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Dietary and serum vitamin D and preeclampsia risk in Chinese pregnant women: a matched case–control study

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Abstract

The effect of vitamin D (VD) on the risk of preeclampsia (PE) is uncertain. Few of previous studies focused on the relationship between dietary VD intake and PE risk. Therefore, we conducted this 1:1 matched case–control study to explore the association of dietary VD intake and serum VD concentrations with PE risk in Chinese pregnant women. A total of 440 pairs of participants were recruited during March 2016 to June 2019. Dietary information was obtained using a seventy-eight-item semi-quantitative FFQ. Serum concentrations of $25(OH)D_2$ and $25(OH)D_3$ were measured by liquid chromatography–tandem MS. Multivariate conditional logistic regression was used to estimate OR and 95 % CI. Restricted cubic splines (RCS) were plotted to evaluate the dose–response relationship of dietary VD intake and serum VD concentrations with PE risk. Compared with the lowest quartile, the OR of the highest quartile were 0·45 (95 % CI 0·29, 0·71, $P_{trend} = 0·001$) for VD dietary intake and 0·26 (95 % CI 0·11, 0·60, $P_{trend} = 0·003$) for serum levels after adjusting for confounders. In addition, the RCS analysis suggested a reverse J-shaped relationship between dietary VD intake and PE risk (*P*-nonlinearity = 0·02). A similar association was also found between serum concentrations of total 25(OH)D and PE risk (*P*-nonlinearity = 0·02). In conclusion, this study provides evidence that higher dietary intake and serum levels of VD are associated with the lower risk of PE in Chinese pregnant women.

Key words: **Preeclampsia: Vitamin D: Chinese: Pregnant women: Case – control study**

Preeclampsia (PE) is a pregnancy-specific disease characterised by hypertension with proteinuria after 20 weeks of gestation[1]. It is a systemic inflammatory condition that can lead to a series of serious maternal complications, including acute renal failure, diffuse intravascular coagulation syndrome, pulmonary oedema and respiratory distress syndrome[2]. It is one of the main causes of maternal, fetal and neonatal mortality[3] and affects 2·7–8·2 % of pregnant women worldwide[4]. PE is also associated with fetal growth restriction and preterm delivery[5]. Currently, there is no cure for

Abbreviations: PE, preeclampsia; VD, vitamin D; FFQ, food frequency questionnaire; GDM, gestational diabetes mellitus; BMI, body mass index; RCS, restricted cubic splines; RCT, randomised clinical trial; VEGF, vascular endothelial growth factor.

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PE other than delivery[6], but mothers suffering from PE and their offspring continue to have long-term adverse effects after placental delivery[7]. Therefore, PE prevention is of great public health significance.

Vitamin D (VD) is a fat-soluble vitamin that functions in regulating Ca and P homoeostasis[8], enhancing immunity and preventing CVD and has anti-inflammatory properties[9]. Ergocalciferol and cholecalciferol are two important types of VD[10]. In the human body, ergocalciferol is mainly derived from some plant foods, while cholecalciferol is mostly derived from skin synthesis in response to sunlight and from animal foods[11]. Immune and inflammatory responses in mothers are associated with PE, so there may also be a relationship between VD and PE risk[12]. VD deficiency is closely associated with adverse maternal and child outcomes[13]. Several epidemiological studies[14–20] have explored the association between VD and the risk of PE. While some studies[15,16,19,20] have suggested that VD deficiency is a risk factor for PE, others[14,17,18] have reported that there is no significant association between serum concentrations of total 25(OH)D ($25(OH)D_2 + 25(OH)D_3$) and the risk of PE. The inconsistent results of previous studies possibly were due to differences in the study populations and the limitation of sample size. Moreover, most of the studies on this association were conducted in Western countries. The efficiency of VD synthesis in the skin is affected by skin colour[21], and VD intake varies with dietary habits. As skin colour and dietary patterns are known to differ between Chinese and Western populations[22], it is reasonable to infer that the VD status of Chinese populations is different from that of their Western counterparts. A cohort study from south-eastern China reported that the prevalence of VD deficiency is high in Chinese pregnant women, and that VD deficiency at 23–28 weeks of gestation is strongly associated with an increased risk of severe PE[23]. Nevertheless, this study only focused on the relationship between serum VD concentrations and PE prevalence. Notably, it has been found that dietary VD intake is also linked to the maternal VD status[24]. Therefore, this case–control study was conducted to explore not only the associations between serum VD concentrations and PE risk but also the relationship between dietary VD intake and PE risk in Chinese pregnant women. We hypothesised that there was a dose–response relationship of dietary VD intake and serum VD concentrations with PE risk.

