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ORIGINAL ARTICLE

Caries lesions progression in adults: A prospective 2-year cohort study

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Abstract

Objective: Dental caries is one of the most prevalent chronic non-communicable diseases worldwide. There is a lack of evidence, especially in adult populations, documenting caries disease progression considering lesion severity, activity and tooth surface-level characteristics. The study aimed to investigate the extent to which primary active caries lesions in adults affect caries lesions progression compared with inactive caries lesions over a 2-year follow-up period, considering their severity, surface and tooth type.

Methods: A prospective study data set from a cohort of workers in a factory in Belarus were used. Participants aged 18–64 years with 20 or more natural teeth were included in the study. The participants were clinically examined twice within an interval of 2 years and completed a self-reported questionnaire. One calibrated examiner evaluated caries lesions using the International Caries Detection and Assessment System (ICDAS) and the Nyvad system. The primary outcome was caries lesions' progression. The lesion was classified as 'progressed' if it turned to a more advanced severity stage, was restored or missing/extracted due to caries. A multilevel Poisson regression was used to estimate the association between baseline caries lesions' characteristics and caries lesion progression.

Results: Out of 495 participants, 322 people completed clinical examinations at baseline and 2 years later, with an attrition rate of 35%. The prevalence of active DS1-6 and DS5-6 lesions at the baseline was 83.8% and 64.8%, respectively. In 2 years, 24% of active non-cavitated and 31% of active micro-cavitated/shadowed caries lesions progressed, while 15% of inactive caries lesions, non- or micro-cavitated/shadowed, progressed. The adjusted rate ratio (RR) for $ICDAS_{3+4}$ caries lesions progression was 1.41 (CI 95% 1.16, 1.70) than $ICDAS_{1+2}$ lesions. The RR for $ICDAS_{1+2}$, active and $ICDAS_{3+4}$, active lesions was 1.78 (CI 95%, 1.40, 2.27) and 1.97 (CI 95%, 1.53, 2.55), respectively than $ICDAS_{1+2}$, inactive lesions. The RR for caries lesions progression on proximal surfaces and on pits and fissures was 1.57 (CI 95%, 1.30, 1.89) and 1.37 (CI 95%, 1.11, 1.67), respectively than smooth surface lesions.

Conclusion: In caries active adults over 2 years, most non- and micro-cavitated/shadowed active and inactive caries lesions did not progress. Among caries lesions that showed progression, more severe lesions were more likely to progress than less severe lesions; active lesions were more likely to progress than inactive lesions. Pit and fissure caries lesions and proximal lesions were more likely to progress than smooth surface lesions.

KEYWORDS
adult, dental caries, disease progression, epidemiology, longitudinal studies

1 | INTRODUCTION

Contemporary caries management approaches that are focusing on caries risk assessment and non-surgical treatment methods must rely on a current understanding of carious lesion development and progression and need diagnostic systems able to determine carious lesions from their very early stages, along with their depth and activity.[1,2] These requirements are essential for achieving the best possible dental health outcome. Visual/visual-tactile examination is one of the principal methods currently utilized in clinical practice and epidemiological surveys because it permits differentiation between non-cavitated and cavitated lesions, as well as between active and inactive lesions. These are the pivotal elements on which the best caries management options can be chosen.[1,3] The two visual/visual-tactile caries diagnostic systems: the Nyvad[4] and the International Caries Detection and Assessment System (ICDAS)[5] have been developed and recommended for use in research and clinical practice.[3,6] The most recently updated ICDAS system that is integrated in The International Caries Classification and Management System (ICCMS) involves caries lesions' activity assessment based on the modifications of the Nyvad et al. and the Ekstrand et al. criteria.[7] Most of the caries-related epidemiological data in adults are based on cross-sectional studies, which lack information regarding caries lesion behaviour and rates of progression over time.[8,9] Furthermore, some existing cohort studies in adults are using outdated caries diagnostic criteria (e.g. WHO) which do not take into account different stages and activity of caries lesions.[10–13] Moreover, most cohort studies on caries progression with the use of contemporary caries diagnostic systems (e.g. ICDAS, Nyvad) were performed in children.[1,14–17] Some of these studies are only focusing on lesion severity assessment,[14] while others include lesion severity and activity assessment,[1,16,17] and few of them take into account the surface and tooth type when assessing lesion progression.[1,14]

