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Vitamin D deficiency prevalence and risk factors among pregnant Chinese women

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Abstract

Objective: To evaluate vitamin D deficiency prevalence and risk factors among pregnant Chinese women.

Design: A descriptive cross-sectional analysis.

Setting: China National Nutrition and Health Survey (CNNHS) 2010–2013.

Subjects: A total of 1985 healthy pregnant women participated. Possible predictors of vitamin D deficiency were evaluated via multiple logistic regression analyses.

Results: The median serum 25-hydroxyvitamin D level was 15·5 (interquartile range 11·9–20·0, range 3·0–51·5) ng/ml, with 74·9 (95 % CI 73·0, 76·7) % of participants being vitamin D deficient (25-hydroxyvitamin D <20 ng/ml). According to the multivariate logistic regression analyses, vitamin D deficiency was positively correlated with Hui ethnicity ($P = 0·016$), lack of vitamin D supplement use ($P = 0·021$) and low ambient UVB level ($P < 0·001$). In the autumn months, vitamin D deficiency was related to Hui ethnicity ($P = 0·012$) and low ambient UVB level ($P < 0·001$). In the winter months, vitamin D deficiency was correlated with younger age ($P = 0·050$), later gestational age ($P = 0·035$), higher pre-pregnancy BMI ($P = 0·019$), low ambient UVB level ($P < 0·001$) and lack of vitamin D supplement use ($P = 0·007$).

Conclusions: Vitamin D deficiency is prevalent among pregnant Chinese women. Residing in areas with low ambient UVB levels increases the risk of vitamin D deficiency, especially for women experiencing advanced stages of gestation, for younger pregnant women and for women of Hui ethnicity; therefore, vitamin D supplementation and sensible sun exposure should be encouraged, especially in the winter months. Further studies must determine optimal vitamin D intake and sun exposure levels for maintaining sufficient vitamin D levels in pregnant Chinese women.

Keywords
Vitamin D
25-Hydroxyvitamin D
Deficiency
Insufficiency
Pregnancy
China

Pregnant women with low serum 25-hydroxyvitamin D (25(OH)D) levels are more likely to contract gestational diabetes, pre-eclampsia and bacterial vaginosis, and they are more likely to give birth to infants who are small for gestational age or who have a low birth weight[1]. Serum 25(OH)D levels in the fetus and the infant at birth are dependent on the maternal pool of 25(OH)D and transplacental transfer[2]. Maternal vitamin D status affects child bone-growth levels by changing periosteal bone formation patterns during childhood[3]. Additionally, lower maternal vitamin D levels may cause offspring adiposity by influencing the programming and development of muscle and fat tissue[4]. Because pregnancy serves as a critical period of fetal skeletal and nerve growth, suboptimal maternal vitamin D levels during pregnancy may have several other health consequences for the offspring[5].

The major source of vitamin D for most human populations is sunlight exposure between approximately 09.00 and 15.00 hours (local solar time) in the spring, summer and autumn[6]. At high latitudes, solar elevation angles and ambient UVB levels are always low, and UVB exposure periods required to acquire an ideal quantity of vitamin D are sometimes impractical, especially during cooler

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seasons. Vitamin D deficiency is very common among pregnant women who live in high-latitude areas[7]. Vitamin D insufficiency is also highly prevalent in some sun-rich areas such as India[8] and South Carolina[9]. Currently, vitamin D deficiency levels among pregnant women constitute a widespread and urgent health issue that must be remedied.

In some countries, such as the UK, pregnant women can obtain free vitamin supplements, including vitamin D supplements, from local health departments. These vitamin D supplements help raise serum 25(OH)D levels in pregnant women[10] and may also decrease preterm birth risks[11]. Free vitamin D supplements are not offered to pregnant women in China. Previous studies have always focused on cities or regions of China and have shown that pregnant Chinese women present a high prevalence of vitamin D deficiency or insufficiency[12–15]. Universal vitamin D screening for all pregnant Chinese women has not been reported on before.