Methods

Study participants

This case–control study was conducted at the First Affiliated Hospital of Zhengzhou University, Henan, China. The inclusion and exclusion criteria have been reported previously[25]. Pregnant women who had been diagnosed with PE according to the China Diagnosis and Treatment Guidelines for hypertensive disorders in pregnancy (2015)[26] were included in the case group. Pregnant women without PE at the same hospital were enrolled in the control group.

The sample size of this 1:1 matched case–control study was calculated based on the OR estimated from previous studies (OR = 2·4)[27]. According to the results of the pilot survey, approximately 25 % of the controls would have higher serum VD concentrations. With 80 % statistical power and 0·05 two-sided significance level, the sample size of each group was estimated to be 121.

From March 2016 to June 2019, 1180 pregnant women (532 PE cases and 648 controls) completed a background and FFQ, and blood samples of 422 participants (175 PE cases and 247 controls) were successfully collected. Pregnant women with incomplete data on the FFQ (*n* 41) or implausible values of total energy intake (< 800 or > 4200 kJ/d[28]) (*n* 12) were excluded. The controls were 1:1 matched with the cases by age ((SD 3) years), gestational age ((SD 1) week) and gestational diabetes mellitus status (yes/no). After matching, a total of 440 pairs of pregnant women were included in our analysis of the association between dietary VD intake and PE risk, and 150 pairs of participants were included in our analysis of the association between serum concentrations of total 25(OH)D and the risk of PE (Fig. 1).

Written informed consent was obtained from all participants prior to the study. This study was approved by the Ethics Committee of Scientific Research and Clinical Trials of the First Affiliated Hospital of Zhengzhou University (No. Scientific research-2016-LW-34).

Data collection

The participants were interviewed face-to-face by trained interviewers. A structured questionnaire was used to collect information about socio-demographic characteristics, personal lifestyle (e.g. passive smoking, time of sun exposure and physical activity) and dietary intakes. Reproductive history, medical history and relevant medical diagnoses were collected from the medical records of the hospital. Gestational age was calculated from the first day of the last menstrual period. Passive smokers were defined as participants who had been exposed to exhaled smoke for at least 5 min/d over the past year. The BMI was calculated as the ratio of weight (kg) to height squared (m^2). Users of VD supplements, including pure VD supplements, multivitamins and cod liver oil, were defined as participants who had taken the relevant pills for at least 1 month during the pregnancy.

Assessment of dietary vitamin D intake

A seventy-eight-item semi-quantitative FFQ, which has been tested for reliability and validity[29], was used to assess the dietary intake of the participants during the last 3 months before delivery. The intake frequency (never, monthly, weekly or daily) and the amount consumed of each food were recorded. The dietary VD intake (μg/d) was calculated using the US Department of Agriculture Food Composition Database[30]. The energy intake (kJ/d) was calculated using the China Food Composition 2004[31] and the China Food Composition (2nd Edition)[32].

Laboratory analysis of serum vitamin D concentrations

Approximately 5-ml fasting blood samples were collected when the participants were about to delivery. The blood samples were centrifuged at 2500 rpm at 4°C for 10 min to separate the sera, and the serum samples were stored at –80°C until analysis.

