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Relationship of dietary nutrients with early childhood caries and caries activity among children aged 3–5 years—a cross-sectional study

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Abstract

Background Early childhood caries (ECC) is a challenge for pediatric dentists all over the world, and dietary factor is an important factor affecting the occurrence of ECC. Currently, there is limited research on the impact of dietary nutrient intake from Chinese diets on ECC. The purpose of this study is to explore the correlation of dietary nutrients intake with ECC and caries activity (CA) among children aged 3–5 years, and to provide dietary guidance to slow down the occurrence and development of ECC.

Methods A cross-sectional study was conducted in 2022. A total of 155 children were divided into three groups: caries-free group, ECC group and Severe early childhood caries (SECC) group according to the caries statues. And according to the caries activity test (CAT) value, they were also divided into three group: low CA group (L-CA), middle CA group (M-CA) and high CA group (H-CA). The 24-hour dietary intake information was collected by mobile phone application (APP). The intake of children's daily dietary nutrients were calculated referring to "China Food Composition Tables".

Results In this study, 17, 39,and 99 children were diagnosed with caries-free, ECC, and SECC. There were 33, 36, and 86 children diagnosed with L-CA, M-CA, and H-CA. The risk of ECC was increased with the intake of cholesterol(OR = 1.005) and magnesium (OR = 1.026) and decreased with the intake of iron (OR = 0.770). The risk of SECC was increased with the intake of cholesterol (OR = 1.003). The risk of high CA was increased with the intake of cholesterol (OR = 1.002). The combined application of dietary total calories, carbohydrate, cholesterol, sodium, magnesium and selenium in the diagnosis of ECC had an area under ROC curve of 0.741.

Conclusions The increased dietary cholesterol intake may be a common risk factor for ECC and high CA in children aged 3–5. The combined application of dietary intake of total calories, carbohydrate, cholesterol, sodium, magnesium and selenium has a higher predictive value for the occurrence of ECC.

Keywords Early childhood caries, Caries activity, The decayed, missing and filled teeth, Dietary nutrients, Diagnostic model

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Background

Early Childhood Caries (ECC) is one of the most common chronic non-communicable diseases in children. In 1999, the American Academy of Pediatric Dentistry (AAPD) officially named and defined ECC as "any primary tooth caries in children under or equal to 71 months, including one or more decayed (with or without cavity caries), missing (due to caries), or filled tooth surfaces." [1] In 2016, the global disease burden research reported: about 486 million children worldwide suffered from primary tooth caries [2], while in 2022, the World Health Organization (WHO) reported: about 514 million children worldwide suffered from primary tooth caries [3]. The global oral disease burden is obviously rising. A meta-study in 2021 showed that the incidence of ECC in Africa, America, Europe, Oceania and Asia was 30%, 48%, 43%, 82% and 52% respectively, and the incidence of ECC in Asia was significantly higher than the global average [4]. The results of the fourth oral health epidemiological survey in China in 2018 showed that the caries rates of primary teeth of children aged 3, 4 and 5 were 50.8%, 63.6% and 71.9% respectively, while the proportions of teeth treated with fillings were only 1.5%, 2.9% and 4.1% [5]. Compared with ten years ago, the caries rate of primary teeth of five-year-old children in China increased by 5.8%, but the treatment rate only increased by 1.3% [6]. This shows that the task of the prevention and treatment of ECC is arduous in China, and how to accurately predict and prevent ECC at an early stage is the focus of attention of Chinese pediatric dentists.

The occurrence and development of ECC are related to many factors, including enamel hypoplasia, oral colonization with elevated levels of cariogenic bacteria (especially Mutans streptococci [MS]), diet (substrate of bacterial metabolism) and time, among which diet is an important risk factor for ECC [7]. Studies have shown that a healthy diet can provide six nutrients to maintain human reproduction, growth and survival, including carbohydrates, fat, protein, inorganic salts, vitamins and water (dietary fiber is called "the seventh nutrient"), while an unhealthy diet not only causes premature death [8], but also affects children's oral health.Wang X et al. [9] evaluated the dietary quality of 150 children aged 2–5 in Hebei Province and found that ECC was related to excessive dietary intake and dietary imbalance, high cereal intake and low food diversity. Zhang M et al. [10] included 1301 children aged 3–5 in Shandong province for epidemiological investigation and found that exclusive breastfeeding in the first six months after birth and high-frequency-sweet eating before sleep were the high-risk influencing factors of ECC in the 3-year-old group and the 5-year-old group respectively. The previous researches between ECC and diet mostly focus on the influence of different food types, eating frequency and food diversity on children's caries [9, 10], while the research on the correlation between ECC and inorganic salts or vitamins focuses on the correlation between ECC and inorganic salt ions or vitamins in saliva or blood. Shen H et al. [11] found that the serum potassium level in biochemical indexes of blood test of children with high caries risk was higher than that of children without caries. Chen Z et al. [12] detected the serum of 1510 children aged 24–72 months in Hangzhou and found that there was a significant difference in vitamin D levels between ECC children and caries-free children. Compared with children with sufficient vitamin D, the prevalence of ECC in children with vitamin D deficiency increased significantly. At present, there are few studies on the correlation between the intake of nutrients and ECC, and they always focus on individual nutrients, but there is no report on the correlation between total nutrients and ECC.

Caries activity test(CAT) is one of the key indicators in caries risk prediction [13]. Before the formation of dental caries, the microenvironment in the oral cavity has changed, such as the increase in the number of cariogenic bacteria, the decrease in the diversity of microbial communities in dental plaque, the increase in acidic products in dental plaque, the decrease in the PH of dental plaque and saliva, and the decrease in saliva buffering capacity, etc. CAT can find the limit of dental caries from the above changes as a test index to detect the sensitivity of individuals or groups to dental caries. According to the results people can take different preventive measures, thus improving the prevention and treatment efficiency [14, 15].

Cariostat is one of the most commonly used methods to detect caries activity(CA) in clinic. Nishimura M et al. [13] showed that the CAT value of preschool children was positively correlated with the number of decayed teeth (dt). Wang XY [16] also found that there was a positive correlation between the CAT and dmft in children aged 3–5 years, and the sensitivity, specificity, false negative rate, false positive rate and accuracy of Cariostat in the diagnosis of dental caries were 57.8%, 80.7%, 42.2%, 19.3% and 63.9%, respectively. The above results show that there is a correlation between children's CAT and decayed, missing and filled teeth (dmft), so CAT was a reliable index to predict the occurrence and development of ECC. Many studies have shown that children's CA may be related to their daily diet [16–18]. Wang XF et al. [19] found that the CAT value of children aged 2–5 was significantly increased with the dietary deficiency and dietary imbalance and significantly decreased with food diversity, but they didn't find that the scores of different food types had statistical significance on CA. It suggests that whether the influence of dietary factors on CA comes from the insufficient or excessive intake of some dietary nutrients caused by unbalanced diet. However, at present, there is no report on the influence of dietary nutrients intake on CA in preschool children.

