Original Contribution

The Vitamin D Hypothesis Revisited: Race-Based Disparities in Birth Outcomes in the United States and Ultraviolet Light Availability

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Skin color has been proposed to contribute to race-based health disparities in the United States because of differences in ultraviolet (UV) light–induced vitamin D synthesis. The prediction of this hypothesis, herein named the UVD hypothesis, is that racial disparities in health outcomes are correlated with UV light availability. This paper investigates whether UV light availability is associated with disparities in the rates of low birth weight (LBW) and preterm birth (PTB) between whites and blacks, because these outcomes are thought to be influenced by vitamin D status and to shape disease risk in later life. Data on LBW and PTB from 2007 (n = 2,825,620 births) were compared with data on UV light exposure across the United States. Contrary to the predictions of the UVD hypothesis, LBW and PTB rate disparities were greatest in states with the highest UV light exposure. Notably, income inequality was positively and significantly related to LBW and PTB disparities, even after controlling for UV light availability. The results of this analysis demonstrate that there is a significant environmental gradient in racial disparities in birth outcomes in the United States, but other social or environmental factors associated with living in the southern United States are likely stronger contributors to disparities in birth outcomes than UV light–induced vitamin D status.

health disparities; low birth weight; preterm birth; skin color

Abbreviations: LBW, low birth weight; PTB, preterm birth; SE, standard error; UV, ultraviolet.

In the United States, there are disparities in health between whites and blacks for a broad spectrum of disorders, ranging from adverse birth outcomes to cardiovascular disease (1–5). Substantial research demonstrates that differences in socioeconomic status and experiences of discrimination contribute to these disparities (6–11). For example, poverty and racial discrimination have been associated with birth weight, risk of depression, and physical health among blacks (8, 12, 13). Despite these consistent associations, there is still an interest in identifying additional environmental or genetic factors that contribute to racial differences in health in order to eliminate these disparities.

One recently proposed hypothesis is that differences in vitamin D synthesis as a result of skin color variation may contribute to racial disparity in health outcomes (14–18). This hypothesis is based on several observations. First, vitamin D insufficiency has been associated with higher risks of pregnancy complications, bone disorders, cardiovascular disease, diabetes, and several types of internal cancers, many of which differentially affect blacks (19, 20). Second, darker skin is less capable of producing vitamin D given the same ultraviolet (UV) light exposure because more melanin leads to decreased efficiency of provitamin D3 synthesis (21). Because approximately 90% of an individual’s vitamin D requirements are provided through UV light–induced photosynthesis (22), it has been suggested that natural variation in skin color may underlie some of the race-based variance in health outcomes affected by vitamin D status. Although provocative, many of the specific predictions of this hypothesis (herein named the UVD hypothesis) have yet to be tested.

Of the different health outcomes that are commonly discussed in the context of the UVD hypothesis, adverse birth outcomes are of particular interest. Vitamin D intake and levels in serum during pregnancy have been associated with offspring birth size (23–25) and length of gestation (26) and are believed to influence birth outcomes through interactions...
with placental sex steroid production (27), calcium homeostasis (28), inflammation (26), and changes in glucose/insulin metabolism (29). Notably, recent research suggests that being born small increases the risk of developing chronic disease in adulthood (30, 31). Because blacks have much higher rates of low birth weight (LBW) and preterm birth (PTB) than whites (32), this disparity may partially explain why these groups also have higher rates of cardiovascular disease in later life (33).

The purpose of this study is to test the UVD hypothesis, which suggests that variation in UV light–induced vitamin D synthesis is an important contributor to disparities in birth outcomes between whites and blacks in the United States. If the UVD hypothesis is correct, then we would predict that higher UV light exposure would be associated with lower rates of adverse birth outcomes overall, as well as lower rates of disparity in these outcomes between whites and blacks. UV light availability as a measure is strongly correlated with vitamin D levels and has been associated with several health disorders (34–39). For example, UV light availability has been inversely associated with lung cancer risk in 111 countries (39), as well as the risk of death from cardiovascular disease, respiratory disease, and stroke in the United States (40). We collected data on UV light exposure by US state and compared these data with the incidence of LBW and PTB among white and black women across the United States. Other economic and health variables previously associated with adverse birth outcomes, such as income inequality, were included to assess potential confounding. Importantly, the results of this analysis do not address whether UV light exposure has any influence on birth outcomes; instead, they assess whether variation in UV light–induced vitamin D synthesis is a significant contributor to racial disparities in birth outcomes in the United States.

