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Original Article

Dietary Starch and Its Relationship with Caries Progression: Long-Term Findings from Finland

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ABSTRACT

This study aimed to investigate the link between starch consumption (quantity and source) and progression of dental caries in adults across an 11-year period. Information was collected from 1,679 adults aged 30 years or older who participated in a series of three nationwide surveys in Finland. During the baseline survey, all participants completed a 128-item, semi-structured food frequency questionnaire that had been previously validated. from which daily starch intake (grams and % of total energy) and intake of seven starch-rich food categories (including potatoes, potato derivatives, roots/tubers, refined cereals, pasta, whole grains, and legumes) were estimated. Dental caries status was assessed in clinical examinations and expressed using the DMFT index, analyzed as a repeated measure. Associations between baseline starch intake and 11-year DMFT change were evaluated with linear mixed-effects modeling, adjusted for sociodemographics, lifestyle, sugar consumption, and general health. The average DMFT index was 21.9 (95% CI: 21.6–22.2) in 2000, increasing by 0.47 (95% CI: 0.38–0.56) in 2004/05, and a further 0.33 (95% CI: 0.20–0.45) in 2011. No association was detected between overall starch intake and DMFT progression, regardless of whether intake was expressed in grams/day or as % of energy intake. Among the seven food categories, only pasta intake showed an inverse association with DMFT at baseline, but it was unrelated to changes over the follow-up period. Over an 11-year timeframe, starch intake—neither in total quantity nor by food type—showed no significant relationship with dental caries development in Finnish adults.

Keywords: Dental decay, Adults, Roots, Legumes, Potatoes, Starch

Introduction

Starch constitutes the principal carbohydrate in human nutrition and is a primary source of energy for the body [1, 2]. It serves as the main storage form of glucose in plants such as root vegetables, cereals, and legumes, being entirely composed of glucose molecules [1]. Due to this, starch plays a crucial role in providing dietary glucose and contributes significantly to postprandial blood glucose fluctuations [3, 4]. Depending on their digestibility in humans, starches are categorized into three groups: rapidly digestible starch (RDS), slowly digestible starch (SDS), and resistant starch (RS) [5]. RDS is absorbed quickly in the small intestine, converting to glucose within 20 minutes, and is present in freshly cooked starchy foods like boiled potatoes, as well as in processed starch-rich products such as bread, instant potato mixes, and potato crisps. SDS is metabolized more gradually, with glucose released over 20 to 120 minutes, and is typically found in pasta, nuts, and seeds. RS resists digestion in the small intestine and is fermented by gut microbiota, producing short-chain fatty acids; it is mainly found in whole grains and legumes [5–7]. Although specific daily limits for starch intake have not been established, the World Health Organization (WHO) advises that dietary carbohydrates should predominantly originate from whole grains, legumes, fruits, and vegetables [8]. This advice is likewise endorsed by the European Food Safety Authority

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(EFSA) panel responsible for nutrition, novel foods, and food allergens [9] and is reflected in the Nordic Nutrition Guidelines published in 2023 [10].

Although starch is not inherently cariogenic because oral bacteria do not ferment it directly, salivary amylase can break starch down into sugars during ingestion, raising questions about its potential association with dental caries [11, 12]. Evidence in this area is limited. The UK's Scientific Advisory Committee on Nutrition (SACN) noted insufficient data on how starch or starchy foods influence oral health outcomes [13]. A systematic review informing WHO carbohydrate guidelines [8] identified low-quality evidence from four cohort studies (including one in adults) showing no significant link between total starch intake and dental caries. However, low-quality evidence from two pediatric cohort studies suggested a possible association between RDS consumption—one focusing on processed starch snacks, the other on sugar-starch interactions—and caries. Overall, available data are scarce, and heterogeneity in study design prevented meta-analysis [14]. Another review reported that frequent intake of processed foods containing both sugars and starches between meals was correlated with dental caries in children (three cohort studies) [12]. Importantly, most studies examined combined sugar-starch effects, making it difficult to determine the independent influence of starch. Furthermore, nearly all research was conducted in children rather than adult populations.

There is a clear gap in longitudinal research examining starch consumption and its potential impact on adult dental health. To address this, the present study investigates both overall starch intake and key dietary sources—including rapidly digestible starch (RDS)—within the Finnish adult population. Dental caries data were collected over three separate survey waves spanning 11 years, while adjusting for lifestyle factors, dietary habits, and other determinants of oral health. Findings from this study may help shape future dietary guidance regarding starch consumption. In Finland, naturally occurring fluoride in water is minimal, with 98% of municipal water supplies and 95% of private wells containing less than 0.1 mg/L fluoride [15]. The primary goal was to assess the relationship between starch intake—both in total amount and specific food types—and changes in dental caries among adults over an 11-year period. We hypothesized that higher starch consumption, particularly from RDS-rich foods, would be associated with increased caries incidence.