Given this, it is important to conduct studies longitudinally assessing caries lesions in adults, using contemporary diagnostic criteria, taking into account their severity and activity as well as tooth and surface type. This will help to better understand the pattern of caries disease progression and to plan appropriate caries management options. The study aim was to investigate the extent to which primary active caries lesions affect caries lesions progression compared with inactive caries lesions in adults over a 2-year follow-up period, considering their severity, surface and tooth type. The objectives of this study were: (1) to estimate the extent to which caries lesions' severity (non-cavitated/micro-cavitated + shadow) and activity (active/inactive) status is associated with caries lesion progression; and (2) to estimate the extent to which tooth type (molar/premolar/anterior) and tooth surface type (smooth, proximal, pit and fissure surfaces) is associated with caries lesion progression. The hypotheses were the following: more severe lesions are more likely to progress than less severe lesions; active lesions are more likely to progress than inactive lesions; occlusal and proximal surface lesions are more likely to progress than smooth surface lesions; caries lesions located on molars and premolars are more likely to progress than lesions located on anterior teeth.

2 | MATERIALS AND METHODS

A prospective cohort study data set was used to examine caries lesion progression in a sample of adults working in a factory in Belarus over a 2-year follow-up period. The research project was approved by the Ethical committee of Belarusian State Medical University (Protocol no. 13; 16.12.2011). Participants who agreed to consent underwent two clinical examinations by the same trained and calibrated examiner at the dental office at the factory's medical center at the baseline and 2 years later. Before the start of the examination, each participant completed a self-report questionnaire containing questions concerning sociodemographic (e.g. age, gender, level of education) and oral health-related behaviours (e.g. tooth brushing frequency, fluoride toothpaste use, number of dental visits per year).

The study participants were recruited from industrial assembling factory in Borisov city (Belarus) which is located 74 km of the capital, Minsk. The selection of this factory was based on feasibility to recruit a sample of adults and the presence of dental office on site to enable clinical evaluation. The concentration of fluoride in drinking water in Belarus is less than 0.2 mg/L.[18] Inclusion criteria were adults aged 18 years or older with 20 or more natural teeth who had at least one primary caries lesion. Exclusion criteria were individuals with: (1) orthodontic appliances; (2) multiple

teeth with hypocalcified enamel; (3) systemic disorders with oral manifestation. Participants were informed that their participation was voluntary, they could withdraw from the study at any time, and they were free to ask any questions regarding their oral health. The factory administration notified all factory workers about the possibility of participating in a research project on caries lesions progression. The participants were invited to attend the factory's dental office for dental examinations while coming for routine preventive medical check-ups organized in the factory's medical center. Each participant who was available in a particular day for medical exam and agreed to take part in the project was notified when to come to dental office for the examination. The data collection was anonymous, kept confidential and stored securely. All participants provided a written informed consent before data collection. Each participant was asked to visit the dental clinic twice over 2 years. During the baseline examination, all participants received detailed oral hygiene instructions and if any restorations were needed, they were advised to have an appointment with a dentist in a state or private dental clinic. At the end of the second appointment, participants were provided with detailed information about the status of their teeth and treatment needs.

All clinical examinations were performed by one examiner trained for the use of the ICDAS and Nyvad diagnostic systems. At the baseline and follow up examinations the first 10 participants were examined twice to calculate intra-examiner reliability.