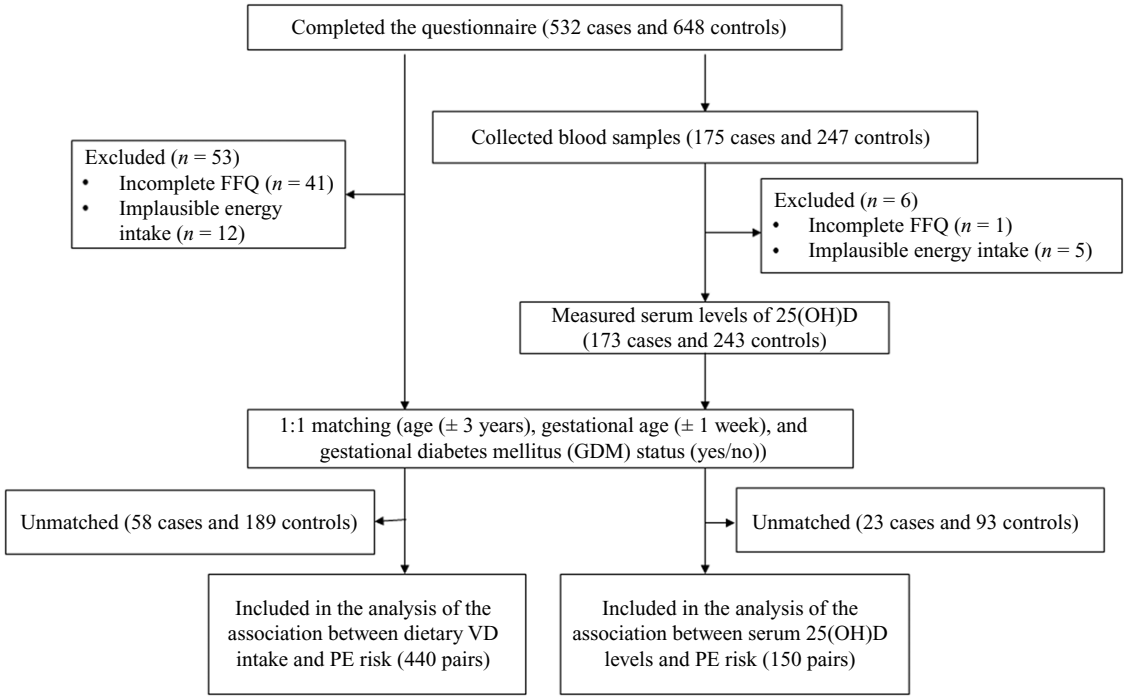

Fig. 1. Flow diagram for the matched case–control study.

Serum concentrations of 25(OH)D_2 and 25(OH)D_3 were detected by liquid chromatography–tandem MS, whose precision and accuracy have been tested[33]. Briefly, the serum samples (200 µl) were mixed with an internal standard solution (400 µl) and vortexed for 60 s to precipitate proteins, which were then extracted with hexane. This mixture was centrifuged (12 000 rpm, 5 min), and the supernatants were decanted and then evaporated under a stream of nitrogen gas until dryness. The resulting extract was dissolved in ethanol (100 µl) and then analysed by liquid chromatography (Shimadzu)–tandem MS (AB Sciex) to determine the serum concentrations of 25(OH)D_2 and 25(OH)D_3. For the chromatographic separation, 0·1 % formic acid solution and 0·1 % methanol solution of formic acid were used as mobile phase A and mobile phase B, respectively. The MS analysis of 25(OH)D_2 and 25(OH)D_3 was performed in the positive electrospray ionisation mode and the multiple reaction monitoring mode. Serum concentrations of total 25(OH)D were obtained by adding the serum concentrations of 25(OH)D_2 and 25(OH)D_3[34,35]. All procedures were performed by the same technician who was blinded to the participants' case/control status. VD deficiency was defined as a serum 25(OH)D concentration ≤ 20 ng/ml, VD insufficiency as a serum 25(OH)D concentration of 21–29 ng/ml and VD sufficiency as a serum 25(OH)D concentration ≥ 30 ng/ml, according to the published Endocrine Society's Practice Guidelines on Vitamin D[36].