Materials and Methods

Study population and data sources

For this study, data were drawn from adults who participated in the Health 2000 survey as well as at least one of its subsequent follow-up investigations **(Figure 1)**. The baseline survey (wave 1) of Health 2000 recruited a nationally representative cohort of 8,028 adults aged 30 years and older residing in mainland Finland. Of these, 6,335 individuals (79%) underwent dental examinations, and 5,401 participants had at least one natural tooth [16]. During the 2004/05 follow-up (wave 2), a random subset of 2,000 previously examined adults was selected for re-evaluation. Individuals who had passed away, were completely edentulous, or lived in areas with fewer than 15 participants at baseline were excluded from the follow-up. Following these exclusion criteria, 1,248 adults were invited to undergo a repeat dental examination, of whom 1,049 (84%) participated. The third wave, Health 2011, focused on 7,694 surviving participants from the Health 2000 survey residing in mainland Finland. Dental assessments were performed in two out of five geographic regions (Southern and Northern Finland), with 3,713 adults invited and 1,684 re-examined, representing a 45% participation rate [17]. All examinations and data collection were conducted by the Finnish Institute for Welfare and Health (THL), with ethical approval obtained separately for each wave from the Ethics Committee of the Hospital District of Helsinki and Uusimaa. Written informed consent was secured from every participant.

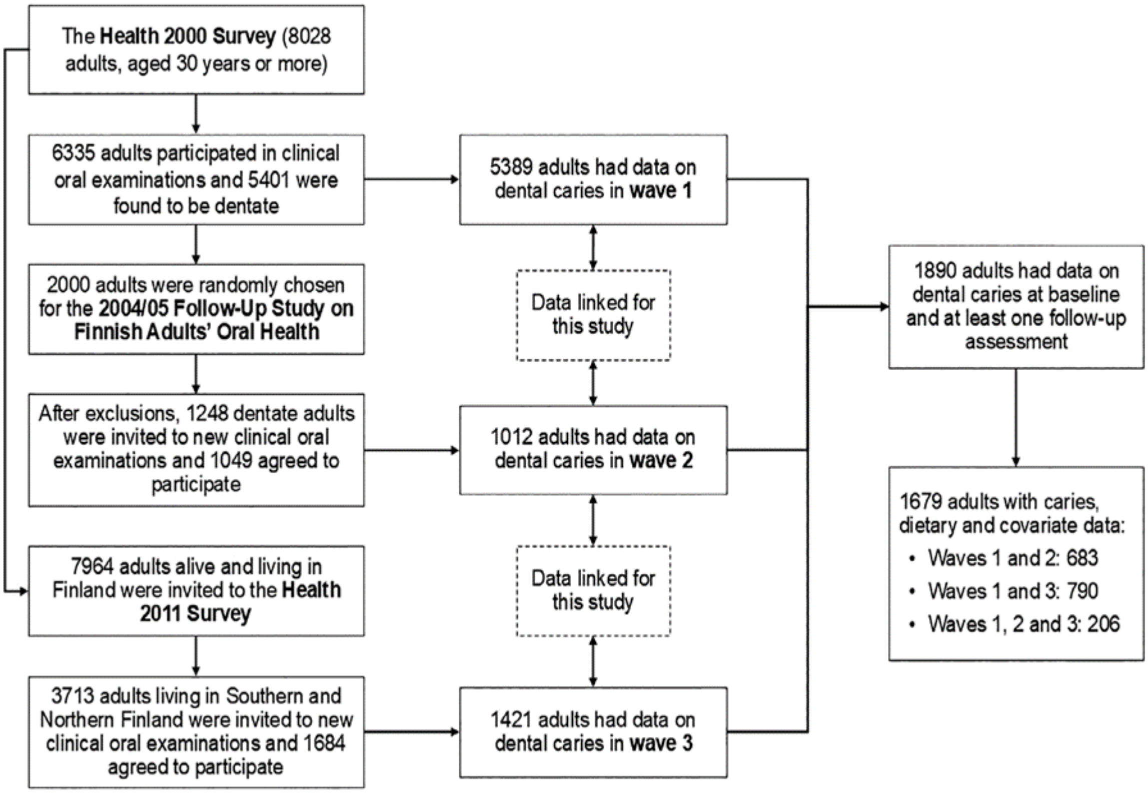

Figure 1. Flow diagram illustrating participant inclusion across surveys and the linkage of their data.