The accurate evaluation of food weight is very important to calculate children's dietary nutrients intake. At present, the commonly used dietary survey methods at home and abroad include 24-hour dietary review, chemical analysis and food frequency questionnaire (FFQ), but these traditional methods have some limitations such as more manpower costs, more material costs and recall bias which affect the accuracy of dietary records [20]. Recently, with the pursuit of more reasonable and balanced dietary intake and the development of smart devices, various mobile phone applications (APP) related to food estimation comes into being. In this study, children's meals were photographed and recorded by mobile phone APP, which not only shortened the operating time (e.g., food weighing and recording), but also reduced the recall bias. And then more accurate 24-hour dietary intake of children can be obtained.

At present, the research on dietary nutrition abroad mostly refers to the nutrient composition tables or national food databases of various countries, but there are obvious differences in eating habits between China and the West. Chinese diet structure is dominated by plant foods, such as grains, beans, vegetables and fruits, supplemented by a small amount of animal foods. While the western diet is dominated by animal foods, such as meat, eggs and milk, supplemented by fruits and vegetables. Therefore western dietary nutrition data may not be applicable to China. "China Food Composition Tables"is a data table of Chinese food nutrition composition established by the Institute of Nutrition and Health of China Center for Disease Control and Prevention with reference to several databases at home and abroad. It is a collection of existing animal and plant food data in China. It absorbs the development and progress of nutrition, analytical chemistry and food science in recent years and strives to keep pace with the professional development in food classification and data expression, which makes it more widely used in nutrition research, diet investigation and the research of the relationship between diet and disease in China [21]. Compared with the previous research methods, it can provide more comprehensive and reliable data, which is more in line with Chinese food nutrients content standards. In this study, the dietary nutrients intakes of children aged 3–5 with different caries status were evaluated and analyzed with reference to "China Food Composition Tables", and the influences of dietary nutrients intakes on their caries status and CA were discussed, so as to provide scientific basis for preventing and slowing down the occurrence and development of ECC in Chinese children's dietary nutrition.

Methods

Study population

A cross-sectional study design was carried out in 2022. In this study 155 healthy children aged 3–5 were selected from the Department of Pediatric Stomatology of Hebei Medical University and four kindergartens in Shijiazhuang, Hebei Province by sample sampling method.

The recruitment of participants is based on the inclusion and exclusion criteria preseted in this study. Inclusion criteria: (1) Healthy children living with their parents/legal guardians; (2) Only primary dentition; (3) Children who obtain the informed consent of parents/legal guardians; Exclusion criteria: (1) Children with permanent dentition or mixed dentition; (2) Children or their parents/legal guardians uncooperative; (3) Children with any systemic diseases that may affect the health of teeth and the intake of dietary nutrients; (4) Children who took antibiotics 2 weeks before the study; (5) Children who take other drugs that may affect their oral health or dietary intake for a long time; (6) Children undergoing orthodontic treatment.

Sample size estimation

According to the results of the fourth oral health epidemiological survey in China released in 2018, the caries rate of deciduous teeth of children aged 3–5 years old was 62.5%, the allowable error was 15% of the total rate, and the test level was 5%. Calculated by PASS(Version 15), the sample size was about 120 cases. Taking 10% of the lost-visit rate, and finally 155 children were included.

Ethical considerations

This study was approved by the Medical Ethics Committee of Stomatological Hospital of Hebei Medical University (No. [2018] 028) and conducted with reference to the Declaration of Helsinki issued in 1964 and its revised ethical principles. Before the start of the study, the parents/legal guardians of the children who participated in the study were informed in detail of the purpose of the study, research methods, possible risks or adverse reactions to the children who participated in the study, and then the written informed consent of the parents/legal guardians of the recruited children was obtained. The data in this study were confidential and only used for scientific research. In addition, we would also give some scientific dietary guidance to the participating children and their parents/legal guardians.

Dental examinations

The examiners were trained and calibrated the clinical examination method, evaluation method and recording method before the research to control the examiner bias. The dental examination were completed by two pediatric dentists with rich clinical experience, and the Kappa value between the two examiners was greater than 80%. The WHO dental caries inspection standard was adopted to evaluate the caries status of children. After cleaning the dental surfaces and using cotton rolls to isolate moisture, the decayed (without filled), missing (due to caries), and filled surface (dmfs) and the dmft of children were examined and recorded by using sterile stomatoscope and CPI probe under sufficient illumination. According to the diagnostic criteria of oral health defined by AAPD, the samples were divided into three groups: caries-free group, ECC group and Severe Early Childhood Caries (SECC) group. At present, the international diagnostic standard of SECC is that one or more dmfs on any maxillary anterior teeth, or 3 years old (dmfs ≥ 4), 4 years old (dmfs ≥ 5) and 5 years old (dmfs ≥ 6).

Caries activity tests

The caries activity test was conducted by a strictly trained pediatric dentist from 9: 00 am to 11: 00 am and from 3: 00 pm to 4: 00 pm. Before sampling, children were required to rinse their mouths with clear water and spat or swallowed saliva in their mouths to avoid a large number of food residues or saliva affecting the test results. According to the instructions of the Cariostat kit (GangDa Medical Technology Co. LTD., Beijing, China), examiners wore disposable medical rubber gloves and used special sterile cotton swabs to repeatedly wipe the buccal surfaces of maxillary molars and labial surfaces of mandibular incisors for 3–5 times to collect dental plaque, and then immediately put the cotton swabs into 2.5 ml Cariostat reagent bottle. The reagent bottle was sealed and the label was attached to the bottle where it did not block the liquid in the bottle, so as not to affect the observation of the inspection results. The reagent bottle was cultured in a constant temperature incubator at 37 °C for 48 ± 4 h, and the CAT results were read and recorded in comparison with the standard colorimetric card under natural light. CAT results can be divided into seven grades, including 0, 0.5, 1.0, 1.5, 2.0, 2.5 and 3.0. According to the results, children were divided into three group: 0–1.0 for low CA group (L-CA group), 1.5 for middle CA group (M-CA group) and 2.0–3.0 for high CA group (H-CA group).

Intake of dietary nutrients in 24 h

The 24-hour diets of the examined children were recorded by the WeChat APP (Beijing Sihai Huachen Technology Co., Ltd.) to avoid the recall bias. Before the survey, Parents/legal guardians were instructed and trained by professionals to use the APP. And then 25 parents/legal guardians were randomly selected to test their correct use of the APP to determine whether to further explain the operation method of the software.