Statistical analysis

The paired *t* test or Wilcoxon signed rank-sum test was used to test the differences in quantitative variables, and the paired χ^2 test was used to test the differences in qualitative variables between the PE and non-PE participants. The dietary intake data were adjusted for total energy intake using the residual method[37]. According to the distribution among the controls, the dietary VD intake and serum VD concentrations were categorised into quartiles (Q1–Q4). The OR and 95 % CI for the associations of dietary VD intake and serum VD concentrations with PE risk were estimated using multivariate conditional logistic regression models, with the lowest quartile used as the reference group[38]. Tests for trend were performed by entering the median of each quartile as a continuous variable in the regression models. The covariates in the multivariate logistic regression model were selected according to reported risk factors[2] and the results of univariate analysis in our study ($P < 0{\cdot}15$). Model 1 was adjusted for age, gestational age, pre-pregnancy BMI, family history of hypertension, education level, parity, physical activity and time of sun exposure. Daily energy intake, vegetables intake (energy-adjusted) and fruits intake (energy-adjusted) were additionally taken into model 2. Sensitivity analysis of the relationship between dietary VD intake and PE risk was performed by excluding participants with gestational diabetes mellitus. Potential nonlinear associations of dietary VD intake and serum VD concentrations with PE risk were examined using restricted cubic splines (RCS). The 20th, 50th and 80th percentiles were kept as the knots. The RCS were calculated using SAS 9.1 (SAS Institute Inc.) and R 4.0.3. All other analyses were performed using SPSS 25·0 (SPSS Inc.). A two-tailed *P* value less than 0·05 was considered statistically significant. The missing values in our study were ignored because they were less than 10 %.

Results

The characteristics of the 440 pairs of participants are shown in Table 1. Compared with the women without PE (controls), those with PE (cases) were more likely to have a family history of

Table 1. Socio-demographic, lifestyle characteristics and selected preeclampsia risk factors of the participants (*n* 440 pairs) (Mean values and standard deviations; median values and interquartile range)

	Cases			Controls			
	n	Mean/median	SD/IQR	*n*	Mean/median	SD/IQR	*P**
Age (years)†	440	30·88	5·03	440	31·03	4·85	0·11
Gestational age (weeks)†	440	34·17	2·90	440	34·24	2·67	0·07
Pre-pregnancy BMI (kg/m^2)†	440	23·67	3·89	440	22·35	3·35	< 0·001
Gestational diabetes mellitus (%)	440	13·0		440	13·0		1·00
Polycystic ovarian syndrome (%)	440	2·3		440	1·4		0·45
Family history of hypertension (%)	440	38·0		440	18·9		< 0·001
Education level (%)							0·01
Junior high school or below	207	46·9		164	37·4		
Senior high school	75	17·1		83	18·9		
College or above	158	36·0		192	43·7		
Income (Yuan/month) (%)							0·41
≤ 2000	61	13·9		46	10·5		
2001–4000	216	49·1		211	48·0		
4001–6000	78	17·7		82	18·6		
> 6000	59	13·4		81	18·4		
Passive smoker (%)	440	15·2		439	13·2		0·49
Parity (%)							0·001
0 birth	185	42·3		135	30·7		
1 birth	180	40·9		211	48·0		
≥ 2 births	73	16·6		93	21·1		
Time of sun exposure (%)							0·02
< 0·5 h/d	128	29·1		174	39·5		
0·5–1 h/d	143	32·5		129	29·3		
1–2 h/d	104	23·6		89	20·2		
> 1 h/d	64	14·5		48	10·9		
Season for 25(OH)D determination (%)							0·92
Spring	107	24·3		124	28·2		
Summer	92	20·9		81	18·4		
Autumn	128	29·1		126	28·6		
Winter	104	23·6		102	23·2		
Vitamin D supplement user (%)	440	68·6		440	70·5		0·61
Physical activity (MET-h/d)†	440	26·95	3·96	440	26·60	4·48	0·24
Daily energy intake (kJ/d)†	440	7742·07	2109·87	440	8209·34	2178·36	0·001
Energy-adjusted dietary vegetables intake (g/d)‡	440	326·90	230·16, 423·65	440	299·02	204·35, 393·69	0·001
Energy-adjusted dietary fruits intake (g/d)‡	440	316·00	189·62, 442·38	440	275·58	164·38, 386·78	0·004
Energy-adjusted dietary vitamin D intake (μg/d)‡	440	2·11	0·86, 3·36	440	2·76	1·30, 4·23	< 0·001

IQR, interquartile ranges; MET, metabolic equivalent task.
Categorical variables were evaluated using paired χ^2 tests.
* Continuous variables were evaluated using paired *t* tests or Wilcoxon rank-sum tests.
† Described as means and standard deviations.
‡ Described as median and IQR.

hypertension, lower level of education, fewer parities, longer sun exposure time, higher pre-pregnancy BMI, less energy and VD intake, and more vegetable and fruit consumption. However, there were no significant differences in age, gestational age, monthly income, passive smoking status, physical activity level, VD supplement usage, gestational diabetes mellitus status (yes/no) or family history of hypertension between the cases and controls. The median value of energy-adjusted dietary VD intake during the last 3 months before delivery was 2·11 μg/d for the cases and 2·76 μg/d for the controls.