In the present study we evaluate the prevalence of vitamin D deficiency in a nationally representative sample of pregnant women in China. We also predict the main risk factors of vitamin D deficiency among pregnant Chinese women based on age, gestational age, self-reported pre-pregnancy BMI, parity, ethnicity, ambient UVB levels in areas of residence, daily outdoor activities, vitamin D supplementation levels, smoking habits, gestational hypertension and gestational diabetes. National vitamin D data are instrumental to the development of health polices regarding pregnant Chinese women. The Chinese Center for Disease Control and Prevention may use these data to provide advice on vitamin D supplements for at-risk groups.

Materials and methods

Study design and participants

Data for the present analysis were taken from the China National Nutrition and Health Survey (CNNHS) 2010–2013. This survey was a nationally representative cross-sectional study that had been conducted by the Chinese Center for Disease Control and Prevention to assess the health and nutrition of Chinese civilians. It covered all thirty-one provinces, autonomous regions and municipalities directly under the central government throughout China (except Taiwan, Hong Kong and Macao). A stratified multistage probability sampling design was used in the selection of participants. The country was divided into four strata according to economic characteristics and social development. These were large cities, small to medium cities, general rural areas and poor rural areas. It involved the random selection of 150 districts (urban) or counties (rural). Serum samples were collected from pregnant women from June 2013 to March 2014. We planned to survey thirty pregnant women at random in each district or county. Briefly, approximately 4500 pregnant women were invited to participate in CNNHS 2010–2013, and 3836 participated (response rate 85 %). We excluded participants who did not have adequate serum samples for 25(OH)D measurement and those with a history of kidney disease or chronic liver disease. The final sample for the current cross-sectional analysis included 52 % (n 1985) of the participants. All the participants were given a urine human chorionic gonadotrophin test. The study was conducted according to the guidelines laid down in the Declaration of Helsinki and all procedures involving human subjects were approved by the Ethics Committee of the National Institute for Nutrition and Health, Chinese Center for Disease Control and Prevention. All participants in the survey signed an informed consent form.

Data collection

Demographic data (age, ethnicity) and data on gestational age, parity, pre-pregnancy BMI, vitamin D supplement use, smoking habits and daily outdoor periods were collected based on self-reports. Questions regarding gestational diabetes symptoms were also included in the questionnaire, and all participants were asked to provide a medical report completed by a licensed doctor. Blood pressure levels were measured twice from each participant's right arm while in a seated position after 5 min of rest; the mean of the two measurements was used for analysis. Gestational hypertension was defined as a blood pressure level >140/90 mmHg at two separate times least 6 h apart[16]. Gestational diabetes mellitus was identified as a fasting capillary blood glucose level >7·0 mmol/l[17].

Blood samples were collected in the morning after a fasting period of 10–12 h on the day after the participants signed an informed consent form and were centrifuged within 0·5–1 h following collection. Serum samples were then aliquoted and stored at –80°C until they were analysed. Serum 25(OH)D levels were measured by a 25-Hydroxy Vitamin D EIA kit (Immunodiagnostic Systems Ltd, Boldon, UK) using a microplate reader (BioTek Synergy H1 Hybrid Reader). Inter-assay CV were 6·8 and 6·1 % at 12·8 and 43·6 ng/ml, respectively. In our study, participants with a serum 25(OH)D concentration of less than 12 ng/ml (30 nmol/l) were considered to present severe levels of vitamin D deficiency; those with a concentration between 12 and 20 ng/ml were considered to present vitamin D deficiency; and those with a concentration between 20 and 30 ng/ml were considered to present vitamin D insufficiency. Serum 25(OH)D concentrations between 30 and 50 ng/ml were regarded as normal and concentrations above 50 ng/ml (particularly >60 ng/ml) may have adverse effects[18,19].

Ambient UVB measurements

We estimated ambient UV radiation exposure levels for each participant using the Chinese administrative division codes of each participant's current residential address. Latitude and longitude coordinates were found for each code and were matched against UVB data available from a 1° latitude × 1° longitude grid from the NASA Goddard Space Flight Center Data Archive Center database of readings of the total ozone mapping spectrometer (TOMS) mounted on the Nimbus-7 satellite. This database was used to estimate the average erythemally weighted UVB dose (J/m^2) reaching the Earth at each location from June 2013 to March 2014. The HDFtool of Matlab 7·11·0 (R2010b) was utilized to read the database. Ambient UVB levels for the entire sample were then classified into tertiles.