The parents/legal guardians were asked to upload photos of all foods (including meals, drinks, snacks and supplements) eaten by children on a certain day of weekend to the APP. The examined children were asked to eat normally (excluding special circumstances such as eating out or parties). Each food in the photos is photographed separately and a one-yuan coin is used as a reference. Before uploading the records, parents/legal guardians could make some necessary supplements or explanations for the information that was difficult to confirm only by photos. The next day, the researchers re-verified the food intake calculated by APP according to the uploaded records, and further confirmed the relevant information. If mistakes or omissions were found, parents should be asked to upload photos again to obtain reliable information on children's dietary intake. After confirmation, the researchers would further sort out all the information and calculate the types and intake of children's daily common dietary nutrients referring to the "China Food Composition Tables".

Statistical analysis

Statistical analysis was carried out by SPSS 26, and the test level was $P = 0.05$. There is no missing data. In descriptive statistics, the counting data was expressed by percentage (%), and the measuring data was expressed by median and quartile interval because of skew distribution.

The univariate analysis was conducted to evaluate demographic data (Mann-Whitney U test, Kruskal-Wallis H test, Chi-Squared test).

The Kruskal-Wallis H test was used to evaluate the difference of nutrient intake among caries-free group, ECC group and SECC group and the variables with $P < 0.1$ were included in the multinomial logistic regression analysis. The Kruskal-Wallis H test was also used to evaluate the difference of nutrient intake among L-CA, M-CA and H-CA and the variables with $P < 0.1$ were included in the ordinal logistic regression analysis. The OR and 95% confidence interval were calculated.

The Spearman correlation analysis was conducted to evaluate the associations between CAT value and dmft, the nutrient intake and CAT value, and the nutrient and dmft.

The receiver operating characteristic curve (ROC) was used to evaluate the diagnostic value of related nutrient intake levels for ECC, and the area under curve(AUC), sensitivity, specificity and Youden index were calculated.

Results

General information

A total of 170 children aged 3–5 participated in the study, 15 of whom failed to upload photos as required. And finally 155 children were included.(shown in Fig. 1) The

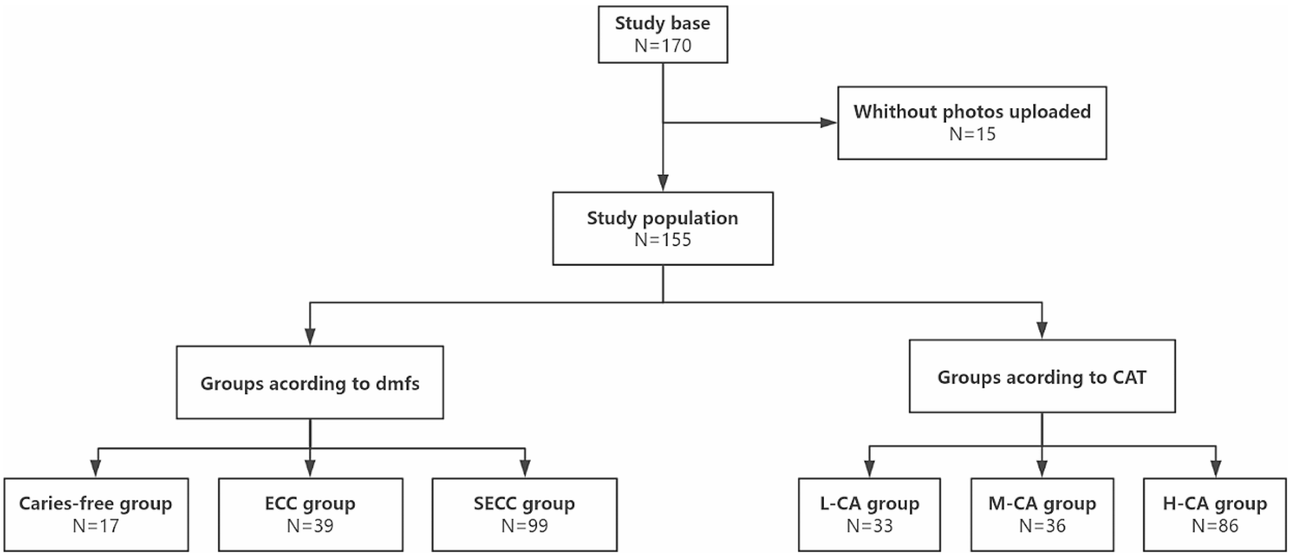

Fig. 1 Flow diagram for study subject inclusion

Table 1 Caries status of different ages and sexes

Variables	number(%)	Caries prevalence(%)	*P*-value	dmft median(IQR)	*P*-value	Caries group			*P*-value
						caries-free[*n*(%)]	ECC[*n*(%)]	SECC[*n*(%)]	
Gender			0.649		0.380				0.893
Male	74(47.7)	87.8		8(2.75,12.25)		9(52.9)	18(46.2)	47(47.5)	
Female	81(52.3)	90.1		6(4,10.5)		8(47.1)	21(53.8)	52(52.5)	
Age			0.002*		0.001*				0.006*
3(years)	41(26.5)	73.2[a]		5(0,8)[a]		11(64.7)	8(20.5)	22(22.2)	
4(years)	72(46.5)	94.4[b]		7(4,11)[b]		4(23.5)	20(51.3)	48(48.5)	
5(years)	42(27.1)	95.2[b]		9.5(4,13.25)[b]		2(11.8)	11(28.2)	29(29.3)	
total	155	89		7(3, 12)		17(11.0)	39(25.2)	99(63.9)	

[a, b]Different letters indicate statistical differences. *Significantly different at $P<0.05$

Table 2 CA of different ages and sexes

Variables	Caries group			*P*-value
	L-CA[*n*(%)]	M-CA[*n*(%)]	H-CA[*n*(%)]	
Gender				0.406
Male	13(39.4)	20(55.6)	41(47.7)	
Female	20(60.6)	16(44.4)	45(52.3)	
Age				0.482
3(years)	10(30.3)	10(27.8)	21(24.4)	
4(years)	15(45.5)	19(52.8)	38(44.2)	
5(years)	8(24.2)	7(19.4)	27(31.4)	
total	33(21.3)	36(23.2)	86(55.5)	

