Season of birth, neonatal vitamin D status, and cardiovascular disease risk at 35 y of age: a cohort study from Sweden\textsuperscript{1–4}

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ABSTRACT

Background: Lower vitamin D status during gestation may be associated with cardiovascular disease risk later in life. No studies have assessed this hypothesis with a follow-up time reaching beyond childhood.

Objective: The objective was to assess the link between season of birth, neonatal 25-hydroxyvitamin D\textsubscript{3} [25(OH)D\textsubscript{3}] status, and adult cardiovascular disease risk.

Design: Markers of cardiovascular and metabolic disease risk were measured in 284 subjects aged 35 y, born either at the end of the winter or at the end of the summer of 1975. In 275 of these 284 subjects, concentrations of neonatal 25(OH)D\textsubscript{3} were measured in dried blood samples by using a highly sensitive liquid chromatography–tandem mass spectroscopy method.

Results: Subjects born after the winter had lower neonatal 25(OH)D\textsubscript{3} concentrations than did those born after the summer (31.5 compared with 48.5 nmol/L; \(P < 0.001\)). In regression analyses adjusted for sex, season of birth, postnatal age at neonatal sample collection, preterm birth, maternal age, education, smoking, fish consumption per week, exercise per week, and current 25-hydroxyvitamin D, higher neonatal 25(OH)D\textsubscript{3} (per 50 nmol/L) was associated with 25.8% (95% CI: 0.0%, 58.4%) higher triglycerides, and 4.64 (95% CI: 1.93, 7.36) mmol/L higher serum cholesterol in women. Neonatal 25(OH)D\textsubscript{3} (per 1 nmol/L) was directly associated with risk of adult overweight (OR: 1.03; 95% CI: 1.01, 1.05) and with adult obesity in women (OR: 1.09; 95% CI: 1.01, 1.17). Neonatal 25(OH)D\textsubscript{3} was not associated with adult aortic pulse wave velocity, blood pressure, fasting glucose, HDL, LDL, or C-reactive protein. Season of birth was not associated with any of the adult outcomes.

Conclusions: Higher neonatal 25(OH)D\textsubscript{3} was associated with higher fasting insulin, triglycerides, and cholesterol (in women) concentrations and with a higher risk of overweight at 35 y of age but not with other adult cardiovascular disease risk factors. \textit{Am J Clin Nutr} 2014;99:472–8.

INTRODUCTION

A high prevalence of vitamin D deficiency in women of childbearing age has been observed in different parts of the world (1–5). This constitutes a growing public health concern because low vitamin D status—besides its role in bone disease—has been shown to be associated with a higher risk of cardiovascular disease (6, 7), impaired glucose tolerance (7), and the metabolic syndrome (8). In addition to the potential health effects for the pregnant woman herself, it has been hypothesized that vitamin D status during gestation influences later cardiovascular and metabolic health in the offspring (9, 10). In an Indian population, vitamin D deficiency in the third trimester of the mothers was linked to insulin resistance in their 9.5-y-old children (11). In the United Kingdom, lower maternal vitamin D status at 34 wk of gestation was associated with greater offspring fat mass at 6 y of age (12). To date, the relation between early-life vitamin D status and later cardiovascular and metabolic health has been incompletely examined, and no studies with a follow-up time reaching beyond childhood have been conducted.

Apart from small contributions from diet and supplements, exposure of skin to sunlight determines the body’s vitamin D status, measured as serum concentrations of the metabolite 25-hydroxyvitamin D [25(OH)D]\textsuperscript{5} (13). Depending on latitude, sunlight hours can differ substantially between seasons, and 25(OH)D concentrations in populations are lower in the winter than in the summer (14–16).

In this study, we investigated how vitamin D status at the time of birth—measured in stored neonatal blood samples—related to cardiovascular disease and metabolic risk markers in a cohort of 35-y-old Swedes, born either at the end of the winter or at the end of the summer. We hypothesized that low neonatal vitamin D status resulting from birth at the end of the winter would be associated with an adverse cardiovascular disease and metabolic risk profile in adulthood.

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\textsuperscript{5}Abbreviations used: BP, blood pressure; CRP, C-reactive protein; PKU, phenylketonuria; 25(OH)D\textsubscript{2}, 25-hydroxyvitamin D\textsubscript{2}; 25(OH)D\textsubscript{3}, 25-hydroxyvitamin D\textsubscript{3}; 25(OH)D\textsubscript{5}, 25-hydroxyvitamin D\textsubscript{5}.