2.1 | Caries diagnostic criteria and examination

Caries lesion severity was assessed using the ICDAS diagnostic system[5] and caries lesion activity was assessed using the Nyvad system.[4] All examinations were done using the same dental unit with its light source, a dental mirror, a ball-ended WHO probe for the ICDAS evaluation and a sharp standard dental explorer for the Nyvad criteria. Before each examination, the dentist cleaned the teeth surfaces for each participant by using a circular brush attached to low-speed handpiece to remove plaque. If needed additional dental plaque removal was done with a probe during the examination. All surfaces were first examined wet and then air-dried. The dental probe was gently used to remove tooth biofilm if needed, to assess tooth surface integrity and texture. If one surface had both active/inactive lesions or different severity stage, then it was listed as active with the greater severity (i.e. active >inactive; cavitation >microcavity >intact surface). Seven surfaces for upper molars (occlusal mesial fissure, occlusal distal fissure, mesial, distal, lingual groove, and lingual and buccal surfaces), six surfaces for lower molars (occlusal, mesial, distal, buccal fissure, buccal surface and lingual surface), five surfaces for upper premolars and canines (occlusal, mesial, distal, buccal and lingual surfaces), five surfaces for upper incisors (mesial, distal, buccal, lingual groove and lingual surfaces), and four surfaces for lower incisors (occlusal, mesial, distal, buccal and lingual surfaces) were examined. Therefore, the maximum number of the tooth surfaces examined per participant was 174.

2.2 | The ICDAS diagnostic system

The ICDAS codes were used in two digits: the first code represented restoration or crown, the second code represented lesion severity. ICDAS severity codes were ordinally arranged into six categories in which code 1 represents the first visible carious change in enamel, while code six represents extensive cavitation. When the dental examiner could not examine a surface, the surface was missing because of caries, missing because of another reason, or unerupted the following codes were used, respectively: 96, 97, 98 and 99.

2.3 | The Nyvad system

The Nyvad system was used for lesion activity assessment. Caries lesions were considered active if they were located in a plaque stagnation area, showed a whitish/yellowish colour with loss of lustre (matte), were rough/soft with gentle probing using a sharp explorer. Inactive caries lesions had the following characteristics: located away from the gingival margin, showed whitish/brown/black shiny appearance, were smooth/hard with gentle probing using a sharp explorer.[4] A combination of all listed sings of caries lesion's activity was taken into account to make a final decision if lesion is active or inactive. The activity code was the third code added to the first two ICDAS codes. After 2-years, participants were re-examined by the same dentist blinded to the baseline data.

2.4 | Caries lesions transition

When describing the progression of caries lesions, we focused only on primary active and inactive, non-cavitated, micro-cavitated and shadow lesions at the baseline (ICDAS codes 1, 2, 3 and 4). To describe the transition of caries lesions in 2-years follow up, we used the following categories: sound (ICDAS 0), all ICDAS severity codes from 1 to 6, Restored or Missed due to caries. To represent the data transition descriptively, the baseline ICDAS 1 and 2 codes were merged to one category ($ICDAS_{1+2}$) to represent non-cavitated lesions and the ICDAS 3 and 4 codes to one category ($ICDAS_{3+4}$) to represent micro-cavitated/shadow lesions. At the baseline, the differentiation for $ICDAS_{1+2}$ and $ICDAS_{3+4}$ to active and inactive lesions categories was kept. In addition, the lesions transition was presented based on surface type (pits and fissures, proximal and smooth) and tooth type (molars, premolars and anterior).

2.5 | Outcome evaluation (caries lesion's progression)

The outcome was caries lesions' progression presented as a dichotomous variable: 1. progressed or 2. not progressed. The primary caries lesion, active or inactive was considered as 'progress' if it transited to more advanced stage (e.g. from $ICDAS_2$ to $ICDAS_3$), was

restored, or missed due to caries. The primary caries lesion, active or inactive was considered as 'not progress' if it regressed to less severe stage or had the same severity stage. Note, that non-plausible transition scenarios (e.g. $ICDAS_{3+4}$ become sound) were classified as 'not progress'.