*Significantly different at $P<0.05$

total caries prevalence rate was 89%, that of males was 87.8%, and that of females was 90.1%. There was no statistical difference between males and females ($P=0.649$). The caries prevalence rate of 3-year-old children was significantly lower than that of 4-year-old children and that of 5-year-old children ($P=0.002$). In this study, 17 children (11.0%) in caries-free group, 39 children (25.2%) in ECC group and 99 children (63.9%) in SECC group were included. There was no significant difference in gender distribution among the three groups ($P=0.893$), but there was a significant difference in age distribution($P=0.006$). According to their CAT values, the population in this study was divided into three groups: 86 children for H-CA group, 36 children for M-CA group and 33 children for L-CA group. There was no significant difference in age distribution and gender distribution among the three groups ($P=0.482$ and $P=0.406$). (shown in Tables 1 and 2)

Univariate analysis of caries and intake of different nutrients in children aged 3–5 years

The intakes of total calories (P=0.020), carbohydrate (P=0.023), cholesterol (P=0.010), sodium (P=0.040), magnesium (P=0.041), iron (P=0.027) and selenium (P=0.025) were significantly different among caries-free group, ECC group and SECC group. The intakes of total calories, carbohydrate, sodium and selenium in SECC group were significantly higher than that in caries-free group. The intake of Cholesterol in caries-free group was significantly lower than that in ECC group and SECC group. The intake of iron in SECC group was significantly higher than that in ECC group (shown in Table 3).

Multivariate analysis of caries and intake of different nutrients in children aged 3–5 years

The model passed the test (P=0.010). The intake of Cholesterol (OR=1.005, 95%CI=1.002–1.009, P=0.002) and magnesium (OR=1.026, 95%CI=1.002–1.051, P=0.033) were the independent risk factors of ECC. The intake of iron was an independent protective factor of ECC (OR=0.770, 95%CI=0.626–0.946, P=0.013). The increase of cholesterol intake was an independent risk factor for SECC (OR=1.003, 95%CI=1.000-1.006, P=0.030). (shown in Table 4)

The establishment of diagnostic model of ECC for children aged 3–5 years based on dietary nutrient intakes

The predictive evaluation value of indicators with statistical differences in the results of univariate analysis for ECC is as follows: (1) The diagnostic analysis model of ROC curve established by the single application of each index showed that the intake of total calories, carbohydrate, cholesterol, sodium, magnesium and selenium had certain evaluation value. The AUC of total calories, carbohydrate, cholesterol, sodium, magnesium and selenium were 0.684, 0.668, 0.713, 0.681, 0.659, and 0.695, respectively, but the intake of iron had no evaluation value (P=0.284). (2) Comprehensive regression was performed on the above-mentioned single application indexes with evaluation value. The prediction and evaluation efficiency of ECC by the combined application of each indicators was higher than that of each individual indicator and the AUC was 0.741. (shown in Table 5; Fig. 2)

Univariate analysis of CA and intake of different nutrients in children aged 3–5 years

The intake of cholesterol (P=0.036), phosphorus (P=0.035) and selenium (P=0.039) were significantly different. The intake of cholesterol, phosphorus and selenium in L-CA group was significantly lower than that in H-CA group (shown in Table 6).

Multivariate analysis of CA and intake of different nutrients in children aged 3–5 years.

The model passed the test (P=0.021). Only the intake of cholesterol was associated with CA (P=0.022). The CAT value increased with the intake of cholesterol (OR=1.002, 95% CI: 1.000-1.003). (shown in Table 7)

Analysis of related factors of CAT value and dmft in children aged 3–5 years.

There was a positive correlation between the CAT value and the dmft of children aged 3–5 (r=0.570, P<0.01). The CAT value was positively correlated with the intake of total calories (r=0.200, P=0.013), cholesterol (r=0.186, P=0.021), fat (r=0.185, P=0.021), phosphorus (r=0.184, P=0.022) , sodium (r=0.210, P=0.009), iron (r=0.162, P=0.045) and selenium (r=0.202, P=0.012). The dmft was positively correlated with the intake of total calories (r=0.244, P=0.002), protein (r=0.203, P=0.011), carbohydrate (r=0.218, P=0.006), calcium (r=0.162, P=0.043), phosphorus (r=0.249, P=0.002), potassium (r=0.230, P=0.004) , sodium (r=0.186, P=0.02). magnesium (r=0.221, P=0.006), iron (r=0.176, P=0.029), selenium (r=0.187, P=0.02), copper (r=0.160, P=0.047) and manganese (r=0.180, P=0.025). Total calories, phosphorus, sodium, iron and selenium are the common related factors of CA and dmft (shown in Table 8).

Discussion

To date, this study is the first time to explore the relationship of different dietary nutrients intake with ECC and CA of children aged 3–5 in Hebei Province and evaluate the common dietary nutrients affecting the dmft and CAT value in preschool children. The results showed that the occurrence and development of ECC in preschool children might be related to the intake of total calories, carbohydrate, cholesterol, sodium, magnesium, iron and selenium. The CA of preschool children might be related to the intake of cholesterol, phosphorus and selenium. It was found that cholesterol was a common risk factor for ECC and CA, and total calories, phosphorus, sodium, iron and selenium were the common risk factors for CAT value and dmft in this study. It suggests that we can improve children's oral health by controlling the intake of cholesterol, total calories, phosphorus, sodium, iron and selenium in the future. Also it provide new methods for preventing and slowing down the occurrence and development of ECC.

ECC is a disease that is affected by many factors, especially daily diet. Hebei Province is located in North China, with complex and diverse landforms, such as plateaus, mountains, hills, basins and plains. And it is rich in animal resources and plant resources. In this way compared with other regions, Hebei Province has more diverse ingredients and it is a typical representative of China's northern diet [22]. Through the univariate analysis, it was found that there were significant differences in dietary carbohydrate intake among caries-free group,

Table 3 Univariate analysis of caries and intake of different nutritional elements in children aged 3-5 years