Statistical analysis

The participants were divided into sub-classes according to a number of hypothesized predictors for vitamin D status: region stratum, ambient UVB level of living area, season (spring, defined as March to May; summer, defined as June to August; autumn, defined as September to November; winter, defined as December to February), ethnicity, age, gestational age, parity, pre-pregnancy BMI, vitamin D supplement use, daily time spent outdoors, smoking habits, gestational hypertension and gestational diabetes. The Kolmogorov–Smirnov test was used for the normality analysis of each sub-class; most sub-classes did not follow a normal distribution. Therefore, we conducted a Kruskal–Wallis test followed by a Mann–Whitney *U* test to examine relationships between vitamin D levels and the hypothesized predictors.

A multinomial logistic regression analysis was conducted to investigate the relationship between vitamin D deficiency levels and a number of possible predictors (i.e. age, gestational age, pre-pregnancy BMI (continuous, untransformed), parity, ethnicity, ambient UVB level of living area, daily outdoor activity periods, vitamin D supplement use, smoking habits, gestational hypertension and gestational diabetes). For the autumn and winter months, we performed an additional multinomial logistic regression to investigate the relationship between vitamin D deficiency and a number of possible predictors (i.e. age, gestational age, pre-pregnancy BMI (continuous, untransformed), parity, ethnicity, ambient UVB level of living area, daily outdoor activity periods and vitamin D supplement use). The statistical software package SAS version 9·2 was used for data analysis purposes. The primary analysis is descriptive and includes 95 % CI. The significance level was set at $P < 0·05$ using two-sided tests.

Results

As a part of the CNNHS in 2010–2013, serum 25(OH)D levels of 1985 pregnant women were analysed. The median age of the participants was 26·10 (interquartile range 23·50–29·20, range 16·90–43·10) years and the median gestational age of the participants was 22·00 (interquartile range 14·00–31·00, range 2·00–42·00) weeks. The median pre-pregnancy BMI level was 20·53 (interquartile range 19·05–22·50, range 14·02–34·45) kg/m^2, with 16·58 % of the participants being underweight (BMI < 18·5 kg/m^2), 12·83 % being overweight (BMI = 24–28 kg/m^2) and with 1·95 % being obese (BMI > 28 kg/m^2). Only 0·93 % of the participants were classified as presenting gestational diabetes mellitus, 0·74 % exhibited gestational hypertension and 73·04 % of participants were nulliparous. In total, 10·04 % of the participants reported using vitamin D supplements during pregnancy. Only 0·3 % of the women reported smoking while pregnant; 1·9 % reported smoking prior to becoming pregnant but quitting while pregnant. The population was mainly of Han ethnicity (90·3 %). Baseline characteristics and 25(OH)D values are presented in Table 1.

The median serum 25(OH)D level was 15·5 (interquartile range 11·9–20·0, range 3·0–51·5) ng/ml. The prevalence of vitamin D deficiency (25(OH)D < 20 ng/ml) was estimated at 74·9 (95 % CI 73·0, 76·7) %. Of these women with vitamin D deficiency, 25·5 (95 % CI 23·5, 27·4) % presented severe vitamin D deficiency levels (25(OH)D < 12 ng/ml), while 21·1 (95 % CI 20·9, 22·0) % showed signs of vitamin D insufficiency (20 ng/ml ≤ 25(OH)D < 30 ng/ml).