3 | STATISTICAL ANALYSIS

The intra-examiner's agreement for caries lesions diagnosis was assessed using Cohen's Kappa coefficient.[19] The data about sociodemographic status and caries-related behaviours were presented separately for participants who completed baseline examination, the follow up examination and for those who dropped out. For all of these three groups the caries experience and caries prevalence on different diagnostic thresholds were reported. The sample distribution of continuous variables was described using means and standard deviations (SD) and for the categorical data counts and percentages were used. The caries experience was calculated on surface and tooth levels as mean DMFS and DMFT for two diagnostic thresholds: $ICDAS_{1-6}$ and $ICDAS_{5-6}$. In addition, mean number of active caries lesions and their prevalence on tooth and surfaces levels for two diagnostic thresholds (D_{1-6} active and D_{5-6} active) were calculated.

The multilevel Poisson regression was used to estimate the association between baseline lesions' characteristics as exposure variables (caries severity, activity, tooth type and tooth surface type status) and caries lesion progression as an outcome variable. To account for the hierarchy in the data, we used three levels. Level 1: surface (e.g. proximal, pits and fissures, smooth); Level 2: tooth (e.g. molars, premolars, anterior); Level 3: participant (e.g. ID-1, ID-2, … ID-322). The measures of association and the corresponding 95% confidence intervals (CI) were interpreted as rate ratios (RRs) for caries progression from the above model.

Two separate multilevel Poisson regression models were used for analysis. The first model was run to assess the association between caries lesions' severity and caries lesions' progression (objective 1a). In this model, the exposure variable was primary lesion severity status at the baseline only ($ICDAS_{1+2}$ as a reference vs. $ICDAS_{3+4}$), not considering the lesion's activity, while tooth and surface types were considered as covariates. The second model was run to assess the association between the caries lesions' activity and caries lesions' progression (objective 1b) as well as the association of the tooth type, and the tooth surface type and caries lesions' progression (objective 2a and 2b). In this model, the exposure variables were the interaction between severity and activity at the baseline ($ICDAS_{1+2}$ inactive as a reference vs. $ICDAS_{3+4}$ inactive, $ICDAS_{3+4}$ active), surface type (smooth as a reference vs. pits and fissures, proximal) and tooth type (anterior: as a reference vs. molar, premolar). First, an unadjusted Poisson regression analysis for both models was conducted to estimate the crude RRs of caries progression. Then these two models were adjusted for age, gender, education, occupation, living site, monthly income, frequency of toothbrushing, use of fluoridated toothpaste, reason of last dental visit and baseline caries experience (D_{1-6}, active). A crude and fully adjusted model were fitted for each independent variable (e.g. baseline caries severity, baseline caries severity combined with activity, tooth type and tooth surface type). The predicted marginal incidence data of caries lesions progression was created and visualized. All the analyses were performed with R version: 4.1.1 (2021-08-10).[20]

4 | RESULTS

Based on the dataset that was used, 495 adults were examined at the baseline and all of them had at least one primary caries lesion. Out of 495 participants, 322 were evaluated at the 2-year follow up and 173 (35%) were dropped out. Among the main reasons for participants to drop out were change of the job and/or the residence place. At the baseline, 56% of the participants were 35–54 years old; 31% were 18–34 years old, and 14% were 55 years and older; 53% of the participants were females. Most of the participants (95%) were from urban areas; 48% reported graduation from collage, 23% graduated from high school and 29% received university education. Approximately 84% reported their monthly income did not exceed 300 $ (Table 1). About 37% of the participants reported the use of a table fluoride salt; 83% reported using fluoridated toothpaste. About 49% reported brushing their teeth twice or more/day and 45% once a day. Almost 70% of the participants reported visiting dentists in the last year; 47% visited dentist for treatment reason and 17% for the dental emergency.

The intra-examiner's Cohen's kappa was 0.82 (95% CI 0.81, 0.84) when all caries diagnostic codes were included (lesion severity and activity, missed, restored) and 0.84 (95% CI 0.82, 0.85) when lesions' activity was not considered. The main disagreements within the examiner were attributed to non-cavitated active and micro-cavitated active and inactive lesions (supplementary material, Table S1). Mean D_{1-6} MFS value at baseline was 84.5 (±37.5), while mean D_{5-6} MFS was 63.1 (±43). Mean DS_{1-6}, active and DS_{5-6}, active values at baseline were 9.0 (±11.4) and 5.6 (±9.7), respectively. The prevalence of active caries lesions at baseline was 84% and 65% on DS_{1-6} and DS_{5-6} levels, respectively (Table 2). Participants who dropped out had a higher mean number of active DS_{1-6} caries lesions than the follow up group (10.9 (±12.8) vs. 7.9 (±10.4)) and slightly higher prevalence of active DS_{1-6} lesions (87% vs. 82%, Table 2).

