamel caries lesions here was remarkably high. Consequently, polarization of enamel caries lesions was non-existent. Oscarson [2017] reported that of Norwegian 35-49 -year-old adults, 40% had dentin caries lesions and 70% had caries lesions of any stage. In a study on Italian adults, on average 60% had caries lesions, and initial lesions were less common than dentin lesions [Carta et al., 2015]. The prevalence of dentin caries lesions in this study population (40%) is in line with previous studies on Finnish adults [Vehkalahti et al., 2008] and in Nordic countries [Oscarson et al., 2017]. Previous studies have also reported the polarization of dentin caries among Finnish and Scandinavian populations [Vehkalahti et al., 2008; Tanner et al., 2013; Stecksen-Blicks et al., 2014; Oscarson et al., 2017]. The polarization is highly alarming, since it demonstrates that a small group of middle-aged people carry most of the current dentin caries burden.

Despite the oral health promotion and preventive measures targeted to today's adults in their childhood and adolescence, dental caries remains a major problem. The participants in the present study population were six years old at the time when intensive oral health promotion was performed nationally at schools and public dental offices. According to the Primary Health Care Act (66/1972) enforced in 1972 [Ministry of Social Affairs and Health, 1972], primary prevention of oral diseases was emphasized (e.g. self-care education, campaigning for a healthy diet and oral hygiene, fluoride rinses at schools, and children's annual check-ups including topical fluoridating), and all children were targeted, regardless their caries risk level [Vuorenkoski et al., 2008]. The next major health reform was conducted in 2002, when all citizens were entitled to public dental health care and treatment at private sector with subsidized prices. This reform ensured the same availability of public dental health care in all parts of Finland. It required additional resources, which were primarily allocated to operative care while oral health promotion was considered as less urgent [Niiranen et al.,

2008]. Already in 2009, restorative treatment comprised majority of dental procedures performed on adults in Finland [Widstrom et al., 2015]. In the 21st century, less than 10% of Finnish adults report having received oral health promotion at dental office [Suominen-Taipale et al., 2008], while oral health promotion for children and adolescents has been reported to vary [Blomqvist et al., 2014]. Our study shows that adults need continuous individual oral health promotion given via dental professionals. Demonstrating visible plaque to the patient could improve self care. In studies investigating the association of dental caries with oral hygiene, brushing frequency alone is an insufficient variable and therefore, quality of brushing should be included.

It has been proposed that estimating the need for caries management in populations should be based on data on initial caries lesions [Fyffe et al., 2000]. The World Dental Federation (FDI) recommends including all caries stages into epidemiological studies and diagnosis [FDI General Assembly, 2012] while The World Health Organization still recommends to use the DMF index in population based studies [World Health Organization, 2013]. The strength of this study is the availability of all caries lesions. ICDAS has shown good reliability and validity in epidemiological studies even when field examiners have not previously been familiar with the use of ICDAS [Ismail et al., 2007], this was true here as well. Both the intra- and inter-examiner kappa-values showed good reliability concerning caries findings [Alaraudanjoki et al., 2016]. The analysis of single ICDAS scores revealed the stage of caries disease in this adult population. As for gender, differences in prevalence of dentin caries lesions especially on smooth and approximal surfaces was found. This may indicate over all poorer oral hygiene level of males compared to females, even though the clinical significance between the genders may be irrelevant.

Estimating the activity of the lesion is a key element in treatment planning [Ekstrand et al., 2005] because active non-cavitated lesions have an elevated risk to progress to cavitated lesions [Nyvad et al., 2003]. Activity estimation, nowadays included in the ICDAS criteria [International Caries Detection and Assessment System (ICDAS) Committee, 2005], was emphasized in training of the clinical examiners and it was taken into consideration when deciding about restorative treatment need ($ICDAS_3$/$ICDAS_4$). Unfortunately, the software did not allow to record the activity of the lesions and therefore, it could not be included in the analysis. This is a shortcoming in the present study.

Due to the study protocol, professional cleaning of teeth was not performed, even though it is recommended in the ICDAS criteria [Ismail et al., 2007]. Caries was assessed visually using fiber-optic transillumination, while no intra-oral radiographs were taken. It has been showed that use of

intra-oral radiographs and digital imaging fiber-optic transillumination increases the number of detected caries lesions compared to visual examination alone [Laitala et al., 2017]. Here, the number of detected caries lesions might have been even higher if assisting methods had been used.

The pattern of caries development has been shown in several studies. According to them, the surfaces most susceptible to caries are occlusal surfaces, followed by approximal and smooth surfaces [Hannigan et al., 2000; Batchelor and Sheiham, 2004]. In addition, the proportion of approximal and smooth surface lesions of all caries lesions have been shown to increase with age [Hopcraft and Morgan, 2006]. The findings here are in accord with the previous ones with the caries lesions being located mostly on approximal surfaces.