In the logistic regression analysis for all the participants (Table 2), the following factors were associated with vitamin D deficiency (OR; 95 % CI): Hui ethnicity (1·84; 1·12, 3·02; $P = 0·016$, relative to Han ethnicity), ambient UVB level of living area (low: 2·52; 1·89, 3·35; $P < 0·001$, medium: 1·70; 1·28, 2·24; $P < 0·001$, relative to high) and vitamin D supplement use (no: 1·56; 1·07, 2·28; $P = 0·021$, relative to yes). According to a logistic regression analysis of participants whose serum was collected in the autumn months (Table 3), vitamin D deficiency was associated with Hui ethnicity (2·35; 1·20, 4·57; $P = 0·012$, relative to Han ethnicity) and ambient UVB level of living area (low: 2·71; 1·85, 3·97; $P < 0·001$, medium: 2·22; 1·49, 3·31; $P < 0·001$, relative to high). According to a logistic regression analysis of participants whose serum was collected during the winter months (Table 3), vitamin D deficiency was associated with age (0·96; 0·92, 1·00; $P = 0·050$, per year increase in age), gestational age (1·02; 1·00, 1·04; $P = 0·035$, per unit increase in gestational age), pre-pregnancy BMI (1·09; 1·01, 1·16; $P = 0·019$, per unit increase in BMI), ambient UVB level of living area (low: 5·54; 3·17, 9·68; $P < 0·001$, relative to high) and vitamin D supplement use (no: 1·97; 1·20, 3·24; $P = 0·007$, relative to yes).

Discussion

More than half of the pregnant Chinese women participating in the present study were vitamin D deficient

Table 1 Characteristics of the study participants: healthy pregnant Chinese women (*n* 1985), China National Nutrition and Health Survey 2010–2013

		25(OH)D (ng/ml)			Percentage with 25(OH)D (ng/ml)			
Variable/group	*n*	Mean	95 % CI	*P* value	<12	12–20	20–30	>30
Total	1985	16·6	16·3, 16·9		25·5	49·4	21·1	4·0
Age (years)	1985			0·001				
<20	56	13·9[a]	12·2, 15·6		46·4	39·3	12·5	1·8
20–25	724	16·2[b]	15·8, 16·7		27·5	50·4	18·5	3·6
25–30	787	16·7[b]	16·3, 17·2		23·4	50·3	22·9	3·4
30–35	309	17·5[b]	16·7, 18·3		23·3	45·6	24·6	6·5
≥35	109	16·8[b]	15·5, 18·1		22·9	52·3	19·3	5·5
Gestational age	1985			0·024				
First trimester	440	17·0[a]	16·4, 17·6		21·6	52·3	21·8	4·3
Second trimester	837	16·7[a]	16·3, 17·2		25·9	47·8	22·3	3·9
Third trimester	708	16·2[b]	15·7, 16·7		27·4	49·6	19·1	4·0
Parity	1977			<0·001				
0	1444	16·2[A]	15·9, 16·5		27·4	49·5	19·9	3·3
1	493	17·8[B]	17·2, 18·4		19·3	49·7	24·7	6·3
≥2	40	15·7[A]	13·5, 17·9		32·5	42·5	20·0	5·0
Pre-pregnancy BMI (kg/m^2)	1840			0·831				
<18·5	302	16·8	16·1, 17·6		25·8	47·0	22·5	4·6
18·5–24·0	1288	16·6	16·3, 17·0		24·7	50·2	21·2	4·0
24·0–28·0	215	16·2	15·4, 17·1		26·0	54·0	15·8	4·2
>28·0	35	15·9	13·9, 18·0		22·9	51·4	22·9	2·9
Region strata	1985			<0·001				
Large cities	467	15·6[A]	15·1, 16·2		30·8	48·2	18·8	2·1
Small to medium cities	557	17·3[B]	16·8, 17·9		22·1	48·5	23·7	5·7
General rural areas	540	18·5[C]	18·0, 19·1		15·2	50·6	27·8	6·5
Poor rural areas	421	14·2[D]	13·6, 14·6		37·3	50·6	11·4	0·7
Vitamin D supplementation	1972			0·134				
No	1792	16·5	16·2, 16·8		25·9	49·4	20·8	3·9
Yes	180	17·4	16·0, 18·5		19·4	51·7	23·3	5·6
Season	1985			<0·001				
Spring	55	10·0[A]	9·3, 10·7		78·2	21·8	0·0	0·0
Summer	50	18·3[B]	16·6, 20·0		14·0	50·0	32·0	4·0
Autumn	951	17·9[B]	17·4, 18·3		19·2	49·7	24·9	6·1
Winter	929	15·6[C]	15·2, 15·9		29·4	50·7	17·8	2·2
Ambient UVB (J/m^2)	1985			<0·001				
Low	788	15·6	15·2, 16·0		32·5	48·4	15·2	3·9
Medium	647	16·2	15·7, 16·6		27·0	48·8	21·3	2·8
High	550	18·5	18·0, 19·1		13·6	51·6	29·1	5·6
Time outdoors (h/d)	1984			0·208				
<0·5	248	16·2	15·4, 17·0		29·8	43·5	24·6	2·0
0·5–1	657	16·4	15·9, 16·9		25·9	51·1	19·3	3·7
1–2	655	17·0	16·5, 17·5		22·9	50·8	21·1	5·2
>2	424	16·5	15·8, 17·1		26·2	48·1	21·7	4·0
Ethnicity	1985			<0·001				
Han ethnicity	1793	16·8[A]	16·5, 17·1		24·4	49·8	21·6	4·2
Hui ethnicity	42	10·7[B]	9·2, 12·2		64·3	31·0	4·8	0·0
Other ethnicity	150	16·1[A]	15·1, 17·1		27·3	50·0	19·3	3·3
Smoking habits	1984			0·666				
Non-smoker without passive smoking	906	16·8	16·4, 17·3		24·4	49·3	21·5	4·7
Non-smoker with passive smoking	1035	16·4	16·0, 16·8		26·2	49·9	20·5	3·5
Former smoker	38	15·7	13·8, 17·7		31·6	44·7	21·1	2·6
Current smoker	5	15·5	9·2, 21·9		40·0	20·0	40·0	0·0
Gestational hypertension	1892			0·104				
No	1878	16·6	16·3, 16·9		25·3	49·5	21·0	4·2
Yes	14	14·4	10·3, 18·4		50·0	35·7	7·1	7·1
Gestational diabetes mellitus	1836			0·940				
No	1819	16·7	16·4, 17·0		25·0	49·8	21·0	4·3
Yes	17	16·5	13·2, 19·8		35·3	41·2	17·6	5·9