Most active and inactive non-cavitated lesions (76% and 85%, respectively) at baseline did not progress 2 years later. About 24% of active non-cavitated lesions progressed to more severe condition or being restored/missed due to caries while only 15% of inactive non-cavitated lesions progressed. Regarding the micro-cavitated/shadowed lesions, 49% of inactive lesions and 44% of active lesions remained unchanged (Table 3).

In the first regression model, after adjustment for co-variates and confounding factors, it was found that micro-cavitated/shadowed lesions ($ICDAS_{3+4}$) were 1.41 (95% CI 1.16, 1.70) time likely to progress than non-cavitated lesions ($ICDAS_{1+2}$) within 2 years

TABLE 1 Socio-demographic characteristics of participants at the baseline.

	Baseline group (*n* = 495), %	Follow up group (*n* = 322), %	Dropped out group (*n* = 173), %
Age group			
18–34	152 (31)	65 (20)	87 (50)
35–54	276 (55)	208 (65)	67 (39)
55 and older	68 (14)	49 (15)	19 (11)
Gender			
Male	232 (47)	135 (42)	97 (56)
Female	263 (53)	187 (58)	76 (44)
Missing	1 (0.2)	0 (0)	0 (0)
Living site			
Urban	472 (95)	304 (94)	168 (97)
Rural	22 (4)	18 (6)	4 (2)
Missing	2 (0.4)	0 (0)	1 (0.6)
Occupation			
No occupation	7 (1)	4 (1)	3 (2)
Manual	297 (50)	177 (55)	120 (69)
Non manual	190 (38)	141 (44)	49 (28)
Missing	2 (0.4)	0 (0)	1 (0.6)
Education			
High school	114 (23)	68 (21)	46 (27)
College	236 (48)	157 (49)	79 (46)
University	142 (29)	95 (30)	47 (27)
Missing	4 (0.8)	2 (0.6)	1 (0.6)
Monthly income			
Up to 300 $	416 (84)	271 (84)	145 (84)
300–500 $	67 (14)	43 (13)	24 (14)
More than 500 $	4 (0.8)	2 (0.6)	2 (1)
Missing	9 (2)	6 (2)	2 (1)

TABLE 2 Caries experience and prevalence of participants at the baseline.

	Baseline group (*n* = 495)	Follow up group (*n* = 322)	Dropped out group (*n* = 173)
D1-6 MFT mean (± SD)	21.9 (±5.4)	22.5 (±5)	20.8 (± 5.9)
D5-6 MFT mean (± SD)	14.6 (±7.7)	15.7 (±7.3)	12.5 (±8.2)
D1-6 MFS mean (± SD)	84.5 (±37.5)	88.6 (±35.3)	77 (±40.3)
D5-6 MFS mean (± SD)	63.1 (±43)	88.6 (±35.3)	54.1 (±45.5)
DT1-6 active mean (± SD)	4.3 (±3.6)	3.9 (±3.4)	4.8 (±3.9)
DT5-6 active mean (± SD)	1.3 (±2.1)	1.1 (±1.7)	1.7 (±2.45)
DS1-6 active mean (± SD)	9.0 (±11.4)	7.9 (±10.4)	10.9 (±12.8)
DS5-6 active mean (± SD)	5.6 (±9.7)	4.9 (±8.8)	6.8 (±10.9)
Prevalence (%), DS1-6 active	84%	82%	87%
Prevalence (%), DS5-6 active	65%	63%	68%

Abbreviations: DMFT/S, Decayed (D), Missed (M), Filled (F) teeh (T)/surfaces (S); $D_{1\text{-}6}$, all ICDAS 1–6 caries lesions; $D_{5\text{-}6}$, ICDAS 5–6 caries lesions.

follow up. In the second regression model where lesions' severity and activity at the baseline was considered, after adjustments for confounding factors, it was found that active non-cavitated and active micro-cavitated/shadow lesions had 1.78 (95% CI 1.40, 2.27) and 1.97 (95% CI 1.53, 2.55) times the rates of progression than non-cavitated inactive lesions, respectively. The proximal

TABLE 3 Caries lesions' progression over 2 years according to baseline lesions' severity/activity status and the tooth surface type (participants, $n = 332$).