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SUBJECTS AND METHODS

Study cohort

The Swedish Phenylketonuria (PKU) Register comprises dried blood samples from screening for rare metabolic disorders of all infants born in Sweden from 1975 onward—a collection of ~4 million individual samples. The samples are stored in darkness.

Starting from birth dates in February (winter) and September (summer), subjects born at hospitals in the Stockholm region (latitude 59° north) in 1975 were identified from the PKU Register. Subjects were invited to participate in the study in the order that they appeared in the registry’s data storage system. Birth dates ranged from 9 February to 7 March in the winter group and from 14 September to 29 September in the summer group. In total, 1305 individuals were considered for participation in the study; of these, 284 participated (Figure 1). Response rates were not influenced by sex or season of birth; of those who did not participate, 513 (50.2%) were women and 498 (48.8%) were born in the winter. The study was approved by the regional ethical review board in Stockholm (2010/739–31/3). Written consent was obtained from all participants.

Clinical examination

Study participants were clinically examined at Karolinska University Hospital in Stockholm between 5 July and 30 August 2010. Information about subjects’ birth date, preterm birth (birth before 37th week of gestation), and postnatal age at blood sampling for metabolic screening was retrieved from the PKU Register. At enrollment in the study, participants were asked about the origin of their parents [Nordic (Sweden, Finland, Norway, Iceland, Denmark) or non-Nordic], level of education (categorized as primary, secondary, or higher education), smoking, previously diagnosed diabetes mellitus or hypertension, current medications, hours of physical activity per week, weekly fish consumption, and family history of diabetes mellitus.

On the day of examination, participants were asked to refrain from smoking, consumption of Swedish snuff (moist powder tobacco), and intake of coffee, vitamin C, or cyclooxygenase inhibitors. All measurements were performed according to predefined standard operating procedures. Aortic pulse wave velocity was measured by using an AtCor Medical SphygmoCor Pulse Wave Velocity System and SphygmoCor Software according to specified procedures. The proximal site for the aortic pulse wave velocity measurement was the carotid artery, and the distal site was the femoral artery. Participants were rested (sat for 5 min) before blood pressure (BP) was measured. Two readings were taken 3 min apart in the left and right arms, respectively, by using a validated automated oscillometric device (Omron M6 HEM-7001-E; Omron Corporation). If the diastolic or systolic BP measurements differed by >5 mm Hg between measurements, the subject rested for 5 min and then a third reading in the left arm was taken. The lowest diastolic and systolic BP values were defined as the subject’s BP. Participants with a systolic BP ≥140 mm Hg or a diastolic BP ≥90 mm Hg, or who were pharmacologically treated for hypertension, were categorized as hypertensive. Prehypertension was defined as 140 mm Hg > systolic BP ≥120 mm Hg or 90 mm Hg > diastolic BP ≥80 mm Hg and no pharmacologic treatment of hypertension. Height and weight were measured by using a measuring tape and digital scales. BMI was calculated as kg/m². Overweight was defined as a BMI ≥25 and obesity as a BMI ≥30. Fasting blood glucose, blood lipids, C-reactive protein (CRP), and plasma 25(OH)D and insulin concentrations were measured at an accredited and standardized (International Organization for Standardization 1518, Geneva, Switzerland) clinical chemistry laboratory at Karolinska University Hospital. Patients had been instructed to fast for ≥8 h before blood sampling.

A fasting plasma glucose concentration from 5.6 to 6.9 mmol/L was defined as impaired fasting glucose according to the American Diabetes Association criteria. Subjects with a fasting plasma glucose ≥7 mmol/L or who were pharmacologically treated for diabetes mellitus were categorized as diabetic.