Variable	Group	*N*	Mean Rank	Kruskal-Wallis H	*P*
Total calories kJ	Caries-free	17	52.65[a]	7.838	0.020*
	ECC	39	73.08[a, b]		
	SECC	99	84.29[b]		
Protein g	Caries-free	17	55.06	5.274	0.072
	ECC	39	77.56		
	SECC	99	82.11		
Fat g	Caries-free	17	57.35	4.267	0.118
	ECC	39	77.64		
	SECC	99	81.69		
Carbohydrate g	Caries-free	17	54.76[a]	7.513	0.023*
	ECC	39	71.44[a, b]		
	SECC	99	84.58[b]		
Dietary fiber g	Caries-free	17	61.65	2.534	0.282
	ECC	39	79.95		
	SECC	99	80.04		
Cholesterol mg	Caries-free	17	48.56[a]	9.194	0.010*
	ECC	39	87.65[b]		
	SECC	99	79.25[b]		
Vitamin A ugRAE	Caries-free	17	73.82	0.793	0.673
	ECC	39	73.69		
	SECC	99	80.41		
Thiamin mg	Caries-free	17	74.65	0.620	0.734
	ECC	39	74.05		
	SECC	99	80.13		
Riboflavin mg	Caries-free	17	79.35	1.484	0.476
	ECC	39	70.46		
	SECC	99	80.74		
Niacin mg	Caries-free	17	73.00	0.283	0.868
	ECC	39	77.31		
	SECC	99	79.13		
Vitamin C mg	Caries-free	17	88.59	1.329	0.515
	ECC	39	73.55		
	SECC	99	77.93		
Vitamin E mg	Caries-free	17	77.29	0.146	0.929
	ECC	39	75.79		
	SECC	99	78.99		
Calcium mg	Caries-free	17	73.94	2.959	0.228
	ECC	39	68.31		
	SECC	99	82.52		
Phosphorus mg	Caries-free	17	59.71	5.785	0.055
	ECC	39	70.41		
	SECC	99	84.13		
Potassium mg	Caries-free	17	63.41	5.282	0.071
	ECC	39	68.79		
	SECC	99	84.13		
Sodium mg	Caries-free	17	53.00[a]	6.430	0.040*
	ECC	39	76.74[a, b]		
	SECC	99	82.79[b]		
Magnesium mg	Caries-free	17	56.12[a]	6.401	0.041*
	ECC	39	72.38[a]		
	SECC	99	83.97[a]		

Table 3 (continued)

Variable	Group	N	Mean Rank	Kruskal-Wallis H	P
Iron mg	Caries-free	17	67.00[a, b]	7.255	0.027*
	ECC	39	64.31[a]		
	SECC	99	85.28[b]		
Zinc mg	Caries-free	17	72.29	2.364	0.307
	ECC	39	69.97		
	SECC	99	82.14		
Selenium ug	Caries-free	17	51.12[a]	7.411	0.025*
	ECC	39	76.74[a, b]		
	SECC	99	83.11[b]		
Copper mg	Caries-free	17	55.12	5.462	0.065
	ECC	39	76.51		
	SECC	99	82.52		
Manganese mg	Caries-free	17	53.35	5.857	0.053
	ECC	39	79.10		
	SECC	99	81.80		

[a, b]Different letters indicate statistical differences. *Significantly different at $P < 0.05$

Table 4 Multivariate analysis of caries and intake of different nutrients in children aged 3–5 years

Group	Variable	B	S.E.	Wald	P	Exp(B)	95%CI for Exp(B)	
							Lower Bound	Upper Bound
ECC	Total calories kJ	0.000	0.001	0.012	0.913	1.000	0.999	1.001
	Protein g	0.013	0.041	0.104	0.747	1.013	0.935	1.098
	Carbohydrate g	0.006	0.013	0.228	0.633	1.006	0.980	1.033
	Cholesterol mg	0.005	0.002	9.306	0.002*	1.005	1.002	1.009
	Phosphorus mg	-0.004	0.003	1.983	0.159	0.996	0.992	1.001
	Sodium mg	0.001	0.001	0.871	0.351	1.001	0.999	1.002
	Magnesium mg	0.026	0.012	4.551	0.033*	1.026	1.002	1.051
	Iron mg	-0.262	0.105	6.183	0.013*	0.770	0.626	0.946
	Selenium ug	-0.011	0.046	0.056	0.814	0.989	0.903	1.083
	Copper mg	-0.474	1.217	0.152	0.697	0.623	0.057	6.767
	Manganese mg	0.251	0.573	0.191	0.662	1.285	0.418	3.950
	Potassium mg	-0.002	0.001	2.296	0.130	0.998	0.996	1.001
SECC	Total calories kJ	0.000	0.001	0.228	0.633	1.000	0.999	1.001
	Protein g	-0.007	0.036	0.044	0.835	0.993	0.925	1.065
	Carbohydrate g	0.010	0.012	0.721	0.396	1.010	0.987	1.035
	Cholesterol mg	0.003	0.002	4.696	0.030*	1.003	1.000	1.006
	Phosphorus mg	-0.003	0.002	2.269	0.132	0.997	0.992	1.001
	Sodium mg	0.000	0.001	0.035	0.852	1.000	0.999	1.002
	Magnesium mg	0.009	0.011	0.767	0.381	1.009	0.989	1.030
	Iron mg	0.006	0.053	0.011	0.918	1.006	0.906	1.117
	Selenium ug	0.011	0.038	0.090	0.764	1.011	0.939	1.090
	Copper mg	-1.251	1.074	1.358	0.244	0.286	0.035	2.348
	Manganese mg	0.269	0.496	0.295	0.587	1.309	0.495	3.461
	Potassium mg	0.000	0.001	0.002	0.962	1.000	0.998	1.002

*Significantly different at $P<0.05$. B: Regression coefficient; S.E.: Standard error; Wald: Chi-square value; Exp(B): Odds ratio (OR). CI: Confidence interval

ECC group and SECC group, but through multinomial logistic regression analysis the intake of carbohydrate was not the independent risk factor of ECC and SECC in this study. This result was similar to that of Laine MA et al. [23] and Cantoral A et al. [24]. They also found no correlation between carbohydrate intake and children's caries status. However, Allam GG et al. [25] conducted diet records and oral examination on 120 Egyptian children, and found that their caries status was positively correlated with carbohydrate intake between meals. The different results of our study may be due to the fact that our study only pays attention to the correlation between total carbohydrate intake and caries status, but it does not focus on the types of carbohydrate and eating frequency,

Table 5 Predictive value of nutrients intake on ECC

Index	AUC	*P*	95%CI		Sensitivity	Specificity	Youden Index
			Low	High			
Total calories kJ	0.684	0.014	0.512	0.855	86.2%	64.7%	50.9%
Carbohydrate g	0.668	0.024	0.495	0.841	79.7%	64.7%	44.4%
Cholesterol mg	0.713	0.004	0.590	0.837	78.3%	70.6%	48.9%
Sodium mg	0.681	0.015	0.538	0.824	79.7%	58.8%	38.5%
Magnesium mg	0.659	0.033	0.484	0.833	87.7%	52.9%	40.6%
Selenium ug	0.695	0.009	0.549	0.841	85.5%	52.9%	38.4%
combined application	0.741	0.001	0.595	0.886	93.5%	58.8%	52.3%

AUC: Area under curve. CI: Confidence interval

which also affect children's caries status. Some studies have found that monosaccharides and disaccharides with smaller molecular weights such as sucrose, lactose, fructose and glucose have higher cariogenic property, while macromolecular polysaccharides have lower cariogenic property, and refined sugar has higher cariogenic property than coarse sugar [26, 27]. Nakai Y et al. [28] included 118 Japanese children aged 1–4 and examined their teeth. It was found that the frequent intake of sugar between meals was related to a higher incidence of ECC. With the increase of the frequency of sugar intake between meals, the proportion of ECC children increased. The frequent intake of carbohydrates keeps teeth in acidic environment for a long time, which leads to the demineralization and caries.