Initially, 1,890 adults with at least one natural tooth participated in baseline dental assessments and were eligible for at least one follow-up examination **(Figure 1)**. Out of these, 211 individuals were removed from the analysis: 98 participants lacked baseline dietary intake information, and 113 had missing data for other covariates. Consequently, the analytic sample comprised 1,679 individuals. Among them, 1,473 had caries data available for two survey waves, while 206 had complete data across all three waves.

Variables

Dental caries was defined as the primary outcome and assessed through clinical examinations conducted by a team of five calibrated dentists. All waves followed the same examination protocol. Each participant was positioned in a dental chair, and teeth were inspected using fiber-optic lighting, a mouth mirror, and a WHO periodontal probe. Compressed air was applied to dry teeth, and cotton rolls were used for isolation. A tooth was classified as decayed if lesions extended into the dentine on either coronal or root surfaces, exhibited cavitation, undermined enamel, or showed clearly softened dentine [18]. The consistency of caries detection was high, with inter-examiner and intra-examiner Kappa scores of 0.87 and 0.95, respectively [18]. Caries experience was quantified using the DMFT index (number of decayed, missing, and filled teeth) and analyzed as a repeated measure over time.

Baseline assessment of starch consumption

For this study, starch intake at the first survey wave (baseline) served as the primary exposure variable. Habitual dietary patterns over the previous year were collected using a validated semi-structured 128-item food frequency questionnaire (FFQ) [19–21]. The FFQ included commonly eaten foods and nutritionally significant items, divided into 12 groups: dairy, cereals, spreads, vegetables, potatoes/rice/pasta, meats, fish, poultry and eggs, fruits and berries, desserts, sweets/snacks, and beverages. Standardized portion sizes were assigned for each item using natural units such as slices, pieces, glasses, or tablespoons.

Participants indicated frequency of consumption using nine options: never or rarely, 1–3 times per month, once weekly, 2–4 times weekly, 5–6 times weekly, once daily, 2–3 times daily, 4–5 times daily, or more than 6 times daily. Questionnaires were completed at participants' homes and returned to THL, where a nutritionist checked for missing or implausible data.

Information from the FFQ was processed to estimate participants' consumption of starch, sugars, total energy (EI), and the specified food groups, referencing the Finnish Food Composition Database (Fineli®, THL, Finland). Total starch intake was categorized into five equal groups (quintiles) based on both grams per day (g/day) and its proportion of total energy intake (%EI). Seven major starch-containing food categories were analyzed based on prior literature [5–7]: (i) potatoes, (ii) potato-based products (e.g., fries, chips), (iii) roots and tubers, (iv) legumes (peas, beans, nuts, seeds), (v) wholegrains (barley, oat, rye) [22], (vi) pasta, and (vii) refined grains (total grains minus wholegrains and pasta, e.g., wheat, rice). Intake for each of the seven starch-containing food groups was divided into five equal groups (quintiles) based on grams consumed per day. Additional foods that contain starch, such as crackers, were excluded from the analysis because they are rarely consumed by adults in Finland and have combined starch and sugar content, which complicates attributing effects solely to starch.

To identify potential confounding factors in the relationship between starch intake and dental caries, the disjunctive cause criterion [23, 24] was applied. According to this approach, proper adjustment for confounding is achieved by: (1) including any variable that influences the exposure, the outcome, or both; (2) excluding variables known to act as instruments; and (3) adding proxy variables for unmeasured factors affecting both the exposure and the outcome.

Variables considered to influence both starch intake and dental caries were sex, age, educational level, and self-perceived health. Elements assumed to primarily affect dental caries included sugar consumption, frequency of toothbrushing, use of fluoride toothpaste, interdental cleaning (flossing or brushes), and patterns of dental visits. Factors mostly associated with starch consumption comprised marital status, physical activity, alcohol intake, body mass index (BMI), and presence of chronic diseases.

Participants self-rated their general health on a scale from 1 to 5, and responses were condensed into three groups: good, moderate, or poor. Brushing habits were reported using a five-level scale (never, less than daily, once daily, twice daily, or more than twice daily) and subsequently classified as less than once per day, once per day, or twice or more per day. Sugar consumption was categorized into five equal groups based on daily intake (grams/day). The frequency of using fluoride toothpaste and interdental cleaning tools (such as floss or interdental brushes) was collected with a four-point scale (never, less than weekly, weekly, daily) and then grouped into daily, less than daily, or never. Attendance at dental clinics was recorded and later grouped as either for preventive check-ups or only for treatment of problems, including individuals who had never sought dental care.

Marital status was classified into cohabiting (married or living with a partner) and living alone (single, divorced, separated, or widowed). Physical activity was assessed by two components: leisure-time exercise (LTE) lasting ≥30 minutes with mild exertion, and commuting activity by walking or cycling to work (WCW). Participants were classified into four groups: ideal (LTE ≥4 times/week and WCW ≥30 min/day), sufficient (meeting either LTE or WCW threshold), low (LTE 2–3 times/week and WCW <30 min/day), or sedentary (LTE ≤1/week and WCW <30 min/day).