Measurement of neonatal vitamin D status

Two 3.2-mm punches were obtained from the dried neonatal blood spots of 275 of the 284 participants. Nine of the samples could not be found in the PKU Register. 25(OH)D can exist in 2 forms: 25-hydroxyvitamin D₃ [25(OH)D₃] and 25-hydroxyvitamin D₂ [25(OH)D₂]; the latter can be obtained only from dietary sources and supplements. Both 25(OH)D₃ and 25(OH)D₂ were measured in the dried blood spots by using a highly sensitive liquid chromatography–tandem mass spectroscopy assay (17) performed at a laboratory included in the Vitamin D External Quality Assessment Scheme (18). 25(OH)D₂ was detected only in 29 samples (11%), at concentrations that were only just above the lowest concentration of assay quantification: 7.57 ± 4.35 (mean ± SD) nmol/L. Because of uncertainties in the detecting thresholds for 25(OH)D₂, only 25(OH)D₃ concentrations were used in the analyses in this study. The inter- and intraassay CVs were 12.7% and 9%, respectively—similar to that reported in the article describing the assay (17).

On the basis of archived samples from Australia and Denmark, the assay has been shown to reliably detect seasonal (within-year)
differences in 25(OH)D3 concentrations, and the measurements have been shown to correlate strongly with neonatal cord blood concentrations \((r = 0.86)\) (19). The method has been used on dried blood spots stored for >20 y (20) and assessed with respect to punch position, spot volume, and paper type (21). In this study, the punches were taken from the outer part of the dried blood spots.  

25(OH)D3 and 25(OH)D2 are highly protein-bound steroids that are completely excluded from erythrocytes (21). Therefore, to make results comparable with existing studies, 25(OH)D3 and 25(OH)D2 concentrations were reported as adjusted serum concentrations. This required a correction based on a standard neonatal capillary hematocrit of 0.61 (22).  

The dried blood spots in this study—stored for 37 y between collection and analysis—may represent some of the oldest clinical dried blood spot samples examined for 25(OH)D2 to date. A pilot study was therefore conducted on a random small sample of de-identified spots collected 30 y apart \((n = 31; 6 \text{ samples from March 1980, 5 \text{ samples from September 1980, 10 \text{ samples from March 2010, and 10 \text{ samples from September 2011}}})\) to assess the feasibility of this study. Although seasonality in the 25(OH)D3 concentrations was preserved in both archived and contemporary spots (significant seasonal differences only for contemporary spots), a substantial reduction in 25(OH)D3 was seen in the archived spots \((\text{mean } \pm \text{ SD: 28.1 } \pm 11.4 \text{ compared with } 58.6 \pm 26.2 \text{ nmol/L}; P = 0.001)\), which presumably indicates that sample degradation had occurred. We did not find a significant interaction between month and year of sampling that potentially would have indicated proportional differences in degradation between samples with high and low 25(OH)D3 concentrations. The potential degradation of 25(OH)D3 during storage time is a major reason why neonatal 25(OH)D3 was not analyzed on the basis of clinical cutoffs (vitamin D insufficiency or deficiency) but as a continuous variable as described below. The investigators were blind to the season of birth of the participants during collection of dried blood, 25(OH)D3 measurement, and clinical examination.

### Statistical analyses

The distributions of serum concentrations of fasting insulin, triglycerides, and CRP were skewed, and these data were log-transformed before analysis. Data are presented as means \((\pm \text{SDs})\) for normally distributed continuous variables, geometric means, and 95% CIs for variables with a skewed distribution and as proportions (%) for categorical variables. We assessed differences in the adult cardiovascular outcomes by season of birth and by neonatal 25(OH)D3 concentration in univariate and adjusted models. Adjusted models for assessing the relation between season of birth and adult cardiovascular outcomes included sex, preterm birth, maternal age at delivery, participants’ education, exercise, fish consumption, smoking, and 25(OH)D at follow-up. Adjusted models assessing the relation between neonatal 25(OH)D3 and adult cardiovascular outcomes also included season of birth and postnatal age at neonatal blood sampling. Adjusted models including plasma glucose also included family history of diabetes. Because the cardiovascular disease risk markers assessed in this study were considered likely to be associated with one another, no adjustment for multiple comparisons was made.

All of the 25(OH)D measurements at follow-up were performed during the summer (5 July to 30 August). In a regression model adjusted for sex, no association was found between assessment day (number of days after the July 5) and current 25(OH)D concentration (data not shown). Therefore, the date of 25(OH)D measurement at follow-up was not included in the adjusted analyses. Because all of the participants were of Nordic origin, no adjustment was made for ancestry.