Table 2 shows the OR and 95 % CI of PE risk according to the quartiles of dietary VD intake. Dietary VD intake was negatively associated with PE risk. After adjusting for possible confounders, the OR of the highest quartile was 0·45 (95 % CI 0·29, 0·71, $P_{trend} = 0·001$) in model 2. The sensitivity analysis results are shown in online Supplementary Table S1. No substantial changes were observed in the relationship between dietary VD intake and PE risk after excluding fifty-eight pairs of participants with gestational diabetes mellitus.

Online Supplementary Table S2 shows the socio-demographic characteristics and serum concentrations of 25(OH)D of 150 pairs of participants. The cases had a higher pre-pregnancy BMI and lower serum concentrations of 25(OH)D_2, 25(OH)D_3 and total 25(OH)D than the controls. The median value of the total serum 25(OH)D concentration was 11·50 ng/ml for the cases and 14·05 ng/ml for the controls. The associations between serum VD concentrations and PE risk are summarised in Table 3. In model 2, compared with the lowest quartile, the OR of the highest quartile was 0·10 (95 % CI 0·03, 0·35, $P_{trend} < 0·001$) for serum 25(OH)D_2 concentrations, 0·26 (95 % CI 0·11, 0·63, $P_{trend} = 0·008$) for serum 25(OH)D_3 concentrations and 0·26 (95 % CI 0·11, 0·60, $P_{trend} = 0·003$) for total serum 25(OH)D concentrations. The participants' statuses of VD deficiency, insufficiency and sufficiency are presented in online Supplementary Table S3. The percentage of women with VD deficiency and insufficiency in the PE group was higher than that in the control group ($P = 0·046$).

Multivariable-adjusted RCS analyses suggested a reverse J-shaped relationship between dietary VD intake/serum VD

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Table 2. Preeclampsia according to quartiles of dietary vitamin D intake (*n* 440 pairs) (Odds ratios and 95 % confidence intervals)

			Basic model		Model 1†		Model 2‡	
	Median (μg/d)*	Cases/controls (*n*)	OR	95 % CI	OR	95 % CI	OR	95 % CI
Dietary vitamin D intake								
Q1	1·24	173/110	1		1		1	
Q2	2·17	98/110	0·54	0·37, 0·79	0·56	0·36, 0·87	0·60	0·38, 0·93
Q3	3·49	98/110	0·55	0·37, 0·80	0·57	0·36, 0·89	0·61	0·39, 0·96
Q4	6·81	71/110	0·41	0·28, 0·61	0·43	0·27, 0·67	0·45	0·29, 0·71
P_{trend}§	–	–	< 0·001		< 0·001		0·001	

Q, quartile.
* Median intake of vitamin D in controls, which were adjusted for daily energy intake.
§ Performed by entering the median intake in each quartile as continuous variables in the regression models.
† Model 1 was adjusted for age, gestational age, pre-pregnancy BMI, family history of hypertension, education level, parity, physical activity and time of sun exposure.
‡ Model 2 was additionally adjusted for daily energy intake, vegetables intake (energy-adjusted) and fruits intake (energy-adjusted).

Table 3. Preeclampsia according to quartiles of serum concentrations of vitamin D among participants (*n* 150 pairs) (Odds ratios and 95 % confidence intervals)