Alcohol consumption over a week, expressed as grams of pure ethanol, was classified into three categories: non-drinkers, moderate consumers (less than 70 g for women and less than 140 g for men), and high-risk consumers (70 g or more for women, 140 g or more for men). Trained nurses recorded participants' body weight and height using a wall-mounted stadiometer and a bioelectrical impedance scale (InBody 3.0, Biospace, South Korea). Based on these measurements, individuals were grouped by BMI as normal weight (<25 kg/m²), overweight (25–29.9 kg/m²), or obese (≥30 kg/m²). Additionally, participants provided information on whether they had ever been diagnosed with hypertension, diabetes, heart conditions, or stroke.

Statistical analysis

Data analysis was conducted using Stata MP 18 (StataCorp LP, College Station, Texas). Baseline participant characteristics were first examined across quintiles of daily starch intake (g/day) using Chi-square tests. DMFT scores from the three survey waves (2000, 2004/05, 2011) were then compared by starch quintiles, considering both absolute intake (g/day) and proportion of total energy (%EI). Linear regression was applied to detect trends across these quintiles.

To examine 11-year changes in dental caries, linear mixed-effects (LME) models were used. In this framework, repeated DMFT measures (level 1) were nested within individuals (level 2). LME models are suitable for handling incomplete data and uneven observation intervals, while adjusting for correlations among repeated measures for the same participant [25, 26]. Time was modeled categorically (wave 1 = 0, wave 2 = 1, wave 3 = 2), with random intercepts and slopes to account for individual differences in initial DMFT and progression rate. All other predictors were included as fixed effects, and an unstructured covariance matrix was specified.

Initially, a model including only time was fitted to estimate the mean DMFT change between waves. Next, three sequential models were applied to evaluate the effect of baseline starch consumption on DMFT changes over 11 years: Model 1 included starch intake, total energy intake, and time; Model 2 additionally adjusted for sociodemographic characteristics, health behaviors, and general health; Model 3 incorporated a starch × time interaction term. The likelihood ratio test assessed whether the interaction improved model fit; if not, Model 2 was selected [25].

Effects in Models 1 and 2 reflect the impact of starch intake on baseline DMFT scores under the assumption that differences remain constant throughout follow-up (parallel trajectories for quintiles). In contrast, a significant interaction in Model 3 implies that the influence of starch on DMFT changes over time (trajectories for quintiles may diverge or converge) [26]. Separate LME analyses were conducted for starch expressed as g/day and %EI. The same modeling procedure was repeated for each of the seven major starch-containing food groups individually, without controlling for sugar intake.

Supplementary analyses

To examine the reliability of our methods, several additional analyses were performed. First, we assessed differences in baseline characteristics among three groups: participants included in the final dataset, participants lacking follow-up dental caries data, and participants with follow-up caries information but missing dietary or covariate data. This step allowed evaluation of how participant dropout and missing data may have influenced the results. Second, all models were recalculated using only the DFT score rather than the complete DMFT score, in order to understand the impact of including missing teeth on the outcomes. Third, models were rerun while adjusting exclusively for variables considered common determinants of both starch intake and dental caries—specifically, sex, age categories, educational attainment, and self-reported health—to test the effect of our confounder selection strategy. Lastly, the statistical power of the study to detect the observed associations was determined.

Results and Discussion

A total of 3,564 repeated observations from 1,679 adults were included in the analysis. Participants' average age at baseline was 47.6 ± 11.3 years. The mean daily starch consumption was 130.2 ± 50.3 g, which accounted for 23.2 ± 4.8% of total energy intake. Individuals in the highest quintiles of starch intake tended to be male, older, less educated, living with a partner, physically active, and non-drinkers of alcohol **(Table 1)**.

When examining DMFT scores, crude values increased across quintiles of starch intake measured in g/day during the first two waves (2000 and 2004/05), while the trend was not observed in the third wave (2011). Expressing star ch intake as a percentage of total energy revealed a consistent upward trend in DMFT scores across all waves.

Table 1. Baseline characteristics of participants by selected starch intake quintiles (Q1, Q3, Q5) and covariates. Abbreviation: BMI, body mass index.