Group differences by season of birth were assessed in a univariate analysis by using the \(t\) test for continuous variables, and Fisher’s exact or a chi-square test was used for categorical variables. In addition, the 95% CIs were calculated for the differences between the season of birth groups with regard to the difference between means or proportions (percentages). Continuous outcomes were compared between season of birth groups by using the adjusted multiple regressions. Comparisons between season of birth groups with regard to categorical outcomes variables, adjusted for confounding factors, was made by using logistic regression analyses.

Spearman correlation coefficient (univariate) and adjusted multiple regression analyses were used to assess the relation between neonatal 25(OH)D concentration and each of the cardiovascular disease risk outcomes at 35 y of age. Because it was considered likely that BMI would be associated with the cardiovascular disease risk markers assessed in this study, we also performed adjusted analyses controlling for BMI.

Differences in associations between women and men with regard to each of the cardiovascular disease risk outcomes at 35 y of age were examined by creating interaction variables with sex and neonatal 25(OH)D3 concentration. Regression analyses were performed with each of the cardiovascular disease outcomes as dependent variables and with sex, neonatal 25(OH)D3 concentration, and the interaction variable as independent variables. For cardiovascular disease risk outcomes showing significant interaction effects between sex and neonatal 25(OH)D3 concentrations, sex-specific analyses [correlation coefficient for neonatal 25(OH)D3 concentration and the outcome and adjusted multiple regression analyses] were conducted.

The relation between neonatal 25(OH)D3 concentration and risk of prehypertension/hypertension, overweight, obesity, and impaired fasting glucose/diabetes mellitus were assessed by using logistic regression modeling, estimating ORs and their 95% CIs in both univariate- and multivariate-adjusted models. Subjects with missing data on outcomes ranged between 0 (0%) for BP and 24 (9%) for insulin and were not included in the analyses. The analyses were performed by using STATA/IC 11.0 (Stata Corp LP). All tests were 2-sided, and \(P < 0.05\) was regarded as statistically significant.

### RESULTS

In total, 138 subjects were born in September and 146 were born in February/March 1975. Maternal age at delivery was significantly higher for the group born in September. Other cohort characteristics were equally distributed within the groups (Table 1).

### Outcomes by season of birth

Neonatal 25(OH)D3 concentrations were significantly lower in the group born in February/March, whereas 25(OH)D concentrations at
adult follow-up did not differ between the 2 groups (Table 2).
No significant differences were found between the 2 groups in any of the cardiovascular disease risk markers (Table 3), and adjustment for potential confounders in multiple regression analyses did not affect the results significantly (data not shown).

Season of birth was not associated with risk of prehypertension/hypertension, overweight, obesity, or impaired fasting glucose/diabetes mellitus (Table 3).

Outcomes by neonatal vitamin D

Correlation coefficients and multiple regression analyses that assessed the relation between neonatal 25(OH)D3 concentration and adult cardiovascular disease risk outcomes are shown in Table 4. In adjusted multiple regression analyses, neonatal 25(OH)D3 concentration was associated with weight, fasting insulin (β corresponding to a 25.8% higher concentration per 50-nmol/L higher neonatal 25(OH)D3; 95% CI: 1.0%, 58.4%), and triglycerides (β corresponding to 29.6%; 95% CI: 5.1%, 58.4%) at 35 y of age. The associations between neonatal 25(OH)D3 and adult triglycerides and insulin concentrations were attenuated when adjusted for BMI.

A significant interaction was found between sex and neonatal 25(OH)D3 against adult height, BMI, serum cholesterol, and HDL. Height and HDL increased at a higher rate per 1-nmol/L increase in neonatal 25(OH)D3 concentration in men (β for interaction variable for height: 0.109; 95% CI: 0.011, 0.207) and for HDL (0.109; 0.011, 0.207). BMI and cholesterol increased at higher rates per 1-nmol/L increase in neonatal 25(OH)D3 concentration in women than in men (β for interaction variable for BMI: −0.07; 95% CI: −0.131, −0.0136) and for cholesterol (−0.070; −0.107, −0.034).

In the sex-specific analyses, a higher neonatal 25(OH)D3 concentration was associated with higher adult BMI in women but not in men. Neonatal 25(OH)D3 was associated with adult cholesterol concentrations in women, and the association remained after adjustment for BMI. Neonatal 25(OH)D3 was not associated with adult serum cholesterol in men. The association between neonatal 25(OH)D3 and height as well as HDL was not significant in either sex (Table 4).