METHODS

Data collection

Data for average UV light exposure (based on the UV index, defined below) were collected for Washington, DC, and all states except geographical outliers, Alaska and Hawaii, as well as Connecticut, from which there were no data available. This yielded a total sample size of 48 states or territories. We used UV index annual time series data obtained from the National Oceanic and Atmospheric Administration National Weather Service web site (41). The UV index is a forecast of the amount of UV radiation expected to reach the earth’s surface when the sun is highest in the sky (at solar noon). This variable is therefore influenced by the sun’s elevation in the sky, the amount of ozone in the stratosphere, and the amount of cloud cover. The UV index ranges from 0 at night to 16 in the tropics at high elevations when there is no cloud cover. A mean annual UV index value was calculated for each state by averaging daily values across the year 2007. This value was based on 1 city for the majority of states, but in states where more than 1 index was available (2 were available for California, New York, Pennsylvania, and Texas; 3 were available for Florida), data from the multiple cities were averaged to calculate the state value. Data on average temperature, number of clear days in 2007, and latitude where the UV index data were collected were extracted from the National Oceanic and Atmospheric Administration web site (42) using the same method as was used to calculate the UV index values.

Birth outcome data were collected from the Centers for Disease Control and Prevention web site using publicly available data for all births in 2007 (43). Data were collected for all singleton births to non-Hispanic white mothers (n = 2,222,142) and non-Hispanic black mothers (n = 603,478). The following 2 birth outcome measures were assessed: incidence of LBW (<2,500 g) and incidence of PTB (births occurring before 37 weeks’ gestation). Although the majority of infants born preterm will also be LBW, these 2 outcomes were analyzed separately because they are both commonly investigated and reflect slight differences in etiology and long-term health consequences (44, 45). Gestational age was calculated using last menstrual period data. PTB analysis was limited to noninduced births in order to assess only spontaneous PTB (46).

State-level economic and health variables were included to assess potential confounding. This included data on the percent of the population living in poverty and on health care spending per capita (from the Kaiser Family Foundation State Health Facts (47, 48) for the year 2009. The Gini coefficient, a measure of income inequality, was recorded for each state from US Census Bureau data for the year 2007 (49). Data for each state on smoking prevalence, infant mortality rate, and prevalence of overweight and obesity were collected from the Centers for Disease Control and Prevention for the year 2007 (43, 50, 51).

Statistical analysis

All statistical analyses were conducted using Stata, version 10.0, software (StataCorp LP, College Station, Texas). A univariate analysis was conducted on all variables to assess normality. Data that were not normally distributed (e.g., population density) were then log transformed. After stratification of states by high and low latitudes, 2-way t tests were used to compare economic, environmental, and health variables. These same variables were then compared with UV light and birth outcome measures to assess potential relationships. Linear regression was used to test the study hypotheses. The first set of models evaluated the relationship between UV light availability and racial disparity in LBW incidence (percent non-Hispanic black LBW minus percent non-Hispanic white LBW), as well as the relationship between UV light availability and absolute rates of LBW for both non-Hispanic black and non-Hispanic white women. The second set of models evaluated the relationship between UV light availability and disparities in PTB, as well as absolute rates of PTB for both non-Hispanic black and non-Hispanic white women. Economic and health variables that were correlated with birth outcomes (Gini coefficient, poverty rate, and obesity for LBW; Gini coefficient for PTB) were added to the model to control for potential confounding. Variables were included in the final model only if they were significant predictors of the birth outcome under consideration in order to
maximize model fit (52). The assumption of homoscedasticity was assessed using the Stata estat hettest command. The α level was set to 0.05.