Baseline Characteristics	Total Sample	Q1 (median: 71.6 g/day)	Q3 (median: 123.4 g/day)	Q5 (median: 194.0 g/day)
	n	%	n	%
Sex				
Men	740	44.1	131	39.0
Women	939	55.9	205	61.0
Age (years)				
30–39	498	29.7	102	30.4
40–49	487	29.0	98	29.2
50–59	423	25.2	98	29.2
60–69	209	12.5	34	10.1
70+	62	3.7	4	1.2
Education Level				
Basic	402	23.9	88	26.2
Secondary	678	40.4	139	41.4
Higher	599	35.7	109	32.4
Marital Status				

Cohabiting	1275	75.9	225	67.0
Living alone	404	24.1	111	33.0
Physical Activity				
Sedentary	611	36.4	148	44.1
Low	531	31.6	98	29.2
Sufficient	454	27.0	80	23.8
Ideal	83	4.9	10	3.0
Alcohol Use				
None	173	10.3	16	4.8
Moderate	1158	69.0	222	66.1
Risky	348	20.7	98	29.2
BMI Categories				
Normal	700	41.7	137	40.8
Overweight	659	39.3	130	38.7
Obese	320	19.1	69	20.5
Diabetes Status				
No	1630	97.1	331	98.5
Yes	49	2.9	5	1.5
Heart Disease				
No	1385	82.5	275	81.9
Yes	294	17.5	61	18.2
Hypertension				
No	1252	74.6	261	77.7
Yes	427	25.4	75	22.3
Stroke History				
No	1657	98.7	333	99.1
Yes	22	1.3	3	0.9
Self-Rated Health				
Poor	82	4.9	14	4.2
Moderate	357	21.3	65	19.4
Good	1240	73.9	257	76.5
Toothbrushing Frequency				
≥2 times/day	1153	68.7	239	71.1
Once/day	459	27.3	85	25.3
<1 time/day	67	4.0	12	3.6
Fluoride Toothpaste Use				
Daily	1555	92.6	316	94.1
Less than daily	83	4.9	17	5.1
Never	41	2.4	3	0.9
Interdental Cleaning				
Daily	200	11.9	35	10.4
Less than daily	695	41.4	146	43.5
Never	784	46.7	155	46.1
Dental Visits				
Routine check-ups	1055	62.8	210	62.5
Only when problems arise	624	37.2	126	37.5

Note: For clarity, only the 1st, 3rd, and 5th quintiles (Q1, Q3, Q5) are shown.
Abbreviation: BMI, body mass index.

Table 2. Baseline total starch intake and crude DMFT scores at waves 1 (2000), 2 (2004/05), and 3 (2011).

Total Starch Intake	Wave 1 (n = 1679)	Wave 2 (n = 889)	Wave 3 (n = 996)
In g/day			
Q1 (median 71.6)	21.3 (6.5)	21.7 (5.9)	22.2 (6.0)

Q2 (101.4)	22.3 (6.2)	22.6 (5.7)	23.1 (6.1)
Q3 (123.4)	21.3 (6.7)	21.4 (6.8)	22.0 (6.4)
Q4 (150.5)	22.2 (6.0)	22.9 (5.4)	22.6 (5.8)
Q5 (194.0)	22.4 (6.3)	23.0 (6.3)	22.9 (6.3)
p for trend	0.047	0.039	0.584
As % of energy intake (EI)			
Q1 (17.2%)	21.6 (6.1)	22.0 (5.8)	22.5 (5.7)
Q2 (20.7%)	21.2 (6.6)	21.6 (6.1)	21.9 (6.2)
Q3 (23.1%)	21.5 (6.3)	22.1 (5.9)	22.0 (6.4)
Q4 (25.5%)	21.9 (6.5)	22.2 (6.5)	22.7 (6.2)
Q5 (29.5%)	23.2 (6.1)	23.8 (5.8)	23.6 (6.0)
p for trend	0.001	0.005	0.032

Abbreviations: %EI = percentage of total energy intake; SD = standard deviation; Q = quintiles.
*Linear regression was used to examine trends across intake quintiles.

When time was the sole predictor in a linear mixed-effects analysis, the estimated mean DMFT at baseline was 21.9 (95% CI: 21.6–22.2). By the second wave, the mean increased by 0.47 (95% CI: 0.37–0.56), and an additional rise of 0.33 (95% CI: 0.20–0.45) was observed by wave 3. The negative covariance of −1.86 (95% CI: −2.27 to −1.45) indicated that participants with lower initial DMFT values experienced larger increments over time.
Unadjusted models showed a positive link between total starch intake at baseline and initial DMFT (Model 1), **(Table 3)**, consistent across both grams per day and %EI measures. After controlling for demographic, lifestyle, and health factors (Model 2), **(Table 3)**, this relationship was no longer apparent. Interaction terms between starch intake and time (Model 3) were not statistically significant (p = 0.328 for g/day; p = 0.315 for %EI), indicating that starch consumption did not influence the pattern of DMFT progression over the 11-year follow-up.