25(OH)D, 25-hydroxyvitamin D.
[a,b,c/A,B,C,D]Mean values within a column with unlike superscript letters were significantly different by the Mann–Whitney *U* test ([a,b,c], $P<0·05$; [A,B,C,D], $P<0·01$).

(25(OH)D < 20 ng/ml), even during the summer and autumn seasons. The seasonal prevalence of vitamin D deficiency reached roughly 70 % and 80 % during autumn and winter, respectively. We observed seasonal variations in serum 25(OH)D concentrations among the participants. Serum 25(OH)D concentrations were higher in the summer and autumn months and lower in the winter and spring months. This seasonal variation in serum 25(OH)D

Table 2 Multinomial logistic regression model for 25-hydroxyvitamin D level among healthy pregnant Chinese women (*n* 1668), China National Nutrition and Health Survey 2010–2013

Variable/group	*n*	OR	95 % CI	*P* value
Age	1668	0·98	0·95, 1·01	0·128
Gestational age	1668	1·01	1·00, 1·02	0·060
Pre-pregnancy BMI	1668	1·04	0·99, 1·08	0·085
Parity				
0	1232	1·51	0·64, 3·54	0·342
1	407	1·06	0·45, 2·50	0·888
≥2	29	1·00	Ref.	–
Ethnicity				
Hui ethnicity	122	1·84	1·12, 3·02	0·016
Other ethnicity	29	3·58	0·83, 15·51	0·088
Han ethnicity	1517	1·00	Ref.	–
Ambient UVB				
Low	636	2·52	1·89, 3·35	0·000
Medium	564	1·70	1·28, 2·24	0·000
High	468	1·00	Ref.	–
Daily outdoor activity				
<0·5 h	206	0·87	0·58, 1·31	0·511
0·5–1 h	557	1·19	0·86, 1·65	0·288
1–2 h	566	0·97	0·70, 1·33	0·828
>2 h	339	1·00	Ref.	–
Vitamin D supplementation				
No	1519	1·56	1·07, 2·28	0·021
Yes	149	1·00	Ref.	–
Smoking habits				
Non-smoker with passive smoking	850	1·19	0·94, 1·50	0·144
Current smoker	5	0·59	0·09, 3·88	0·585
Former smoker	32	1·26	0·53, 3·01	0·603
Non-smoker without passive smoking	781	1·00	Ref.	–
Gestational hypertension				
No	1657	0·56	0·12, 2·71	0·471
Yes	11	1·00	Ref.	–
Gestational diabetes				
No	1653	1·22	0·37, 4·02	0·741
Yes	15	1·00	Ref.	–