Association between presence of enamel caries lesions as well as presence of visible plaque, indicating quality of tooth brushing, on buccal surfaces of teeth seems to be evident. Therefore, in addition to tooth brushing frequency, the presence of visible plaque should be observed.

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Statement of Ethics

The subjects have given their written informed consent. The participation was voluntary. The participants were also provided with the right to withdraw from the study and deny the use of their records at any point of the study. The study was approved by the Ethical Committee of the Northern Ostrobothnia Hospital District (74/2011).

Disclosure Statement

The authors declare that they have no declaration of interests.

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Author Contributions

Authors VA and MLL conceived and designed the follow-up study experiments and performed the training and calibration. VA, MLL and AL designed this study. PP and AL analyzed the data. AL, PP, VA and MLL prepared the manuscript.

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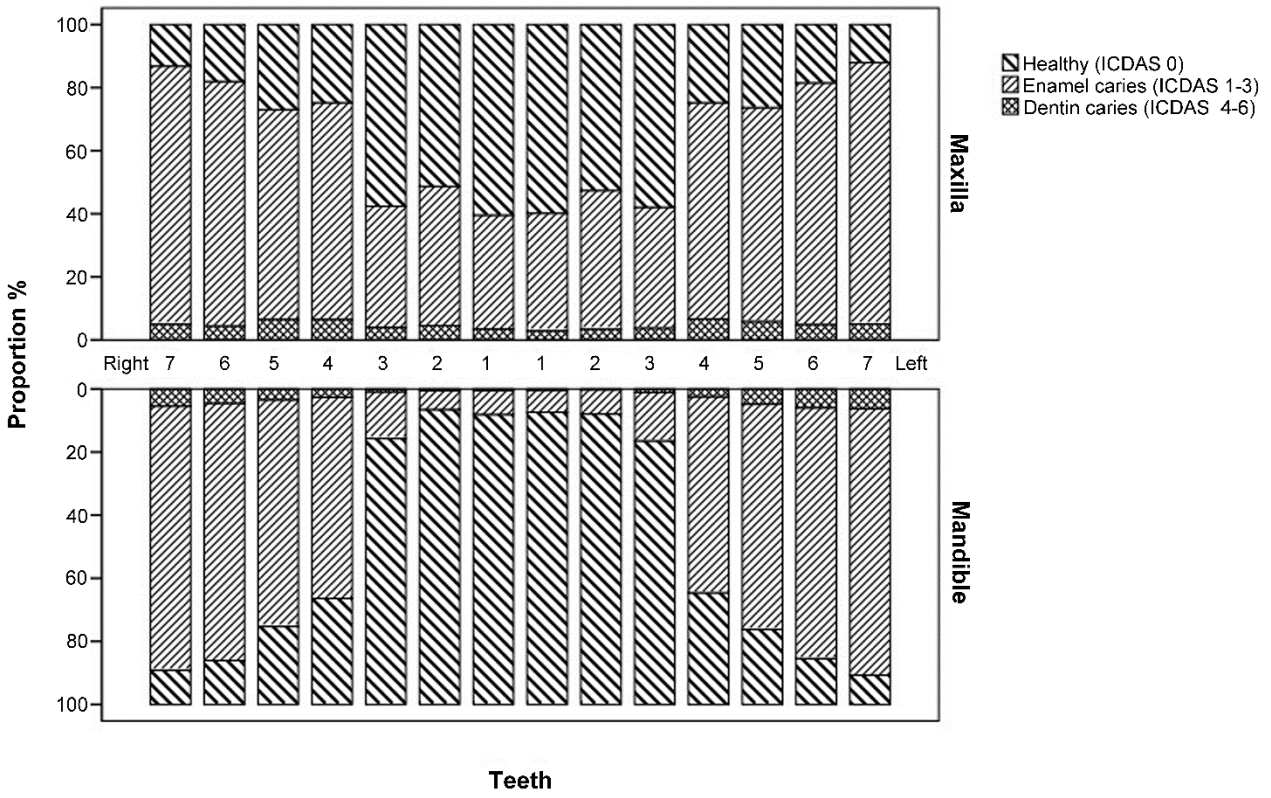
Figure Legends:

Fig. 1. Distribution of teeth with no lesions and enamel or dentin caries lesions in maxilla and mandible.

Fig. 2. Lorenz curve presenting the polarization of the dentin caries lesions ($ICDAS_{4-6}$). The number of teeth with dentin caries lesions per person are described with symbols ≥1, ≥2 and ≥3.