Baseline lesion severity and activity status	Tooth surface status at 2-years follow up						
	Number of surfaces	Sound	$ICDAS_{1+2}$	$ICDAS_{3+4}$	$ICDAS_{5+6}$	Restoration	Missing
$ICDAS_{1+2}$							
Pits and fissures							
Inactive	1688	209 (12)	1242 (74)	101 (6)	10 (1)	112 (7)	14 (1)
Active	84	19 (23)	30 (36)	20 (24)	3 (4)	7 (8)	5 (6)
Proximal							
Inactive	2550	370 (15)	1754 (69)	212 (8)	50 (2)	130 (5)	34 (1)
Active	118	16 (14)	77 (65)	5 (4)	5 (4)	6 (5)	9 (8)
Smooth							
Inactive	1142	294 (26)	719 (63)	45 (4)	12 (1)	53 (5)	19 (2)
Active	227	36 (16)	148 (65)	17 (8)	8 (4)	10 (4)	8 (4)
All							
Inactive	5380	873 (16)	3715 (69)	358 (7)	72 (1)	295 (6)	67 (1)
Active	429	71 (17)	255 (59)	42 (10)	16 (4)	23 (5)	22 (5)
$ICDAS_{3+4}$							
Pits and fissures							
Inactive	240	10 (4)	73 (30)	131 (55)	3 (1)	20 (8)	3 (1)
Active	94	3 (3)	22 (23)	46 (49)	11 (12)	12 (13)	0
Proximal							
Inactive	112	10 (9)	30 (27)	44 (39)	6 (5)	21 (9)	1 (1)
Active	114	10 (9)	20 (18)	38 (33)	21 (18)	24 (21)	1 (1)
Smooth							
Inactive	46	12 (26)	10 (22)	19 (41)	0	5 (11)	0
Active	56	5 (9)	8 (14)	31 (55)	5 (9)	5 (9)	2 (4)
All							
Inactive	398	32 (8)	113 (28)	194 (49)	9 (2)	46 (12)	4 (1)
Active	264	18 (7)	50 (19)	115 (44)	37 (14)	41 (16)	3 (1)

lesions and pit/fissure lesions had 1.57 (95% CI 1.30, 1.89) and 1.37 (95% CI 1.11, 1.67) times the rates of caries progression than the smooth surface lesions, respectively. Regarding tooth type, molars and premolars had 1.41 (95% CI 1.15, 1.73) and 1.31 (95% CI 1.04, 1.64) times the rates of caries progression than anterior teeth, respectively (shown in Table 4). The predicted marginal incidence data of caries lesions progression presented in supplementary material (Figures S1–S4).

5 | DISCUSSION

In this study, it was assessed the extent to which caries lesions' severity and activity status are associated with caries lesion progression in a sample of caries active adults in Belarus. In addition, it was investigated how the tooth and tooth surface types were associated with caries lesion progression. The study findings have shown that in caries active adults: (1) Most active and inactive caries lesions did not show progression within 2 years follow-up. (2) Active caries lesions were more likely to progress to more severe conditions than inactive lesions. (3) When focusing only on baseline caries severity status, tooth surfaces with micro-cavitated/shadow caries lesions had a higher progression rate to more severe conditions compared with non-cavitated caries lesions. (4) The likelihood of progression of inactive micro-cavitated/shadow lesions was almost the same as for non-cavitated inactive lesions.

