The Relationship between Maternal Serum Vitamin D Levels and Infant Neurodevelopment and Anthropometry: A Prospective Observational Study

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Summary This study was designed to determine whether there is a relationship between serum vitamin D levels and neurodevelopment and anthropometry in Chinese infants. A prospective cohort study with 160 women who gave birth to 160 healthy full-term infants and who were followed up for 6 mo was done. It included 80 pregnant women with vitamin D deficiency, and the other 80 pregnant women were enrolled matching the age and delivery method with a 25(OH)D level of more than 50 nmol/L. There was a significant intergroup difference in length, weight or head circumference at birth \( p < 0.05 \). Meanwhile, there was a significant intergroup difference in cognitive development and achievement at 6 mo \( p < 0.001 \). In multivariate analyses, maternal 25(OH)D levels less than 50 nmol/L were independently associated with a higher tendency for a low Bayley mental score (MDI) at 6 mo \( (OR = 2.77, 95\% CI: 1.44–5.35, p = 0.002) \), as well as Bayley motor score (PDI) \( (OR = 2.08, 95\% CI: 1.07–4.04, p = 0.032) \). Thus we observed that maternal vitamin D was associated with infant neurodevelopment and anthropometry.

Key Words vitamin D, infant development, behavior, pregnancy

Vitamin D deficiency is now an increasingly recognized health concern related to its non-classical roles (1) and pregnant women are at high risk for vitamin D deficiency worldwide (2–4). The serum 25-hydroxyvitamin D [25(OH)D], which is considered the best indicator of serum vitamin D level (5), may be affected by ethnicity, vitamin D supplementation, sunlight, season and other factors (6). However, in utero, the vitamin D level of the fetus is entirely dependent on the vitamin D from the mother (7).

Vitamin D deficiency is associated with a variety of poor health outcomes in newborn infants (8, 9). Now the amount of evidence about vitamin D deficiency in early life being associated with poor neurodevelopment and anthropometry outcomes is increasing. Low maternal vitamin D has been confirmed to increase the risk of atypical behavior among adult offspring (10) and has important ramifications for the developing brain including enlarged lateral ventricles, thinner cortex, and more cell proliferation (11). Some studies have found that when vitamin D deficiency was defined as \(< 30 \text{ nmol/L} \), maternal vitamin D deficiency was significantly associated with lower weight for age in the 1st year of life (12, 13). What’s more, maternal vitamin D deficiency has been confirmed to be associated with impaired infant language development in school-aged children (14), as well as being suggested as a possible environmental risk factor for autism spectrum disorder, highlighting the important role of vitamin D in brain development, neuronal function and gene regulation (15–17).

However, the brain undergoes tremendous growth beginning early in gestation and continuing into the postnatal period. We are aware of seven observational studies that assessed the relationship between vitamin D during early (18), mid (14) and late (19–21) pregnancy, and/or cord blood at birth (22, 23) and child cognitive, language and behavioural development with inconsistent results. This may because various parts of the brain develop at different times and they have different windows of vulnerability including prenatally and postnatally, based on the temporal and regional maturation mediated through a multitude of developmental processes (24). Then, there are few studies from Asia. Furthermore, the the number of prospective longitudinal studies with high quality subjects included is limited. So, we aimed to further evaluate the associations of maternal vitamin D status with infant birth outcomes after a 6-mo follow-up in Chinese infants.

Methods and Materials

Study population. This matched prospective cohort study was conducted at the First Affiliated Hospital of...
Wenzhou Medical University between June 2014 and December 2015. One hundred sixty pregnant women over 28 wk gestation were enrolled including 80 pregnant women with vitamin D deficiency, and the other 80 pregnant women were enrolled matching the age, delivery time and delivery method with a 25(OH)D level more than 50 nmol/L. They gave birth to 160 healthy full-term infants who were fed with human breast milk without vitamin D supplementation. We excluded participants who met the following criteria: (i) multiple pregnancy, genetic metabolic diseases, chromosomal abnormalities, thyroid disease, adrenal disease, kidney disease, pregnancy complications; (ii) women who used drugs affecting the liver or kidney function; (iii) infants with asphyxia, congenital malformations and genetic metabolic diseases. This study was approved by the Ethics Committee of Clinical Research in the First Affiliated Hospital of Wenzhou Medical College (ECCR-201375), and it was in compliance with the declaration of Helsinki with all participants providing written informed consent before participating in the study.