Ref., reference category.

levels is consistent with previous observations of Korean adolescents[20]. While vitamin D deficiency was highly prevalent, our results were similar to those of prior studies. A recent study conducted in south-western China found 83·6 % of pregnant women to exhibit serum 25(OH)D levels of <20 ng/ml[13]. Another study conducted in south-eastern China showed that 68·6 % of pregnant women presented serum 25(OH)D levels of <20 ng/ml[12]. The highest value of 25(OH)D detected in our data was 51·5 ng/ml, implying that no participants were at risk of vitamin D intoxication at levels of >60 ng/ml[18].

Most of our serum samples were gathered during the autumn and winter months. Only 5·3 % of the serum samples were collected in the spring or summer. As not enough participants were recruited in the spring and summer, we focused more heavily on the main risk factors of vitamin D deficiency during the autumn and winter. For the autumn samples, low ambient UVB levels and Hui ethnicity were independent predictors for vitamin D deficiency among the sample of pregnant Chinese women. For samples collected during the winter, vitamin D deficiency levels were correlated with younger age, later gestational age, higher pre-pregnancy BMI levels and low ambient UVB levels. Differences between predictors of vitamin D deficiency for the autumn and winter seasons may be attributable to different ambient UVB levels occurring during these two seasons. Ambient UVB levels were higher in the autumn than in the winter.

Women living in areas of high ambient UVB levels exhibited higher vitamin D levels than women living in areas of low or medium ambient UVB levels. As skin exposure to UVB rays serves as a primary source of vitamin D for most people[6], ambient UVB levels were an expected predictor of vitamin D deficiency in our study. Former studies have shown that vitamin D deficiency is more prevalent among individuals living in high-latitude areas where ambient UVB levels are always low[21–23]. Webb and Engelsen's study suggested that the exposure period needed to reach an ideal vitamin D level increases with increasing latitude and that individuals living at extreme latitudes are not able to produce enough vitamin D via their skin following exposure to UVB, particularly during the winter months[6].

Our results showed that women of Hui ethnicity exhibited lower vitamin D levels than women of Han or other ethnicities (10·7 *v.* 16·8 %), particularly in the autumn

Table 3 Multinomial logistic regression model for 25-hydroxyvitamin D level in autumn and winter among healthy pregnant Chinese women (*n* 1731), China National Nutrition and Health Survey 2010–2013