Table 3. Linear mixed-effects models estimating the impact of starch intake on DMFT changes over 11 years in Finnish adults aged ≥30 years (3,564 observations from 1,679 participants).

Starch Intake	**Model 1**	**Model 2**
	Coefficient (95% CI)	Coefficient (95% CI)
In g/day		
Q1 (median 71.6)	Reference	Reference
Q2 (101.4)	1.09 (0.14, 2.03)	0.68 (−0.13, 1.49)
Q3 (123.4)	0.13 (−0.87, 1.13)	−0.43 (−1.31, 0.45)
Q4 (150.5)	1.18 (0.09, 2.28)	0.15 (−0.81, 1.12)
Q5 (194.0)	1.89 (0.52, 3.27)	0.02 (−1.19, 1.25)
Trend p-value	0.031	0.641
As % of energy intake (EI)		
Q1 (17.2%)	Reference	Reference
Q2 (20.7%)	−0.51 (−1.43, 0.41)	−0.24 (−1.03, 0.55)
Q3 (23.1%)	−0.26 (−1.18, 0.66)	−0.47 (−1.27, 0.33)
Q4 (25.5%)	0.09 (−0.83, 1.01)	−0.47 (−1.27, 0.34)
Q5 (29.5%)	1.51 (0.59, 2.43)	0.01 (−0.82, 0.85)
Trend p-value	0.001	0.818

Note: DMFT values were assessed multiple times and treated as repeated measures within participants. In Model 1, predictors included total daily energy intake and survey wave. Model 2 incorporated additional adjustments for demographic, lifestyle, and health-related factors: sex, age group, marital status, education, alcohol consumption, physical activity, quintiles of starch intake, BMI category, history of diabetes, cardiovascular disease, hypertension, stroke, self-reported overall health, toothbrushing frequency, fluoride toothpaste usage, interdental cleaning practices, and dental attendance patterns. Reported results are expressed as regression coefficients (Coef.).
Abbreviations: %EI = percent of total energy intake; Q = quintiles (median value of intake).

In analyses focusing on individual sources of starch, higher consumption of potatoes, roots and tubers, and wholegrain foods was initially linked to higher DMFT scores at baseline, while greater intake of potato products, refined grains, and pasta showed an inverse relationship before adjusting for other variables (Model 1), **(Table 4)**. After accounting for covariates (Model 2), **(Table 4)**, only pasta intake maintained a significant association with baseline DMFT. Participants in the top fifth of pasta consumption had, on average, 1.31 fewer teeth affected by decay, fillings, or extractions at baseline (95% CI: –2.16 to –0.46) compared with those in the lowest fifth. The interaction between pasta consumption and time was not statistically significant (Model 3, p = 0.134), suggesting that the baseline differences persisted over the 11-year follow-up period. No meaningful time interactions were observed for other food groups, including potatoes (p = 0.350), potato-based products (p = 0.468), roots and tubers (p = 0.358), wholegrains (p = 0.675), refined grains (p = 0.323), or legumes (p = 0.473).

Table 4 presents the results for each food group's association with 11-year DMFT changes among Finnish adults aged ≥30 years (3564 repeated measures from 1679 participants).

Food Categories	**Model 1**		**Model 2**	
	Coef.	(95% CI)	Coef.	(95% CI)
Potatoes (g/day)				
Q1 (median: 67.9)	Reference	Reference	Reference	Reference
Q2 (103.5)	0.70	(−0.22, 1.63)	0.21	(−0.58, 0.99)
Q3 (139.2)	0.49	(−0.45, 1.44)	−0.01	(−0.82, 0.80)
Q4 (180.9)	1.71	(0.77, 2.66)	0.39	(−0.42, 1.21)
Q5 (241.8)	1.86	(0.82, 2.90)	0.07	(−0.83, 0.97)
p-value for trend	<0.001		0.697	
Potato-Based Products (g/day)				
Q1 (median: 0.8)	Reference	Reference	Reference	Reference
Q2 (3.4)	−1.24	(−2.15, −0.34)	−0.03	(−0.82, 0.76)
Q3 (4.5)	−1.55	(−2.48, −0.62)	−0.24	(−1.06, 0.57)
Q4 (5.9)	−2.51	(−3.46, −1.57)	−0.48	(−1.32, 0.36)
Q5 (9.4)	−3.30	(−4.27, −2.33)	−0.47	(−1.36, 0.42)
p-value for trend	<0.001		0.172	
Root Vegetables and Tubers (g/day)				
Q1 (median: 13.7)	Reference	Reference	Reference	Reference
Q2 (24.8)	−0.19	(−1.11, 0.74)	−0.46	(−1.24, 0.33)
Q3 (40.6)	0.96	(0.03, 1.89)	0.06	(−0.74, 0.85)
Q4 (61.0)	0.40	(−0.55, 1.35)	−0.74	(−1.56, 0.08)
Q5 (94.0)	1.56	(0.57, 2.54)	−0.22	(−1.10, 0.65)
p-value for trend	0.001		0.458	
Leguminous Plants (g/day)				
Q1 (median: 2.8)	Reference	Reference	Reference	Reference
Q2 (6.9)	−0.55	(−1.46, 0.35)	−0.59	(−1.35, 0.17)
Q3 (9.9)	0.25	(−0.70, 1.20)	0.17	(−0.63, 0.97)
Q4 (14.6)	−0.20	(−1.15, 0.75)	−0.29	(−1.09, 0.51)
Q5 (32.7)	−0.01	(−0.99, 0.96)	−0.59	(−1.42, 0.24)
p-value for trend	0.770		0.375	
Pasta Products (g/day)				
Q1 (median: 2.9)	Reference	Reference	Reference	Reference
Q2 (3.0)	−0.97	(−1.85, −0.09)	−0.22	(−1.00, 0.56)
Q3 (6.3)	−1.19	(−2.06, −0.32)	−0.06	(−0.84, 0.71)
Q4 (6.4)	−3.08	(−3.92, −2.25)	−0.47	(−1.25, 0.31)
Q5 (19.1)	−4.99	(−5.87, −4.11)	−1.31	(−2.16, −0.46)
p-value for trend	<0.001		0.007	