Data collection. In this study, a pre-designed question-
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**Results**

A total of 160 women and 160 infants were consecutively recruited in our study. We defined vitamin D <50 nmol/L (n=80) as the observation group and ≥50 nmol/L (n=80) as the control group. The characteristics of subjects are summarized in Table 1. The gestational age of the women was 275 (273–280) d and infant body weight was 3460.83±308.00 g in the observation group, including 51 cases of male infants and 29 cases of female infants. In the control group, the gestational age was 276 (273–280) d and infant body weight was 3346.53±321.03 g. The gestational age, infant sex and feeding pattern showed no significant difference (p>0.05). The maternal 25(OH)D of the control group was significantly higher than that of the observation group (56.78 vs 30.83 nmol/L, p<0.001), as was the cord blood vitamin D level (65.36 vs 40.86 nmol/L, p=0.001). There were significant intergroup differences in length, weight and head circumference at birth as well as the anthropometric increases during the first 6 mo (p<0.05). Meanwhile, mental development (MDI) in the control group at 6 mo was significantly higher than in the observation group (104.00 vs 97.76, p<0.001) as was the motor development (PDI). Otherwise, no difference was found in delivery method, living environment, annual per capital income, vitamin D supplements or calcium supplements of the women between the two groups.

Cord blood 25(OH)D correlated positively with maternal 25(OH)D levels (r=0.866, p<0.001, Fig. 1, Table 2). The correlation between the maternal vitamin D levels and the infantile variables in infants included in the study (n=160).

| Variable                      | Correlation coefficient (r value) | p        |
|-------------------------------|----------------------------------|----------|
| Cord blood vitamin D          | 0.8659                           | <0.001   |
| Anthropometric increases within 6 mo |                                  |          |
| Weight                        | 0.1651                           | 0.037    |
| Length                        | 0.1577                           | 0.046    |
| Head circumference            | 0.2116                           | 0.007    |
| Neural development indicators |                                  |          |
| MDI                           | 0.2124                           | 0.007    |
| PDI                           | 0.1668                           | 0.035    |

**Laboratory tests.** Blood samples were obtained at 28 wk gestation. Serum 25(OH)D levels were measured by an electrochemical luminescence system with COBAS e601 (Roche Diagnostics GmbH, Mannheim, Germany). The intra-assay coefficient of variation was 7–10%. According to the Endocrine Society guidelines, we defined the optimal vitamin D level as >75 nmol/L. Vitamin D insufficiency set at a 25(OH)D level between 50 and 75 nmol/L, while vitamin D deficiency was defined as <50 nmol/L (26).

**Statistical analysis.** We described the demographic characteristics and risk factors with mean and standard deviation (SD) for continuous variables, and for the non-normal distribution data with median and quartiles, as well as with rate for the classified variables. Baseline characteristics were compared in two groups (<50 nmol/L and ≥50 nmol/L) using the Chi-square test and the Student t test or the Kruskal-Wallis test, as appropriate. Spearman rank correlation was used for bivariate correlations and scatter diagrams were made. The influence of serum vitamin D levels on infant neurodevelopment and anthropometry was studied by binary logistic regression analysis, which allows adjustment for mediators (including delivery method, living environment, outdoor activity, calcium supplements, birth weight, birth length, birth BMI, birth head circumference and cord blood vitamin D). The results were expressed as adjusted odds ratios (ORs) with the corresponding 95% confidence intervals (CIs). All statistical analyses were performed with SAS software (version 9.2; SAS Institute, Cary, NC). A p value of less than 0.05 indicated statistical significance.
And the Bayley mental score (MDI) was positively correlated with maternal 25(OH)D levels ($r=0.212$, $p=0.007$, Fig. 2, Table 2) as well as the Bayley motor score (PDI) ($r=0.167$, $p=0.035$, Fig. 3, Table 2). This correlation was not significant between cord blood 25(OH)D and MDI or PDI ($p>0.05$, Table 3).

In the logistic regression analysis, maternal 25(OH)D levels less than 50 nmol/L were independently associated with a higher tendency for a low Bayley mental score (MDI) at 6 mo (OR = 2.77, 95% CI: 1.44–5.35, $p=0.002$), as well as a low Bayley motor score (PDI) (OR = 2.08, 95% CI: 1.07–4.04, $p=0.032$). After adjusting for delivery method, living environment, outdoor activity, calcium supplements, birth weight, birth length, birth BMI, birth head circumference and cord blood vitamin D, the results were still significant ($p<0.05$, Table 4).

**Discussions**

In this prospective longitudinal study of pregnancy maternal vitamin D levels and infant develop outcomes in Chinese women, we found that infants of women with deficient vitamin D had higher risk of lower MDI and PDI at 6 mo, and it can affect the length, weight and head circumference at birth as well as the anthropometric increases during the first 6 mo. Another study found that prenatal lower vitamin D status may be associated with adverse neurodevelopmental outcomes such as autism (27). These results suggested that vitamin D deficiency early in life may be a risk factor for infant neurodevelopment and anthropometry, which indicates that optimal maternal vitamin D might help prevent adverse pediatric outcomes.