	Autumn (*n* 848)				Winter (*n* 883)			
Variable/group	*n*	OR	95 % CI	*P* value	*n*	OR	95 % CI	*P* value
Age	848	0·98	0·94, 1·01	0·183	883	0·96	0·92, 1·00	0·050
Gestational age	848	1·01	0·99, 1·02	0·408	883	1·02	1·00, 1·04	0·035
Pre-pregnancy BMI	848	1·02	0·97, 1·08	0·455	883	1·09	1·01, 1·16	0·019
Parity								
0	606	1·22	0·42, 3·58	0·717	653	1·42	0·34, 5·90	0·629
1	222	1·02	0·35, 2·99	0·971	218	1·02	0·25, 4·24	0·978
≥2	20	1·00	Ref.	–	12	1·00	Ref.	–
Ethnicity								
Hui ethnicity	16	2·35	1·20, 4·57	0·012	18	1·18	0·58, 2·37	0·652
Other ethnicity	59	5·49	0·69, 43·47	0·106	72	1·50	0·19, 12·09	0·704
Han ethnicity	773	1·00	Ref.	–	793	1·00	Ref.	–
Ambient UVB								
Low	370	2·71	1·85, 3·97	0·000	271	5·54	3·17, 9·68	0·000
Medium	267	2·22	1·49, 3·31	0·000	305	1·25	0·86, 1·84	0·245
High	211	1·00	Ref.	–	307	1·00	Ref.	–
Daily outdoor activity								
<0·5 h	92	0·93	0·53, 1·61	0·785	120	0·61	0·33, 1·14	0·124
0·5–1 h	280	1·21	0·78, 1·88	0·384	306	1·06	0·63, 1·77	0·825
1–2 h	291	1·03	0·68, 1·57	0·884	292	0·83	0·51, 1·35	0·448
>2 h	185	1·00	Ref.	–	165	1·00	Ref.	–
Vitamin D supplementation								
No	777	1·32	0·77, 2·25	0·307	803	1·97	1·20, 3·24	0·007
Yes	71	1·00	Ref.	–	80	1·00	Ref.	–

Ref., reference category.

months. This finding is attributable to the unique clothing style adopted by Hui women, who are accustomed to wearing a veil and long cloth that exposes only their eyes. In the autumn months, when ambient UVB levels are high, this clothing affects Hui women's vitamin D levels. However, during the winter months, this clothing, according to our data, does not appear to affect vitamin D levels, potentially because ambient UVB levels are depressed during the winter. Additionally, clothing style may not be a major predictor of vitamin D deficiency levels under low ambient UVB level conditions. Saudi Arabian researchers have also found that vitamin D levels can be affected by clothing styles[24].

Pregnant women in their third trimester exhibited lower vitamin D levels than women in their first trimester of gestation (16·2 *v.* 17·0 ng/ml, $P = 0·0243$) in our study. Holmes *et al.* also found that women at 20 and 35 weeks of gestation showed lower vitamin D levels than women at 12 weeks of gestation[7]. An increased demand for vitamin D at early and late pregnancy stages may be a result of changes in Ca and vitamin D metabolism levels, and these changes may result from significant differences in vitamin D levels during different stages of pregnancy. In the winter months, vitamin D deficiency levels were negatively correlated with older gestational ages. Due to low ambient UVB levels in the winter months, increased demands for vitamin D during later pregnancy stages appear to be more serious.

According to our data, pregnant women who are younger than 20 years of age show lower 25-hydroxyvitamin D levels than older women. According to our multinomial logistic regression, age is a risk factor of vitamin D deficiency in the winter. This association between younger age and vitamin D status may be attributable to the growth demands of young girls. This result reflects those of former studies[10,25]. However, as our study can only assess associations, more research is needed to determine whether younger age serves as the main cause of vitamin D deficiency for some pregnant woman. We at least know that pregnancy at a young age may not be beneficial to women's health.

Prior studies have shown that the use of vitamin D supplements may raise vitamin D levels among pregnant women[10] while decreasing preterm birth risks[11]. We thus hypothesized that vitamin D intake serves as an important predictor of vitamin D deficiency. Unfortunately, the CNNHS database does not detail information on total daily vitamin D intake via foods and supplements. Thus, we examined vitamin D supplement usage in our analysis, although this analysis does not serve as an adequate assessment of total daily vitamin D intake levels. In our study, vitamin D supplement use was found to be an independent predictor of vitamin D deficiency, especially in the winter.

For pregnant women, the estimated average vitamin D requirement and RDA published by the US Institute of Medicine in 2010 were designated as 10 and 15 μg/d for 25(OH)D concentrations of 16 and 20 ng/ml, respectively[18]. The vitamin D Dietary Reference Intake published by the Chinese Nutrition Society in 2014 was also reported as

10 μg/d for pregnant women[26]. While vitamin D supplements helped increase 25(OH)D concentrations, only 28·9 and 5·6 % of our participants who were using vitamin D supplements reached optimal serum 25(OH)D levels of 20 and 30 ng/ml, respectively. Additionally, only 9·1 % of our study participants used vitamin D supplements. Vitamin D supplement use is not currently very popular in China. This high prevalence of vitamin D deficiency raises two questions: (i) whether outdoor daylight hours and/or the current Dietary Reference Intake of vitamin D are sufficient to maintain adequate vitamin D levels in pregnant Chinese women; and (ii) whether universal vitamin D supplementation for pregnant Chinese women is needed.