In the logistic regression analyses, neonatal 25(OH)D3 concentration was associated with the risk of being overweight in adulthood in crude and adjusted analyses, and the association persisted in adjusted models for both men and women (Table 5). In women, but not in men, neonatal 25(OH)D3 was associated with the risk of being obese in adulthood. No associations could be seen between neonatal 25(OH)D3 concentration and prehypertension/hypertension or impaired fasting glucose/diabetes mellitus (Table 5).

### Table 2

Neonatal 25(OH)D3 in 1975, postnatal age at sample collection, and 25(OH)D at follow-up in 2010 (at age 35 y) by season of birth

<table>
<thead>
<tr>
<th></th>
<th>Born in February/March 1975 (n = 138)</th>
<th>Born in September 1975 (n = 146)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>Value</td>
</tr>
<tr>
<td>Neonatal 25(OH)D3 (nmol/L)</td>
<td>133</td>
<td>31.5 ± 12.4</td>
</tr>
<tr>
<td>Postnatal age at sample collection (d)</td>
<td>132</td>
<td>4.9 ± 1.3</td>
</tr>
<tr>
<td>25(OH)D at follow-up (nmol/L)</td>
<td>128</td>
<td>78.1 ± 25.4</td>
</tr>
</tbody>
</table>

2 Differences in groups were assessed with a t test.
3 Not translatable to recommended neonatal vitamin D status because of possible degradation during 35-y storage time.
4 Mean ± SD (all such values).
higher concentrations of neonatal 25(OH)D3 possibly associated with the number of outcomes assessed. However, our results imply that vitamin status was associated with a higher percentage of body fat and later fat mass in newborns. At later follow-up at 6 y of age, the direction of this relation had changed so that lower maternal vitamin D status was associated with a higher fat mass in the offspring (12). Another British study showed no association between maternal vitamin D during pregnancy and BMI at the age of 10 y (23). Given the varying findings from different populations and ages in this and other studies, further investigations of the links between early-life vitamin D and later body size and composition are warranted.

The lack of an association between neonatal 25(OH)D3 status and cardiovascular outcomes—including aortic pulse wave velocity and BP—was in broad accordance with studies in children from India (11) and the United Kingdom (23). However, in contrast with the positive association we found between neonatal 25(OH)D3 and adult fasting serum insulin concentration in our study, 9.5-y-old Indian children whose mothers had been vitamin D–deficient during pregnancy and BMI at the age of 10 y (23). Given the varying findings from different populations and ages in this and other studies, further investigations of the links between early-life vitamin D and later body size and composition are warranted.

The findings of this study should be interpreted with consideration of the number of outcomes assessed. However, our results imply that higher concentrations of neonatal 25(OH)D3 are possibly associated with an elevated risk of becoming overweight in adult life. There have been previous reports of age and population-specific associations between early-life vitamin D status and later body fat mass. In contrast with our findings, vitamin D deficiency during pregnancy in Indian mothers was associated with a higher percentage of body fat and a lower percentage of fat-free mass in their 5-y-old sons but not in their daughters (11). However, as in our study, BMI was higher in Indian children whose mothers were not vitamin D-deficient during pregnancy. When the children had reached 9.5 y of age, these associations were no longer seen (11). In a study from the United Kingdom, higher maternal vitamin D in late pregnancy was associated with higher fat mass in newborns. At later follow-up at 6 y of age, the direction of this relation had changed so that lower maternal vitamin D status was associated with a higher fat mass in the offspring (12). Another British study showed no association between maternal vitamin D status and BMI at the age of 10 y (23). Given the varying findings from different populations and ages in this and other studies, further investigations of the links between early-life vitamin D and later body size and composition are warranted.

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between the mother and the child. A comprehensive test battery of clinically relevant outcome measures was chosen to—alone or in combination—reflect future risk of cardiovascular events.