RESULTS

In 2007, 11.8% of all singleton births to black mothers were LBW, compared with 5.3% of births to white mothers. A total of 17.6% of black women gave birth preterm (not medically induced) compared with 10.8% of white women. The racial disparity in the incidence rates of LBW and PTB was significantly higher in southern states, largely driven by higher rates of adverse birth outcomes among black women in the South (for blacks, LBW = 12.1% in southern states vs. 9.3% in northern states, \( P < 0.0001 \); for whites, LBW = 5.8% in southern states vs. 4.9% in northern states, \( P = 0.002 \); for blacks, PTB = 18.4% in southern states vs. 14.7% in northern states, \( P < 0.0001 \); for whites, PTB = 11.9% in southern states vs. 9.9% in northern states, \( P = 0.001 \)) (Figure 1). There was a significant environmental gradient in population size, with a higher number of women giving birth in southern states overall (\( P < 0.001 \)).

States with greater income inequality had greater disparity in birth outcomes across the UV light spectrum (Figure 2). In addition, smoking, obesity, Gini coefficient, poverty rate, UV index value, average temperature, and number of clear days in 2007 were all significantly higher in states at lower latitudes, whereas health care spending was significantly lower in those states (Table 1). Of the economic, health, and environmental variables, poverty rate, Gini coefficient, latitude, mean annual temperature, and obesity were all significantly correlated with disparity in the rates of LBW (Table 2). Gini coefficient, latitude, and temperature were all significantly correlated with disparity in the rates of PTB.

The racial disparity in LBW was greater among women living in areas with higher UV light exposure and greater income inequality (for higher UV light exposure, \( \beta = 0.007 \) (standard error (SE), 0.002), \( P = 0.002 \); for Gini coefficient, \( \beta = 0.34 \) (SE, 0.11), \( P = 0.003 \); adjusted \( R^2 = 0.37 \)). In this model, a 1-point increase in UV score was associated with

![Figure 1. Variation in A) poverty rates, B) ultraviolet (UV) light exposure, and C) preterm birth (PTB) disparity across the United States. Poverty rate data from the Kaiser Family Foundation State Facts, 2009 (47); UV light exposure data from the National Oceanic and Atmospheric Administration, 2007 (41); and PTB data from the Centers for Disease Control and Prevention, 2007 (43).](https://academic.oup.com/aje/article-abstract/179/8/947/109496)
a 0.7% greater racial disparity in LBW between black and white women, whereas a 0.1-point increase in Gini coefficient was associated with a 3.4% greater racial disparity in LBW between these groups. When comparing the relationships among UV light exposure, Gini coefficient, and LBW between black and white women, we found that black women

Figure 2. Relationships between income inequality, as indexed by a higher Gini coefficient, and disparities in A) low birth weight (LBW) and B) preterm birth (PTB) across tertiles of the ultraviolet (UV) index spectrum in the United States. Values represent means (standard deviations). UV light exposure data from the National Oceanic and Atmospheric Administration, 2007 (41); LBW and PTB data from the Centers for Disease Control and Prevention, 2007 (43); and Gini coefficient data from the US Census Bureau, 2007 (49).

Table 1. Summary of Health, Economic, and Environmental Variables Stratified by Low- and High-Latitude States Across the United States, 2007