Whole Grain Foods (g/day)				
Q1 (median: 13.1)	Reference	Reference	Reference	Reference
Q2 (30.8)	1.00	(0.08, 1.92)	0.43	(−0.35, 1.21)
Q3 (57.2)	0.76	(−0.16, 1.69)	−0.66	(−1.45, 0.13)
Q4 (82.7)	2.43	(1.47, 3.38)	0.17	(−0.66, 1.01)
Q5 (122.5)	1.57	(0.59, 2.55)	−0.50	(−1.36, 0.35)
p-value for trend	<0.001		0.168	
Processed Grains (g/day)				
Q1 (median: 48.2)	Reference	Reference	Reference	Reference
Q2 (73.1)	−0.15	(−1.08, 0.78)	0.43	(−0.36, 1.22)
Q3 (98.5)	−0.55	(−1.50, 0.41)	0.23	(−0.58, 1.04)
Q4 (126.2)	−0.75	(−1.75, 0.25)	0.08	(−0.77, 0.93)
Q5 (178.5)	−1.38	(−2.52, −0.24)	0.20	(−0.78, 1.18)
p-value for trend	0.013		0.981	

Note: Mixed-effects linear models were used with DMFT repeated measures nested within participants. Coefficients (Coef.) are reportedIn Model 1, the predictors consisted of total daily energy intake and the survey wave. Model 2 further incorporated adjustments for participants' demographic characteristics, lifestyle habits, and health-related factors, including gender, marital status, education, alcohol consumption, levels of physical activity, BMI classification, history of diabetes, heart disease, hypertension, or stroke, self-rated overall health, toothbrushing frequency, use of fluoride toothpaste, interdental cleaning practices, and patterns of dental visits.
Abbreviation: Q = quintiles.

Supplementary analyses

We conducted additional checks to examine the robustness of our findings. Adults included in the study were generally younger, more often female, better educated, and reported healthier behaviors and overall health than those who either lacked follow-up caries data or had follow-up data but missing diet or covariate information. Analyses using the DFT score instead of DMFT showed no association with total starch intake or individual starch-rich foods. Restricting the adjustment to only variables representing shared causes of starch intake and dental caries also did not alter results. While total starch intake remained unrelated to DMFT, higher pasta consumption corresponded to lower baseline DMFT scores. A post-hoc power calculation demonstrated that the study had an 82.3% probability of detecting the observed 11-year difference in DMFT change between the highest quintile of starch intake (0.56 ± 1.75, n = 336) and the lowest quintile (0.98 ± 2.02, n = 335), using a two-sided t-test assuming unequal variances at a 0.05 significance threshold.

Over the 11-year follow-up, neither the overall amount of starch nor the type of starch consumed showed a meaningful effect on the progression of dental caries. Unadjusted associations were almost entirely explained by covariates, underlining the influence of shared determinants, including demographic and socioeconomic factors. Despite the expected rise in DMFT due to disease accumulation, the observed mean increase of 0.80 over the study period was relatively low compared with adult caries progression rates reported in the literature [27].