Limitations include a lack of data on body composition at follow-up, birth weight, and maternal characteristics, including BMI and vitamin D supplementation. Albeit long follow-up times, compared with those in previous studies, our participants were still young and had not reached an age at which cardiovascular disease and diabetes become more prevalent. Because of potential degradation during storage, neonatal 25(OH)D 3 status could not be stratified by clinically relevant cutoffs. Because the study cohort consisted of subjects born in Stockholm at the end of either the winter or the summer, the relation between neonatal vitamin D and later cardiovascular health could not be studied of either the winter or the summer, the relation between neonatal 25(OH)D 3 concentration and cardiovascular disease risk markers at age 35 y could not be stratified by clinically relevant cutoffs. Because the study cohort consisted of subjects born in Stockholm at the end of either the winter or the summer, the relation between neonatal vitamin D and later cardiovascular health could not be studied of either the winter or the summer, the relation between neonatal vitamin D and later cardiovascular health could not be studied of either the winter or the summer, the relation between neonatal vitamin D and later cardiovascular health could not be studied.
TABLE 5
ORs and 95% CIs for prehypertension/hypertension, overweight, obesity, and impaired fasting glucose/diabetes mellitus at age 35 y by neonatal 25(OH)D3 in nmol/L.

<table>
<thead>
<tr>
<th></th>
<th>n</th>
<th>OR (95% CI)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prehypertension/hypertension</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crude</td>
<td>275</td>
<td>1.01 (1.00, 1.02)</td>
<td>0.152</td>
</tr>
<tr>
<td>Adjusted</td>
<td>240</td>
<td>1.01 (0.99, 1.03)</td>
<td>0.286</td>
</tr>
<tr>
<td>Adjusted, with BMI</td>
<td>239</td>
<td>1.01 (0.99, 1.03)</td>
<td>0.499</td>
</tr>
<tr>
<td>Overweight</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Women, crude</td>
<td>120</td>
<td>1.03 (1.01, 1.06)</td>
<td>0.007</td>
</tr>
<tr>
<td>Women, adjusted</td>
<td>109</td>
<td>1.07 (1.02, 1.11)</td>
<td>0.002</td>
</tr>
<tr>
<td>Men, crude</td>
<td>154</td>
<td>1.02 (1.00, 1.03)</td>
<td>0.059</td>
</tr>
<tr>
<td>Men, adjusted</td>
<td>150</td>
<td>1.03 (1.00, 1.05)</td>
<td>0.019</td>
</tr>
<tr>
<td>Obesity [n (%)]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Women, crude</td>
<td>120</td>
<td>1.06 (1.02, 1.09)</td>
<td>0.003</td>
</tr>
<tr>
<td>Women, adjusted</td>
<td>109</td>
<td>1.09 (1.02, 1.17)</td>
<td>0.014</td>
</tr>
<tr>
<td>Men, crude</td>
<td>154</td>
<td>0.99 (0.97, 1.01)</td>
<td>0.467</td>
</tr>
<tr>
<td>Men, adjusted</td>
<td>130</td>
<td>1.01 (0.98, 1.05)</td>
<td>0.399</td>
</tr>
<tr>
<td>Impaired fasting glucose/diabetes mellitus</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crude</td>
<td>254</td>
<td>1.00 (0.98, 1.02)</td>
<td>0.805</td>
</tr>
<tr>
<td>Adjusted</td>
<td>237</td>
<td>0.99 (0.97, 1.02)</td>
<td>0.686</td>
</tr>
<tr>
<td>Adjusted, with BMI</td>
<td>236</td>
<td>0.99 (0.96, 1.02)</td>
<td>0.551</td>
</tr>
</tbody>
</table>

1 25(OH)D, 25-hydroxyvitamin D; 25(OH)D3, 25-hydroxyvitamin D3. P < 0.05 indicates a significant difference.
2 Logistic regression analysis used, per 1-nmol/L higher 25(OH)D concentration.
3 Adjusted for sex, postnatal age at sample collection, season of birth, preterm birth, maternal age, education, smoking, fish consumption per week, exercise per week, and current 25(OH)D.
4 Adjusted for sex, postnatal age at sample collection, season of birth, preterm birth, maternal age, education, smoking, fish consumption per week, exercise per week, current 25(OH)D, and BMI.
5 Sex-specific analyses were conducted because there was a significant interaction between sex and neonatal 25(OH)D against BMI.
6 Adjusted for sex, postnatal age at sample collection, season of birth, preterm birth, maternal age, education, smoking, fish consumption per week, exercise per week, current 25(OH)D, and family history of diabetes.
7 Adjusted for sex, postnatal age at sample collection, season of birth, preterm birth, maternal age, education, smoking, fish consumption per week, exercise per week, current 25(OH)D, family history of diabetes, and BMI.

REFERENCES