Previous reports have shown the associations between maternal vitamin D and language development in early childhood (14, 20, 21, 25). However, the development of the brain starts early in gestation and continues into the postnatal period. During the fetal period, the forebrain cortical structures of the neocortex and hippocampus begin to develop and differentiation and synaptogenesis continue into the postnatal period (23). The peak rate growth of the cerebellum appears in the 7 mo of age (28). For these reasons we chose the infant at birth and followed up for 6 mo as the object of observation, and found optimal maternal vitamin D could help improve the neurodevelopment and anthropometry. At the same time, Zhu et al. found that there was an inverted-U-shaped relation between cord blood vitamin D status and neurocognitive development in 363 mother-infant pairs (23). A study which enrolled 1,040 Australian women suggested that cord blood vitamin D was positively associated with language development in early childhood (29). However, our study did not show a significant association between cord blood vitamin D and MDI or PDI although the maternal serum vitamin D level in pregnancy was positive associated with cord blood vitamin D. It may be explained by the different period functions of vitamin D because the brain starts its development early in pregnancy. We know that 25(OH)D is activated vitamin D in the liver and then 1,25-dihydroxyvitamin D$_3$ (1,25(OH)$_2$D$_3$) is activated from the kidney with a strong physiological activity. The 1,25(OH)$_2$D$_3$ can be transported to the fetal from the mother after activation. However, the liver and kidney of infants are not fully developed with a defective use of serum vitamin D in infants. This study provided clinical evidence about whether vitamin D supplementation to pregnant women should begin in the first three months of pregnancy when the neocortex and hippocampus begin to develop.

| Variable                     | Correlation coefficient ($r$ value) | $p$   |
|------------------------------|------------------------------------|-------|
| Maternal vitamin D           | 0.8659                             | <0.001|
| Anthropometric increases     |                                    |       |
| Weight                       | 0.2161                             | 0.006 |
| Length                       | 0.1700                             | 0.032 |
| Head circumference           | 0.2437                             | 0.002 |
| Neural development indicators|                                    |       |
| MDI                          | 0.1029                             | 0.195 |
| PDI                          | 0.0825                             | 0.300 |

Fig. 2. Spearman rank correlation between maternal vitamin D and MDI.

Fig. 3. Spearman rank correlation between maternal vitamin D and PDI.
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Findings from several studies have shown inconsistent results for associations between maternal vitamin D and measures of birth size (30–32). Some evidence has suggested that compared with women with adequate vitamin D levels, women with deficient vitamin D levels had infants with lower birth weights and a higher risk of being small for their gestational age (SGA) (13). An observational study by Morley et al. found low maternal 25(OH)D in late pregnancy is associated with reduced intrauterine long bone growth and slightly shorter gestation (32). As also shown in our study, maternal vitamin D status can affect the length, weight and head circumference at birth as well as the anthropometric increases during the first 6 mo, and the relationship was still significant between the cord blood vitamin D levels and anthropometric increases. Studies showed that infants born to mothers who use vitamin D supplements had significantly higher cord blood 25(OH)D levels than infants born to who don’t use vitamin D supplements, and this correlation between maternal and infant serum vitamin D was maintained even 4 mo after birth (33). However, Brooke et al. found that birth weights of children born at term did not differ between Asian women in the vitamin D-supplemented group and mothers in the non-supplemented group during pregnancy (30). By contrast, in the present study, the birth weight, length and head circumference in the observation group were significantly larger than those in the control group. This result may be influenced by a variety of factors such as the grouping by maternal vitamin D levels as well as the cross-sectional design of the study. Thus, randomized controlled trials of vitamin D supplementation in pregnant women are warranted to determine whether this association is causal and reversible.

Vitamin D may influence infant neurodevelopment and anthropometry via different biological mechanisms. Vitamin D impacts on bone development during fetal growth may be sustained to affect later infant stature (34, 35). Vitamin D or calciferol is essential for Ca\(^{2+}\) homeostasis and bone mineralisation, and therefore vital to fetal and infant development (36). Otherwise, vitamin D influences originating during the fetal period include extra-skeletal pathways involving fetal programming and gene expression (37, 38). Additional possible mechanisms are that vitamin D may also be important in fetal brain development by supporting neuronal differentiation and maturation, synthesis of neurotransmitters, and regulation of damaging reactive oxygen species, among other functions based on the results of animal studies (10, 39–42).

There are several limitations in our study. Firstly, it was impossible to prove a causal relationship due to the cross-sectional nature of our design. Secondly, the small sample may affect the stability of the results. Despite these limitations, to the best of our knowledge, we observed meaningful relationships between infant development and maternal vitamin D. Future studies that include important covariates like parental IQ and large sample sizes will help clarify conflicting results reported to date among studies.

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Author contributions
The authors were responsible for the following tasks: Mei-Zhu Chi drafted the manuscript; Lin Zhu, Zeng-Li Zhang, Fang-Fang Jin, Hao-Run Shao, Jia-Yin Zheng, Chao Wu and Guang-Qiong Hu conducted the search and summarised the data. All authors contributed to the data analysis, verification, and writing and revising of the manuscript.

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