Unexpectedly, foods containing high amounts of RDS—such as potatoes, tubers, roots, and refined grains—did not show any connection with changes in dental caries. This result mirrors a 3-year longitudinal study conducted on US children, which found that eating unprocessed starches like boiled potatoes, rice, or bread did not increase caries incidence [28]. However, our findings did not support their claim that consuming processed starches (for example, potato crisps) frequently between meals leads to greater caries development [28]. In our study, the potato product group—which included French fries and potato chips—was comparable to the processed starch category from the previous research, yet consumption levels among participants were low and likely below that of children. Similarly, foods rich in SDS or RS, such as whole grains and legumes, despite their documented general health advantages [8], showed no measurable impact on dental caries. Out of the seven food groups analyzed, only pasta demonstrated an association, and this was observed exclusively at baseline. Pasta is a starch-heavy food with a low glycemic index, generating a modest post-meal blood sugar response, and constitutes a central element of the Mediterranean diet [29, 30]. Its potential protective role may arise from reduced digestibility—limiting starch availability to oral bacteria—and increased satiety after meals. Although semolina, pasta's main ingredient, is typically classified as RDS, its starch structure undergoes modifications during processing and cooking. The pasta preparation process forms a dense matrix that decreases the proportion of native RDS, a structure that becomes further stabilized during cooking and remains even after long cooking times [30].

Additionally, studies indicate that meals containing pasta or potato-based dishes enhance feelings of fullness, satisfaction, and reduce hunger, potentially lowering the likelihood of consuming desserts or snacks between meals [31, 32]. Pasta intake could also reflect adherence to an overall healthier lifestyle. Therefore, these results should be interpreted with caution. As emphasized, the observed association with dental caries was cross-sectional at baseline and did not extend longitudinally. Moreover, we did not observe a similar effect with other RS-rich foods, such as legumes. Confirmation of these outcomes will require further longitudinal research.

This study offers several key strengths, such as a large cohort, an extended follow-up involving three separate caries evaluations across 11 years, and rigorous checks for both intra- and inter-examiner reliability during caries assessments. Additionally, a broad set of covariates was considered. Despite these advantages, some limitations should be noted.

Firstly, the data were collected between 2000 and 2011. Although questions may arise about the current applicability of these results, the impact of dietary factors on caries development—particularly free sugars—has remained largely consistent over time, even with dietary improvements and widespread preventive practices.

Secondly, as is typical in longitudinal research, the sample size decreased due to participant dropouts and incomplete data. Those who remained in the study tended to be younger, more educated, and displayed healthier lifestyles and overall health, limiting the extent to which the results can be generalized to the wider population.

Thirdly, dietary information was collected through a single administration of a validated FFQ at wave 1. Although this method captures usual dietary patterns over an extended period, it does not offer the detailed resolution provided by more intensive approaches such as food diaries or repeated 24-hour dietary recalls [33]. Nonetheless, validation studies indicated that energy intake measured by the FFQ represented 95% of that obtained from 7-day food records [19], confirming the accuracy of this assessment. Information regarding the timing of food consumption (e.g., during versus between meals) and specific properties of starch-rich foods, such as their oral retention, was not available.

In conclusion, dental caries were quantified using the DMFT index, which has its limitations. One frequent issue involves distinguishing teeth lost specifically to caries from those missing due to other factors such as periodontitis, injury, or orthodontic extractions in adults. Notably, similar findings were observed when the DFT index was used instead of the complete DMFT measure.

The study's results indicate that the total amount of starch consumed may not directly determine the risk of developing dental caries. Research should instead focus on whether different starch types have varying impacts, if any. Looking at food groups also allows for consideration of factors specific to each country, such as the availability of certain foods and traditional dietary habits. Even in the absence of clear oral health benefits from SDS or RS, dental professionals should continue encouraging consumption of whole grains, fruits, vegetables, and legumes as primary carbohydrate sources due to their well-established general health benefits [8–10].

There is a need for more precise approaches to assess starch digestibility in epidemiological studies. Starch properties are influenced by multiple factors, including storage conditions, preparation techniques, processing, combination with other ingredients, and serving temperature [2, 7]. The widely recognized classification of starch into RDS, SDS, and RS [1, 5] is difficult to apply in large-scale studies because existing food composition tables do not provide such detailed breakdowns [14]. As a result, researchers often use general food categories as substitutes for specific starch types. Incorporating metrics such as the glycemic index or glycemic load of foods into future studies could yield additional insights. Employing refined starch classifications alongside repeated, detailed dietary assessments (e.g., multiple-pass 24-hour recalls) would help clarify the link between starch intake and dental caries.

It is also important to consider that starch is usually consumed within complex dietary patterns rather than in isolation. Future studies should explore how different components of the diet may interact, either enhancing or mitigating effects on oral health.

Conclusion

In conclusion, over the 11-year follow-up among Finnish adults, neither the quantity nor the type of starch intake was associated with changes in dental caries.

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