This study found that the intake of cholesterol in caries-free group was lower than that in ECC group and SECC group, and the difference was statistically significant. This study also concluded that excessive cholesterol intake is an independent risk factor for CA. This result was similar to that of Subramaniam P et al. [29] and Sharma A et al. [30]. They found that the saliva cholesterol level of children was positively correlated with their caries status, and the saliva cholesterol level of ECC children was slightly higher than that of caries-free children. The reason may be that the high cholesterol level can reduce the saliva flow rate [30], thus affecting the buffering capacity of saliva and the clearance rate of food, and finally leading to the occurrence and development of dental caries.

The results of this study showed that dietary magnesium intake was an independent risk factor of ECC, and the magnesium intake of children in ECC group is higher than that of children without caries. And it was similar to the research results of Babu NV et al. [31], who found that the DMFT/dmft scores and the content of magnesium ions in saliva of autistic children were higher than those of normal children. Interestingly, most studies believed that magnesium ions could inhibit dental caries, which could inhibit the growth of cariogenic bacteria and hinder the development of dental caries [32, 33]. The different conclusions of this study may be due to the excessive intake of magnesium in ECC group, which leads to the imbalance of calcium ions and magnesium ions in the local oral microenvironment. In this way, it further produces competitive inhibition and promotes the dissolution of hydroxyapatite and the release of calcium ions [34].

It was found that the iron intake of ECC group was lower than that of caries-free group, and iron was an independent protective factor of ECC in this study. As an essential trace element of human, iron plays an important role in various life activities. Previous studies have found that iron ions can inhibit the growth of Streptococcus mutans [35], and at the same time, iron ions can also inhibit the dissolution of enamel [36, 37]. Mohamed WE et al. [38] detected the serum of 80 children aged 24–71 months in Egypt and found that there was a positive correlation between the occurrence of iron deficiency anemia and the occurrence of ECC. Jha A et al. [39] also found that the ferritin level of ECC children decreased by nearly 2 times compared with caries-free children through serum testing of 266 children in 2021. The incidence of iron deficiency anemia in ECC children is 6 times higher than that in caries-free children. However, this study also found that the iron intake of children with SECC was higher than that of children with ECC, and there was no statistical difference between SECC children and caries-free children, which was contrary to the conclusions of Zhu S et al. [40] and Atri Y et al. [41]. This may be due to the excessive defects or loss of teeth leading to the decline of children's chewing ability, which affects the digestion and absorption of iron.

Consistent with the previous results [17], this study also found this the CAT value was positively correlated with the dmft. This may be due to the stronger acid-producing ability of oral cariogenic bacteria in high CA children, which in turn leads to more serious caries. The result further proves that Cariostat method can be used to evaluate the risk of caries in preschool children, thus providing a method for realizing the "early detection, early diagnosis and early treatment" of ECC.

This research revealed that CAT value was positively correlated with the intake of total calories, cholesterol, fat, phosphorus, sodium, iron and selenium. The dmft

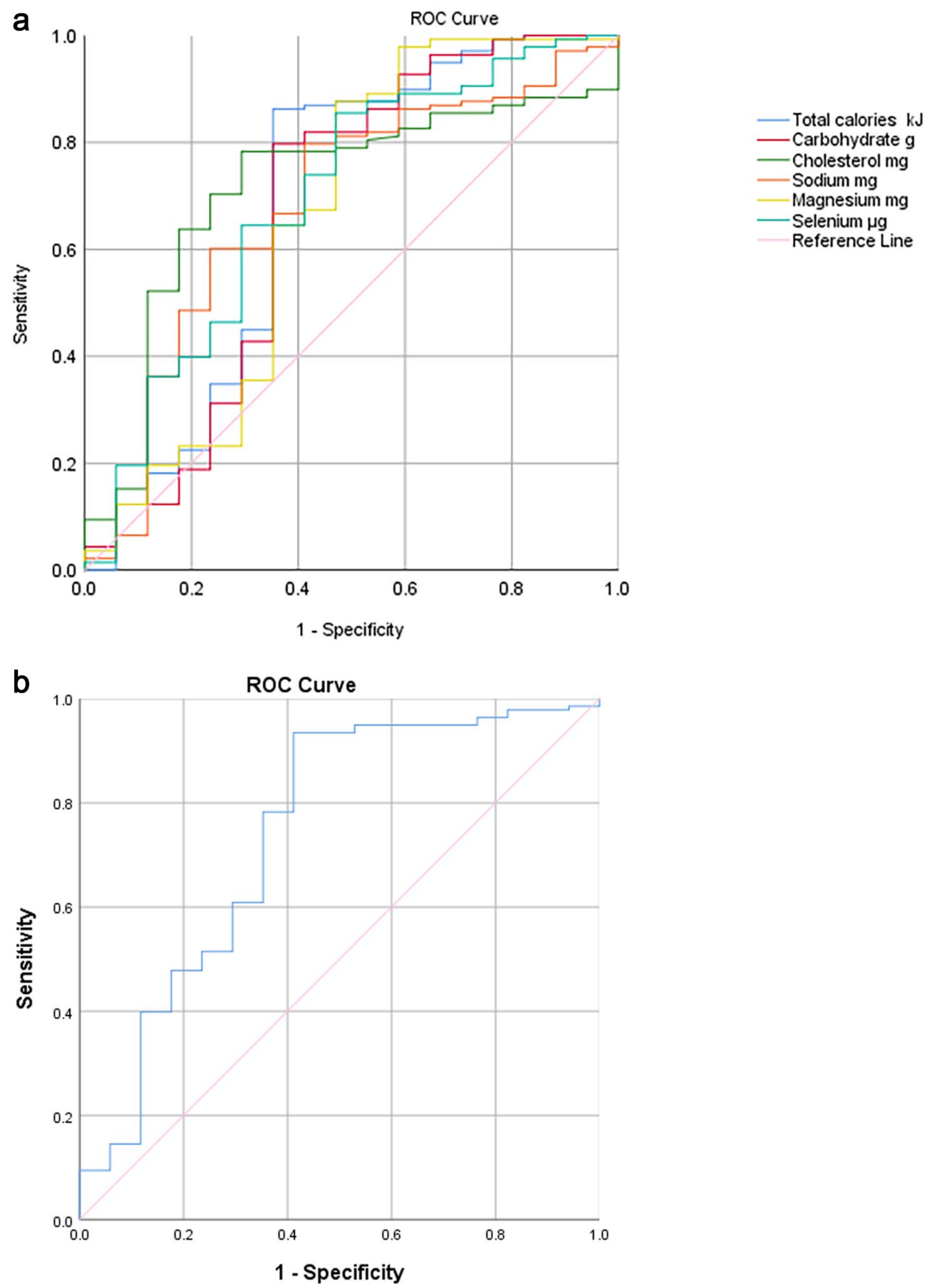

Fig. 2 **a** ROC curve of single index (Total calories, Carbohydrate, Cholesterol, Sodium, Magnesium, Selenium). **b** ROC curve of combined application of each single index