			Basic model		Model 1†		Model 2‡	
	Median (ng/ml)*	Cases/controls (*n*)	OR	95 % CI	OR	95 % CI	OR	95 % CI
Serum concentrations of 25(OH)D_2								
Q1	0·47	77/37	1		1		1	
Q2	0·91	41/37	0·52	0·27, 1·00	0·46	0·21, 1·00	0·35	0·14, 0·85
Q3	1·30	18/38	0·19	0·09, 0·42	0·16	0·06, 0·41	0·10	0·03, 0·32
Q4	2·61	14/38	0·13	0·06, 0·32	0·14	0·05, 0·42	0·10	0·03, 0·35
P_{trend}§	–	–	< 0·001		< 0·001		< 0·001	
Serum concentrations of 25(OH)D_3								
Q1	6·25	53/37	1		1		1	
Q2	10·00	31/37	0·61	0·33, 1·11	0·36	0·16, 0·78	0·33	0·14, 0·79
Q3	15·35	41/38	0·77	0·44, 1·37	0·44	0·20, 0·96	0·31	0·13, 0·75
Q4	25·30	25/38	0·49	0·26, 0·93	0·29	0·13, 0·65	0·26	0·11, 0·63
P_{trend}§	–	–	0·06		0·01		0·008	
Serum concentrations of total 25(OH)D								
Q1	7·80	62/37	1		1		1	
Q2	11·60	30/37	0·55	0·31, 0·98	0·34	0·16, 0·73	0·30	0·13, 0·71
Q3	17·10	33/38	0·58	0·32, 1·04	0·32	0·14, 0·73	0·23	0·09, 0·57
Q4	27·10	25/38	0·45	0·24, 0·82	0·28	0·12, 0·61	0·26	0·11, 0·60
P_{trend}§	–	–	0·02		0·004		0·003	

Q, quartile.
* Median intake of vitamin D in controls, which were adjusted for daily energy intake.
§ Performed by entering the median intake in each quartile as continuous variables in the regression models.
† Model 1 was adjusted for age, gestational age, pre-pregnancy BMI, family history of hypertension, education level, parity, physical activity and time of sun exposure.
‡ Model 2 was additionally adjusted for daily energy intake, vegetables intake (energy-adjusted) and fruits intake (energy-adjusted).

concentrations and PE risk (Fig. 2). With increasing levels of VD, the risk of PE first decreased sharply and then plateaued after the inflection points of 3·5 μg/d for daily dietary VD intake (*P*-overall association = 0·003, *P*-nonlinearity = 0·02), 1 ng/ml for serum 25(OH)D_2 concentrations (*P*-overall association < 0·001, *P*-nonlinearity = 0·24), 12 ng/ml for serum 25(OH)D_3 concentrations (*P*-overall association = 0·001, *P*-nonlinearity = 0·03) and 15 ng/ml for total serum 25(OH)D concentrations (*P*-overall association < 0·001, *P*-nonlinearity = 0·02).

Discussion

In this matched case–control study conducted in China, we observed a negative relationship between dietary VD intake and PE risk. The RCS analysis results revealed a significant non-linear association between dietary VD intake and PE risk. Similar associations were also observed between serum 25(OH)D concentrations and PE risk. Our findings have important public health implications for the prevention of PE through lifestyle interventions.

Evidence on the relationship between dietary VD intake and PE risk is limited. In a cohort study conducted in the USA[39], no association was observed between the risk of PE and the intake of VD. However, it is important to note that the VD intake in that study was not only from diet but also from supplements. In addition, in a Norwegian cohort study, intake of VD supplements was found to decrease the risk of PE, while dietary intake of VD had no effect[40]. In contrast, we observed a reverse J-shaped association between dietary VD intake and PE risk in our study. The inconsistency between the results of the Norwegian study and our study may be due to the differences in dietary VD intake levels, lifestyle, dietary patterns and skin colours between the sample populations.