An important limitation of the current study was the loss of follow-up that exceeded 20% of the sample (34.9%). In this study the participants at baseline and follow-up were similar regarding sociodemographic and oral health behavioural characteristics except for the age. It was found that majority of participants who dropped out were younger (18–34 years), which makes sense as young adults are always searching for new jobs to improve their income. At the same time, this may affect the effect size estimate by underestimating the findings related to caries progression rates since the dropped-out group had a higher average number

TABLE 4 Two-years primary caries lesions progression rate in study participants based on lesions' baseline severity and activity status, the surface, and the tooth type.

Exposure variables	Crude rate ratio, 95% CI	Adjusted rate ratio, 95% CI
First level: Surface		
Lesion severity status (ref. $ICDAS_{1+2}$)[a]		
$ICDAS_{3+4}$	1.42 (1.18, 1.71)	1.41 (1.16, 1.70)
Lesion activity/severity status (ref. $ICDAS_{1+2}$, inactive)[b]		
$ICDAS_{1+2}$, active	1.65 (1.32, 2.06)	1.78 (1.40, 2.27)
$ICDAS_{3+4}$, inactive	1.07 (0.80, 1.43)	1.10 (0.81, 1.47)
$ICDAS_{3+4}$, active	2.01 (1.57, 2.56)	1.97 (1.53, 2.55)
Surface type (ref. smooth)		
Pits and fissures	1.28 (1.06, 1.56)	1.37 (1.11,1.67)
Proximal	1.41 (1.18, 1.69)	1.57 (1.30,1.89)
Second level: Tooth		
Tooth type (ref. anterior)		
Molar	1.33 (1.10, 1.61)	1.41 (1.15,1.73)
Premolar	1.28 (1.02, 1.59)	1.31 (1.04,1.64)

[a]For the first model our exposure variable was primary lesion severity status at the baseline only, not taking into account lesion's activity. The model was adjusted for age, gender, education, occupation, living site, monthly income, frequency of toothbrushing, use of fluoridated toothpaste, reason of last dental visit and baseline caries experience (D1–6, active). Tooth and surface type were treated as covariates.

[b]For the second model our exposure variables were primary lesions severity/activity status at the baseline, tooth and surface types. The model was adjusted for age, gender, education, occupation, living site, monthly income, frequency of toothbrushing, use of fluoridated toothpaste, reason of last dental visit and baseline caries experience (D1–6, active).

of active non-cavitated and cavitated caries lesions than the follow-up group of the same age. Another limitation was that the length of the follow-up is only 2 years and more longitudinal follow-up time would give us more insight about the caries lesions progression in adults. Nonetheless, a 2-years follow-up time in caries active adults was enough to see the changes in caries lesions progression. Although it seems that transition of non-cavitated caries lesions to 'missing' category may not be plausible within 2 years follow-up, it maybe explained by the presence on other surface(s) a more severe caries-related condition which may led to the tooth extraction. The main disagreements within the examiner were attributed to non-cavitated active and micro-cavitated active and inactive lesions. This measurement error may have led to an underestimation of the true incidence RR in the current study findings. However, according to the regression analysis, the estimated effect sizes were considerably large. That is the true effect size may be higher that the estimated one, hence the conclusion remains unchanged.

Alongside these limitations, this study also has several strengths: it is a prospective cohort study in adults on caries progression where clinical examinations were performed based on tooth surface level using contemporary caries diagnostic criteria that permit assessing caries lesion severity and activity status. Furthermore, a multilevel Poisson regression model was used to control for important confounding variables and took in to account the nesting effect of the data (individual, surface, tooth). To our knowledge, there is no published article focusing on the same research question in the current scientific literature in an adult population. Moreover, the most recently updated ICDAS system that is integrated in ICCMS involves caries lesions' activity assessment based on the modifications of the Nyvad et al. and the Ekstrand et al. criteria.[7] This highlights the relevance of the study for the current time.

The findings from the current study indicate that the most active and inactive caries lesions remained unchanged within 2 years follow-up. This could be explained by use of fluoridated toothpaste by most of the participants. In addition, about one third of the participants reported use of table fluoridated salt. The fluoride exposure could slow down the lesions' progression.[21] Though, a longer follow-up time may be needed to evaluate the lesions' progression rate in this population sample.