The present study is the first report on the vitamin D status of pregnant Chinese women based on a nationally representative sample. In our study, vitamin D deficiency was found to be highly prevalent among pregnant Chinese women. Therefore, this population should be educated on the importance of vitamin D levels and on ways of obtaining enough vitamin D. Sun exposure serves as the main source of vitamin D for most people[6]. However, two former studies showed that even knowledgeable medical university students in China have little awareness of the health effects of sun exposure[27,28]. These students' attitudes and practices generally focused on reducing sun exposure and on skin protection. In China, women have been found to be more likely to limit their sun exposure levels than men[27]. Most Chinese women limit their sun exposure and use sunscreen to prevent tanning[28]. Medical students, let alone the general Chinese population, know little about the relationship between sun exposure and vitamin D health. Pregnant Chinese women should be instructed to moderately increase their sun exposure habits and to use less sunscreen in order to maintain adequate vitamin D levels. It has been documented that products with a sun protection factor of 8 sufficiently reduce cutaneous cholecalciferol (vitamin D_3) production by 95 %[29]. In our study we found that vitamin D deficiency was significantly correlated with UVB levels and vitamin D supplement use. We also found that women of Hui ethnicity presented a high risk of vitamin D deficiency. We believe that the novelty of these data lies in their demonstration of high vitamin D deficiency prevalence, which requires public recognition. Additionally, our study results will prove instrumental to public education on vitamin D health.

The study presents some limitations. Several studies have shown that sun exposure is an important determinant of serum 25(OH)D levels[30,31]. However, we were unable to determine the sun exposure area and period for each participant. Instead, we recorded daily outdoor periods and ambient UVB levels to estimate sun exposure levels for each participant. We found that ambient UVB levels affect serum 25(OH)D levels. Dietary Ca intake is another crucial factor that affects vitamin D levels. Some experimental studies have shown that dietary Ca deficiency can lead to secondary vitamin D deficiency[32]. We did not estimate dietary Ca intake levels for each participant.

Another limitation is the high rate of missing data for our participants. We must explain why so many participants were excluded from our analysis. The current study serves as one part of the CNNHS 2010–2013. As part of the CNNHS 2010–2013, we sought to assess vitamin A, vitamin D and microelement levels through serum sample analyses. As serum sample collection is difficult and requires considerable laboratory use, time and funding, we only used 52 % of the serum samples collected for vitamin D testing. The other serum samples were used for vitamin A and microelement tests. However, we ensured that the distributions of sociodemographic characteristics (such as age, gestational age, region strata, parity) were equal for utilized and non-utilized samples in the present study on vitamin D. We believe that there was no selection bias between the samples included and those excluded in our study.

The study was a descriptive cross-sectional analysis. All of the results can only inform us of associations between potential predictive factors and vitamin D deficiency levels. From our data, we cannot assess the true causes of high levels of vitamin D deficiency in China. This may be another limitation of our study. While the study was cross-sectional in nature, the findings suggest that higher UVB levels and vitamin D supplement use may prevent vitamin D deficiency.

Conclusion

Vitamin D deficiency was found to be highly prevalent among pregnant Chinese women, especially among those residing in areas of low ambient UVB levels. More than half of the participants were vitamin D deficient, even in the summer and autumn months. In the autumn months, being of Hui ethnicity and residence in an area of low ambient UVB levels served as independent risk factors of vitamin D deficiency. During the winter months, vitamin D deficiency was correlated with younger age, later gestational age, higher pre-pregnancy BMI and low ambient UVB level. Vitamin D supplementation may help pregnant women maintain higher vitamin D levels during the winter months. Further studies must identify optimal outdoor activity and vitamin D intake levels needed to maintain sufficient vitamin D levels among pregnant Chinese women.

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