was positively correlated with the intake of total calories, protein, carbohydrate, calcium, phosphorus, potassium, sodium, magnesium, iron, selenium, copper and manganese. Total calories, phosphorus, sodium, iron and selenium were the common related factors of CA and dmft, which suggested that they might be more reliable and worthy indicators for predicting the caries status of preschool children.

Dietary calorie mainly comes from carbohydrates, fat and protein in food. Adequate calorie intake can provide necessary support for human life. While insufficient or excessive calorie intake will lead to underweight, emaciation and obesity, which will further affect children's oral health [42–45]. This study found that the value of dmft and CAT in children increased with the total calories intake. This may be because with the improvement of living conditions, children consume more and more

Table 6 Univariate analysis of CA and intake of different nutrient elements in children aged 3–5 years

Variable	Group	*N*	Mean Rank	Kruskal-Wallis H	*P*
Total calories kJ	L-CA	33	66.21	4.400	0.111
	M-CA	36	73.47		
	H-CA	86	84.42		
Protein g	L-CA	33	67.67	3.089	0.213
	M-CA	36	74.94		
	H-CA	86	83.24		
Fat g	L-CA	33	67.79	4.267	0.118
	M-CA	36	71.67		
	H-CA	86	84.57		
Carbohydrate g	L-CA	33	72.27	1.336	0.513
	M-CA	36	74.47		
	H-CA	86	81.67		
Dietary fiber g	L-CA	33	71.00	1.028	0.598
	M-CA	36	79.31		
	H-CA	86	80.14		
Cholesterol mg	L-CA	33	62.48[a]	6.654	0.036*
	M-CA	36	74.14[a, b]		
	H-CA	86	85.57[b]		
Vitamin A ugRAE	L-CA	33	65.30	3.398	0.183
	M-CA	36	80.88		
	H-CA	86	80.41		
Thiamin mg	L-CA	33	75.64	0.145	0.930
	M-CA	36	77.58		
	H-CA	86	79.08		
Riboflavin mg	L-CA	33	75.36	1.097	0.578
	M-CA	36	72.58		
	H-CA	86	81.28		
Niacin mg	L-CA	33	77.33	0.133	0.936
	M-CA	36	80.39		
	H-CA	86	77.26		
Vitamin C mg	L-CA	33	75.44	0.771	0.680
	M-CA	36	83.69		
	H-CA	86	76.60		
Vitamin E mg	L-CA	33	71.15	1.023	0.599
	M-CA	36	81.22		
	H-CA	86	79.28		
Calcium mg	L-CA	33	74.15	1.018	0.601
	M-CA	36	73.75		
	H-CA	86	81.26		
Phosphorus mg	L-CA	33	63.94[a]	6.732	0.035*
	M-CA	36	71.64[a, b]		
	H-CA	86	86.06[b]		
Potassium mg	L-CA	33	64.55	4.352	0.113
	M-CA	36	76.83		
	H-CA	86	83.65		
Sodium mg	L-CA	33	64.67	4.092	0.129
	M-CA	36	77.67		
	H-CA	86	83.26		
Magnesium mg	L-CA	33	65.39	4.056	0.132
	M-CA	36	75.97		
	H-CA	86	83.69		

Table 6 (continued)

Variable	Group	N	Mean Rank	Kruskal-Wallis H	P
Iron mg	L-CA	33	66.45	4.658	0.097
	M-CA	36	72.50		
	H-CA	86	84.73		
Zinc mg	L-CA	33	68.12	3.888	0.143
	M-CA	36	72.11		
	H-CA	86	84.26		
Selenium ug	L-CA	33	61.09[a]	6.473	0.039*
	M-CA	36	78.03[a, b]		
	H-CA	86	84.48[b]		
Copper mg	L-CA	33	72.91	0.749	0.688
	M-CA	36	76.50		
	H-CA	86	80.58		
Manganese mg	L-CA	33	70.33	1.987	0.370
	M-CA	36	74.58		
	H-CA	86	82.37		

[a, b]Different letters indicate statistical differences. *Significantly different at $P<0.05$

Table 7 Multivariate analysis of CA and intake of different nutrients in children aged 3–5 years

Variable	B	S.E.	Wald	P	Exp(B)	95%CI for Exp(B)	
						Low	High
Cholesterol mg	0.002	0.0007	5.270	0.022*	1.002	1.000	1.003
Phosphorus mg	0.001	0.0008	1.603	0.205	1.001	0.999	1.003
Iron mg	0.064	0.0437	2.133	0.144	1.066	0.978	1.161
Selenium ug	-0.032	0.0194	2.789	0.095	0.968	0.932	1.006

*Significantly different at $P<0.05$. B: Regression coefficient; S.E.: Standard error; Wald: Chi-square value; Exp(B): Odds ratio (OR); CI: Confidence interval

processed foods rich in sugar and fat. More and more frequent intake of sugar and fat provides a large amount of acid for cariogenic bacteria, causing enamel demineralization, which in turn leads to dental caries.

Phosphorus is one of the main components of teeth, which plays an important role in the development of teeth. It is found that the decrease of blood phosphorus content will affect the mineralization of teeth, thus reducing the anti-caries ability of teeth. And phosphate ions in saliva and dental plaque also play an important role in anti-caries [46]. Madali B et al. [47] found that DMFT/DMFS was negatively correlated with dietary phosphorus intake through dietary analysis of 70 children aged 2–9. On the contrary, this study found that dietary phosphorus intake was positively correlated with CAT value and dmft. This may be due to the fact that children's dental caries is not only affected by phosphorus intake, but also by calcium intake. Some experiments have proved that the optimum intake ratio of calcium and phosphorus in diet is 0.55, Whenever the intake ratio of calcium and phosphorus is higher or lower than 0.55, the incidence of dental caries increases [48]. In this study, children's intake ratio of calcium and phosphorus was poor, which might have an impact on the results.