It was found that active caries lesions were more likely to progress to more severe conditions than inactive lesions. These findings agreed with previous studies conducted in children with the use of the ICDAS criteria that showed that caries lesions diagnosed as active presented a higher risk to progress than inactive lesions.[1,17] It was also found that, regardless their severity, active lesions were more likely to progress than inactive lesions.

Among lesions that showed progression, the progression of the lesions with greater baseline caries severity scores (ICDAS 3 and 4) was more likely compared with the lesions with lower severity scores. These findings agree with previous studies' findings that were conducted among children using the ICDAS criteria.[1,14,17,22,23] Thus, the lesion severity can provide an additional information about the likelihood of caries lesions progression.

In this study pits and fissures and proximal surface lesions showed a greater likelihood of caries progression than smooth surfaces while adjusted to age, lesion severity and activity status. These finding agree with the findings of two longitudinal studies conducted in children and adolescents investigated caries progression rates based on the surface type.[24,25]

The current study findings showed that the likelihood of caries lesions progression in posterior teeth was higher than in anterior teeth, with minimal difference between molars and premolars. This findings are in agreement with a birth cohort study conducted in New Zealand from the age of 5 to the age of 38 years old, in which it was reported that the highest caries experience in participants in the age of 38 was found in molars and premolars, and the lowest caries experience was in the anterior teeth.[13]

The data of this study generated from adults with high caries activity levels, with generally low socio-economic status, living in urban area, in the region with low concentration of fluoride in water. At the same time most of this study population used fluoridated

toothpastes. Thus, the findings may be extrapolated only to adult population with similar characteristics.

The findings of the current study provide additional evidence about caries lesions progression based on their severity/activity assessment and they may rationalize the use of contemporary visual-tactile caries diagnostic criteria in epidemiology and in clinical dental practice in adults. Timely, early detection of active caries lesions in adults can minimize future surgical interventions and other adverse outcomes and lead to improved long-term oral health in adult population. However, longitudinal studies with a robust methodology and longer follow-up time would bring more insight into caries progression in contemporary adult populations.

Therefore, we can conclude that in this study of a sample of caries-active adults over a period of 2 years, most non- and micro-cavitated active and inactive caries lesions did not show progression. Nevertheless, among the lesions that progressed, it was found that both non-cavitated and micro-cavitated active lesions were more prone to progress than inactive lesions. More severe lesions were more likely to progress than less severe lesions. Thus, the overall activity and severity of non- and micro-cavitated caries lesions were related to the likelihood of caries progression in this population. In addition, lesions' progression rates were dependent on the surface and tooth type. More longitudinal studies with a longer follow-up period should be conducted among adults with various caries risk status using contemporary caries diagnostic criteria to provide comprehensive evidence about caries disease progression in adults.

AUTHOR CONTRIBUTION

Hoda Abdalla, developed the aims, wrote the research protocol, prepared the data, performed the statistical analysis, wrote the manuscript. Paul Allison, guided the project development, developed the research question and objectives of the study designed, supervised this study, and was involved in writing and reviewing the manuscript. Sreenath Arekunnath Madathil, guided data cleaning and analytic approach development, and guided the statistical analysis, and was involved in writing and reviewing the manuscript. Jacques Veronneau, developed the study protocol for the primary study, guided the data collection, and was involved in writing and reviewing the manuscript. Natallia Pustavoitava, recruited the participants, organized and conducted all data collection, and was involved in writing and reviewing the manuscript. Svetlana Tikhonova was involved in research question development, protocol development, management of the project and guiding the data cleaning, data analysis, manuscript writing and reviewing, and data interpretation.

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CONFLICT OF INTEREST STATEMENT

All authors declared no conflicts of interest with respect to this article.

DATA AVAILABILITY STATEMENT

All data related to the research question was analysed during this study and included in this article. Please contact the corresponding author for further inquiries.

PATIENT CONSENT

All participants provided a written informed consent before data collection.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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