Healthy (ICDAS 0)
Enamel caries (ICDAS 1-3)
Dentin caries (ICDAS 4-6)
Maxilla
Mandible
Proportion %
Teeth
Right 7 6 5 4 3 2 1 1 2 3 4 5 6 7 Left
0 20 40 60 80 100

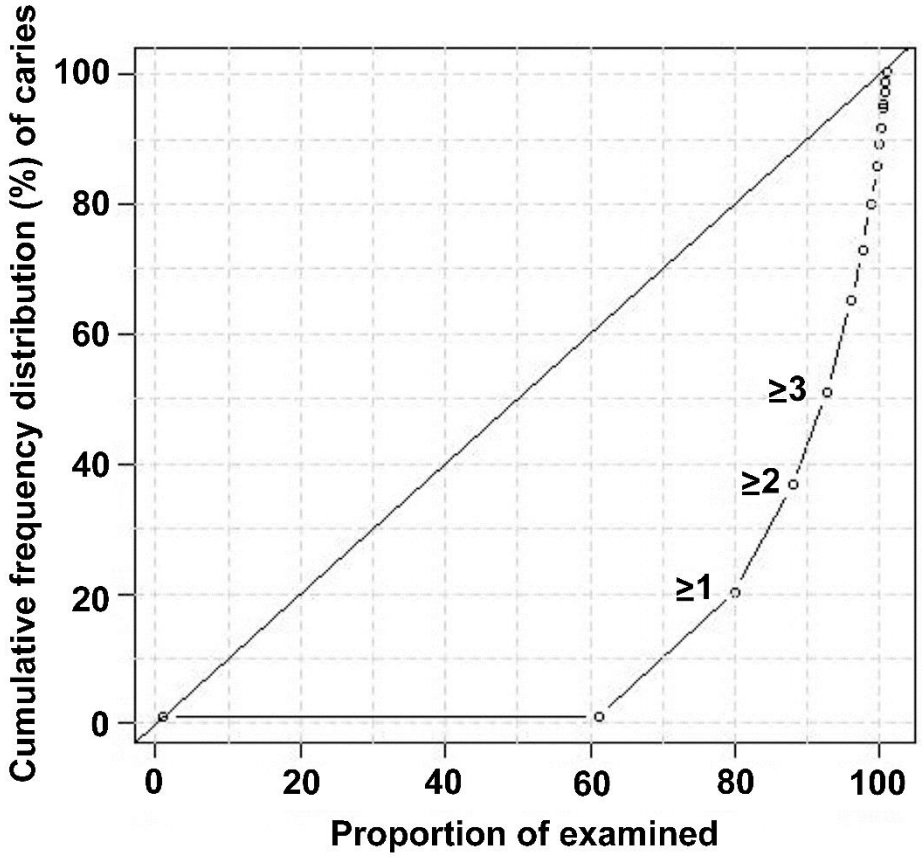

Cumulative frequency distribution (%) of caries
100
80
60
40
20
0
0
20
40
60
80
100
Proportion of examined
≥3
≥2
≥1

Table 1. Mean (standard deviation, SD) number of teeth and teeth with different stages of caries according to gender.

	Male	***Female***	***Total***	***p-value***
Number of teeth	26.5 (2.4)	26.7 (1.8)	26.6 (2.1)	0.511[b]
ICDAS 1-2	11.5 (4.3)	11.5 (4.2)	11.5 (4.2)	0.977[a]
ICDAS 3	2.3 (2.5)	2.1 (2.4)	2.2 (2.4)	0.103[a]
ICDAS 4	0.8 (1.4)	0.5 (1.0)	0.6 (1.2)	<0.001[b]
ICDAS 5	0.3 (0.8)	0.2 (0.7)	0.3 (0.8)	<0.001[b]
ICDAS 6	0.1 (0.5)	0.1 (0.5)	0.1 (0.5)	0.001[b]
Enamel caries ($ICDAS_{1-3}$)	13.9 (4.7)	13.8 (4.5)	13.8 (4.6)	0.044[a]
Dentin caries ($ICDAS_{4-6}$, D)	1.2 (2.0)	0.8 (1.7)	0.98 (1.8)	<0.001[b]
Fractured teeth	0.5 (1.0)	0.4 (0.8)	0.4 (0.9)	<0.001[b]
Missing teeth (M)	1.4 (2.5)	1.2 (1.7)	1.3 (2.1)	0.492[b]
Restored teeth (F)	13.1 (5.3)	12.9 (4.9)	13.0 (5.1)	0.546[a]
DMF	15.3 (5.4)	14.6 (4.9)	14.9 (5.2)	0.006[a]

[a]Independent samples t-test, [b]Mann-Whitney U test

Table 2. An adjusted logistic regression model showing association between dichotomized prevalence of enamel caries lesions (ICDAS1-3>10) and independent variables.

Factor	***OR***	***95% CI for OR***	
		Lower bound	***Upper bound***
Female gender	1.078	0.848	1.371
Brushing at least twice a day	1.342	0.979	1.840
Plaque on >20% of teeth	2.265	1.396	3.675
$ICDAS_{4-6}$ >1	1.593	0.958	2.648
Restored >13	1.555	1.168	2.070
Missing >1	0.763	0.579	1.005
Fractured >1	1.107	0.475	2.581

Logistic model adjusted by interaction terms: $ICDAS_{4-6}$*Missing; $ICDAS_{4-6}$*Fractured; $ICDAS_{4-6}$*Plaque; Restored*Plaque; Fractured*Brushing; Brushing*Plaque