In this study, the intake of sodium was positively correlated with CAT value and dmft, which was consistent with the results of Priyadarshini P et al. [49]. This may be owing to the excessive intake of sodium from the processed food, which leads to the competition between excessive sodium ions and calcium ions in the process of reabsorption. As a result, the loss of calcium ion increases [50, 51], which further affects the occurrence of dental caries.

Selenium is one of the 15 essential trace elements for human. Excessive or insufficient intake will affect health. In the past, many epidemiological studies and animal experiments have found that selenium had a certain cariogenic effect [52–55]. The result also showed that dietary selenium intake of children aged 3–5 was positively correlated with dmft and CAT value in our study. This may be because excessive selenium will affect the mineralization of enamel, making enamel more sensitive to acidic environment [56]. However, Krasniqi S et al. [57]. and Si B et al. [58]. found that a certain concentration of selenium could not only inhibit the growth and reproduction of Streptococcus mutans, but also affect the expression of genes responsible for biofilm formation of Streptococcus mutans. Tran P et al. [59] and Alshahrani SS et al. [60] also found that adding selenium to sealing agent could reduce the biofilm formation of cariogenic bacteria such as Streptococcus salivarius and Streptococcus sanguis. The difference of selenium concentration may be the

Table 8 Analysis of related factors of CAT value and dmft in children aged 3–5 years

		CAT	dmft
CAT	*r*	1	0.570
	P	.	<0.01**
dmft	*r*	0.570	1
	P	<0.01**	.
Total calories kJ	*r*	0.200	0.244
	P	0.013*	0.002**
Cholesterol mg	*r*	0.186	0.071
	P	0.021*	0.378
Protein g	*r*	0.139	0.203
	P	0.085	0.011*
Fat g	*r*	0.185	0.151
	P	0.021*	0.06
Carbohydrate g	*r*	0.15	0.218
	P	0.063	0.006**
Dietary fiber g	*r*	0.073	0.023
	P	0.366	0.777
Vitamin A ugRAE	*r*	0.046	0.033
	P	0.573	0.687
Thiamin mg	*r*	0.04	0.111
	P	0.623	0.169
Riboflavin mg	*r*	0.034	0.105
	P	0.673	0.192
Niacin mg	*r*	-0.006	0.083
	P	0.937	0.306
Vitamin C mg	*r*	-0.059	-0.047
	P	0.462	0.562
Vitamin E mg	*r*	0.019	0.007
	P	0.815	0.932
Calcium mg	*r*	0.059	0.162
	P	0.465	0.043*
phosphorus mg	*r*	0.184	0.249
	P	0.022*	0.002**
Potassium mg	*r*	0.128	0.230
	P	0.111	0.004**
Sodium mg	*r*	0.210	0.186
	P	0.009**	0.02*
Magnesium mg	*r*	0.151	0.221
	P	0.061	0.006**
Iron mg	*r*	0.162	0.176
	P	0.045*	0.029*
Zinc mg	*r*	0.131	0.147
	P	0.104	0.068
Selenium ug	*r*	0.202	0.187
	P	0.012*	0.02*
Copper mg	*r*	0.074	0.160
	P	0.363	0.047*
Manganese mg	*r*	0.155	0.180
	P	0.055	0.025*

*Significantly different at $P<0.05$.**Significantly different at $P<0.01$

reason for the difference of these research conclusions [55]. At present, the research on the effect of selenium intake on ECC and CA in the world is rare and the appropriate dose of selenium to prevent ECC have not been discovered, which needs further study.

Through the analysis of ROC curve, it was found that the intake of total calories, carbohydrate, cholesterol, sodium, magnesium and selenium in diet had certain predictive value for the occurrence of ECC in children aged 3–5, and the combined application of multiple factors was more effective in the diagnosis of ECC. Which has a certain application value in slowing down the occurrence and development of ECC in children by modifying their dietary intake.

The purpose of this study is to provide dietary guidance to prevent ECC and reduce the risk of ECC by analyzing the correlation of different dietary nutrients intake with caries status and CA of preschool children and establishing a comprehensive diagnosis model based on dietary nutrition. Although this study has achieved the above meaningful results, this study still has some limitations. First of all, as a cross-sectional study, this study can not establish the causal relationship of nutrient intake with ECC and CA, and more experimental researches are needed to prove our observed conclusions in the future. Secondly, this study only focuses on the types of food intake, however it does not pay attention to the cooking methods. Different cooking methods may have an impact on the specific utilization rate of food, and then affect the conclusion. Finally, the sample included in this study is limited, and it is expected to carry out larger-scale researches involving more regions in the future.

Conclusion

1. The occurrence and development of ECC in children aged 3–5 years may be related to the intake of total calories, carbohydrates, cholesterol, sodium, magnesium, iron and selenium in diet, among which cholesterol is an independent risk factor for ECC.
2. The CA of children aged 3–5 years may be affected by the intake of cholesterol, phosphorus and selenium in diet, among which cholesterol is an independent risk factor for high CA.
3. The high intake of total calories, phosphorus, sodium, iron and selenium in diet may be the common risk factors affecting CAT value and dmft.
4. The combined application of dietary intake of total calories, carbohydrate, cholesterol, sodium, magnesium and selenium has higher predictive value for the occurrence of ECC.

The above findings can provide dietary guidance for the prevention of ECC, and provide scientific basis and methods for establishing a model based on dietary nutrition to predict and slow down the occurrence and development of ECC.

Abbreviations

ECC	Early Childhood Caries
CA	Caries activity
dmfs	Decayed, missing and filled surface
dmft	Decayed, missing and filled teeth
SECC	Severe Early Childhood Caries
ROC	Receiver operating characteristic curve
AAPD	American academy of pediatric dentistry
CAT	Caries activity test
FFQ	Food frequency questionnaire
APP	Application
WHO	World Health Organization
AUC	Area under curve
DMFT	Decayed, Missing and Filled Teeth
DMFS	Decayed, Missing and Filled Surface
dt	Decayed teeth
MS	Mutans streptococci

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Author contributions
H.S. conceived and designed the study, Z.M., X.W., M.L., Y.Z., and S.M. conducted research. S.M., X.W., and X.L. analyzed and reconciled the data. S.M. and Z.M. wrote the paper. H.S. had primary responsibility for final content.

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Data availability
Data is provided within the manuscript or supplementary information files.

Declarations

Ethics approval and consent to participate
This study was approved by the Medical Ethics Committee of Stomatological Hospital of Hebei Medical University (No. [2018] 028). Also, the written informed consent was obtained from the parents/legal guardians of the recruited children to start the research.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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