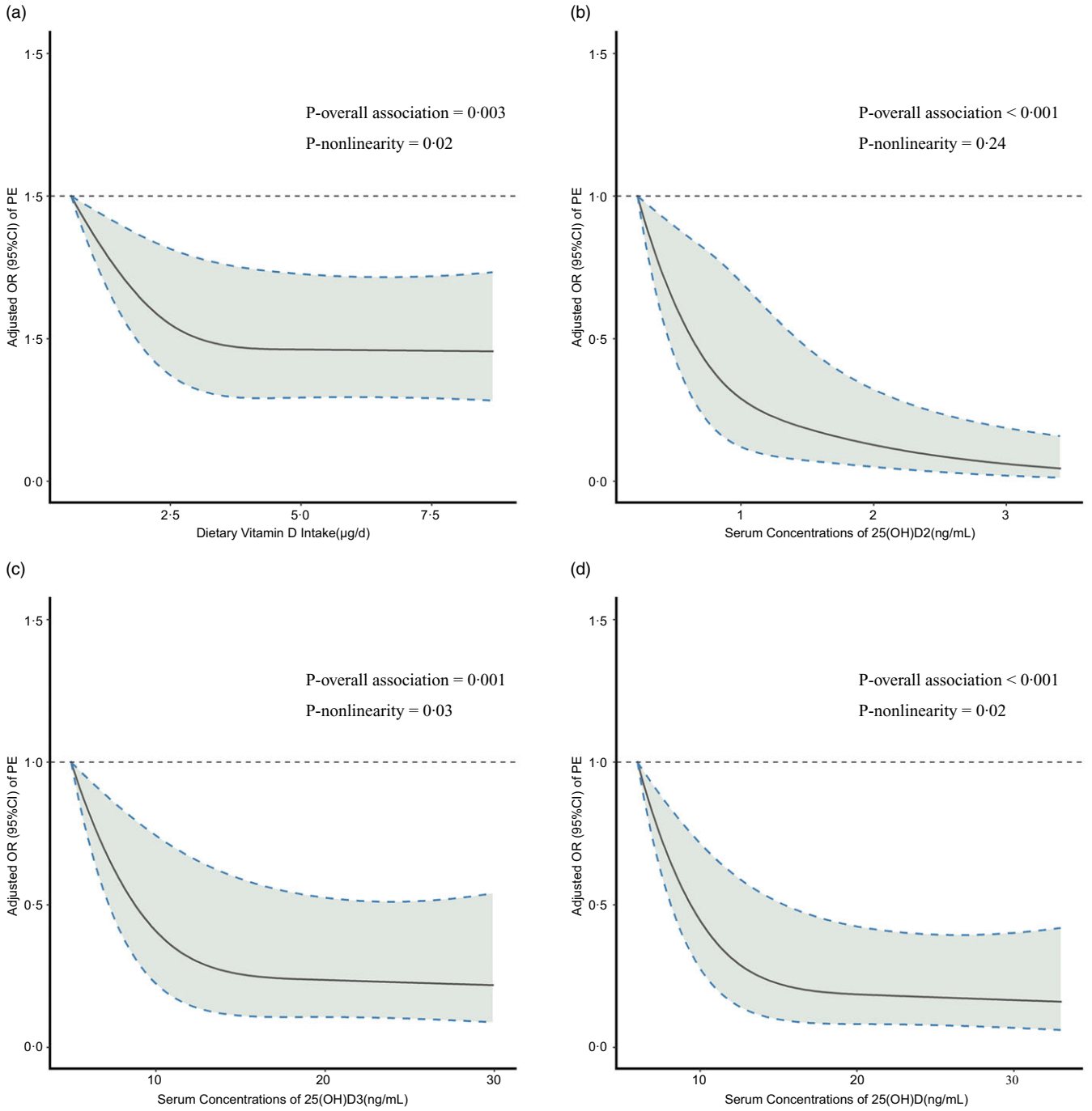

Fig. 2. Multivariable-adjusted OR (solid lines) and 95 % CI (dashed lines) for risk of preeclampsia according to dietary vitamin D intake (a), serum concentrations of 25(OH)D2 (b), 25(OH)D3 (c) and total 25(OH)D (d). The model was adjusted for age, gestational age, pre-pregnancy BMI, family history of hypertension, education level, parity, physical activity, time of sun exposure, daily energy intake, vegetables intake and fruits intake.

The results of our multivariate conditional logistic regression analysis showed that serum VD concentrations were inversely associated with PE risk. This is consistent with the results of some previous studies. A nested case–control study in the USA that included fifty-five PE patients and 219 non-PE pregnant women found that a 50 nmol/l decline in the serum 25(OH)D concentration before 22 weeks of gestation more than doubled the risk of PE (adjusted OR: 2·4; 95 % CI 1·1, 5·4)[27]. In addition, a multicentre case–control study in Western Europe that included eighty-three PE cases and 913 controls found that women with VD sufficiency during the third trimester had a lower risk of PE than women with VD insufficiency and deficiency (OR: 0·43; 95 % CI 0·23, 0·80; $P = 0·008$)[20]. A multicentre randomised clinical trial (RCT) in the USA showed that there was no significant difference in the incidence of PE between two groups of pregnant women who were taking different doses of VD

supplements (4400 *v.* 400 μg/d), but found that serum 25(OH)D concentrations in early pregnancy were a predictor of PE (adjusted OR: 0·96; 95 % CI 0·93, 0·99; $P = 0·025$)[41]. A RCT conducted in India showed that the incidence of PE was lower in the individualised VD intervention group than in the non-intervention group[42]. Besides, another RCT conducted in Saudi Arabia found that high dose of VD supplement reduced the incidence of PE in pregnant women with VD deficiency compared with low dose of VD supplement (4000 *v.* 400 μg/d)[43]. Different intervention doses, time of intervention initiation and baseline VD status of participants may account for the inconsistent results of the VD supplementation trials. In contrast, Powe *et al.*[44] found that serum VD concentrations in early pregnancy were not associated with PE risk. This is probably because the participants included in their study had different races[44]. In our study, the RCS curves suggested that there were reverse J-shaped associations between serum concentrations of VD (25(OH)D_2, 25(OH)D_3, and total 25(OH)D) and the risk of PE. Intriguingly, it has been found that cholecalciferol is more effective than ergocalciferol in increasing the serum concentrations of total 25(OH)D[45,46]. Therefore, further clinical trials are needed to compare the efficacy of ergocalciferol and cholecalciferol supplements in the prevention of PE in pregnant women.

Although it is not clear how VD affects the development of PE, some studies have suggested possible mechanisms. For example, VD has been shown to be an effective endocrine inhibitor of renin biosynthesis that modulates the renin–angiotensin system[47]. Thus, higher serum VD concentrations may prevent hypertension by inhibiting the renin–angiotensin system. In addition, proteinuria in PE is mediated by renal vascular endothelial growth factor, and 1,25-dihydroxyvitamin D_3 has been shown to directly affect *vascular endothelial growth factor* gene transcription[48]. Furthermore, inappropriate immune responses between the mother and fetus may lead to abnormal placental implantation, which contributes to the development of PE. It has been found that most of the VD-related genes involved in PE are associated with systemic changes in maternal immune and inflammatory responses[41]. Thus, VD may affect the occurrence of PE by regulating maternal immune and inflammatory responses.

Our study has the following strengths. First, we collected information about the participants' sun exposure time and whether they had ever taken VD supplements to control the influence of VD from other sources on the relationship between dietary VD intake and PE risk. Second, serum concentrations of 25(OH)D_2 and 25(OH)D_3 were measured separately in our study. In previous studies, the relationship between ergocalciferol and PE has rarely been investigated. Our study provides evidence of the relationship between different types of VD and the risk of PE. Third, the relationship between serum VD concentrations and PE risk was not only explored by multivariate logistic regression but also visualised by RCS in our study. Fourth, we used 1:1 matching and multivariate logistic regression to control for the confounding factors. Thus, our study is more intuitive than prior studies.

However, several limitations of our study should also be acknowledged. First, it is important to note that, as a case–control study, we cannot ignore the possibility of reverse causality. Although PE may affect maternal dietary intake and VD status, we could not find direct evidence that PE impact VD status. Several meta-analyses of RCTs reported that supplementation with VD may reduce the risk of PE[49–51]. However, in the RCT included in these meta-analyses, only a few studies involved in the intervention of supplementing VD alone. Therefore, high quality and larger scale RCT are required to evaluate the effects of VD intake (from dietary or supplements) on the incidence of PE. Second, the use of an FFQ for dietary surveys may have led to recall bias. Therefore, to diminish this bias, we conducted face-to-face interviews and used food photographs to assess the portion size. Third, our study investigated dietary intake of VD for 3 months before delivery, but the occurrence of PE may begin in early pregnancy. Nonetheless, our study can explain the relationship between VD and PE to some extent, as the time from PE onset to delivery is often less than 3 months. In addition, recalling past dietary intake for longer periods may lead to greater recall bias. Therefore, we found it more appropriate to focus on the 3 months before delivery in this study. Fourth, we could not rule out the possibility of residual confounding. Despite these limitations, the findings of our study suggest a protective effect of VD against the development of PE in pregnant women.

Conclusion

In conclusion, higher dietary VD intake or serum VD concentrations are associated with a lower risk of PE in Chinese pregnant women, and this association follows a reverse J-shaped curve. Further prospective cohort studies and RCT are warranted to verify these associations.

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The authors declare no conflict of interest.

Supplementary material

For supplementary materials referred to in this article, please visit https://doi.org/10.1017/S0007114521002956

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