<table>
<thead>
<tr>
<th>Variable</th>
<th>Low-Latitude States, Mean (SD)</th>
<th>High-Latitude States, Mean (SD)</th>
<th>P Valuea</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Health</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Infant mortality rateb,c</td>
<td>7.91 (1.60)</td>
<td>6.11 (0.91)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Smoking rate, %c</td>
<td>19.50 (3.62)</td>
<td>17.66 (2.48)</td>
<td>0.044</td>
</tr>
<tr>
<td>Obesity rate, %d,c</td>
<td>8.91 (0.06)</td>
<td>8.52 (0.04)</td>
<td>0.015</td>
</tr>
<tr>
<td><strong>Economic</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gross state product, US dollars</td>
<td>314,237 (390,741)</td>
<td>239,703 (258,517)</td>
<td>0.43</td>
</tr>
<tr>
<td>Gini coefficientb</td>
<td>0.46 (0.19)</td>
<td>0.45 (0.02)</td>
<td>0.013</td>
</tr>
<tr>
<td>Poverty rate, %f</td>
<td>14.61 (0.0003)</td>
<td>11.23 (0.0002)</td>
<td>0.0002</td>
</tr>
<tr>
<td>Health care spending, US dollarsfg</td>
<td>6,695 (1,014)</td>
<td>7,312 (942)</td>
<td>0.03</td>
</tr>
<tr>
<td>Population densityh</td>
<td>57.48 (53.47)</td>
<td>94.33 (131.57)</td>
<td>0.21</td>
</tr>
<tr>
<td><strong>Environmental</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Relative frequency of births to white versus black mothers</td>
<td>5.73 (1.21)</td>
<td>35.63 (8.90)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Average annual temperature, °C</td>
<td>15.11 (1.48)</td>
<td>8.41 (0.66)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>No. of clear days/year</td>
<td>113.12 (32.64)</td>
<td>90.38 (18.40)</td>
<td>0.0045</td>
</tr>
<tr>
<td>Ultraviolet light indexi</td>
<td>6.95 (0.81)</td>
<td>5.28 (0.48)</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

Abbreviation: SD, standard deviation.

ab P values from 2-sided t test comparing group means of low- versus high-latitude states.
bc Number of deaths per 1,000 livebirths.
c Data for 2006.
dOverweight and obesity.
e Gini coefficient is a measure of income inequality, with 0 equaling perfect equality and 1 equaling total inequality.
f Data for 2009.
g Health care spending per capita per annum.
h Number of people per square mile.
i Indication of the amount of ultraviolet radiation expected to reach the earth’s surface at solar noon.
Vitamin D, UV Light, and Disparities in Birth Outcomes

were more sensitive to the negative effects of UV light exposure and income inequality than were white women (for UV light exposure in black women, $\beta = 0.01$ (SE, 0.002), $P < 0.001$; for Gini coefficient in black women, $\beta = 0.26$ (SE, 0.12), $P = 0.04$, adjusted $R^2 = 0.45$; for UV light exposure in white women, $\beta = 0.005$ (SE, 0.001), $P < 0.001$; for Gini coefficient in white women, $\beta = -0.08$ (SE, 0.06), $P = 0.17$, adjusted $R^2 = 0.30$) (Figure 3).

Disparity in PTB was similarly highest in areas with greater UV light exposure and income inequality (for UV light exposure, $\beta = 0.006$ (SE, 0.003), $P = 0.03$; for Gini coefficient, $\beta = 0.30$ (SE, 0.15), $P = 0.05$, adjusted $R^2 = 0.19$). Each 1-point increase in UV index value was associated with a 0.6% greater racial disparity in PTB, whereas each 0.1-point increase in Gini coefficient was associated with a 3.0% greater racial disparity in PTB. UV light exposure was more strongly associated with PTB risk among black women than among white women, whereas Gini coefficient was unrelated when looking at PTB risk within each racial group (for UV light exposure in blacks, $\beta = 0.02$ (SE, 0.003), $P < 0.001$, adjusted $R^2 = 0.45$; for Gini coefficient in whites, $\beta = 0.20$ (SE, 0.16), $P = 0.21$, adjusted $R^2 = 0.45$; for UV light exposure in whites, $\beta = 0.01$ (SE, 0.002), $P < 0.001$; for Gini coefficient in whites, $\beta = -0.09$ (SE, 0.11), $P = 0.40$, adjusted $R^2 = 0.34$).

**DISCUSSION**

This study evaluated the hypothesis that variation in UV light–induced vitamin D synthesis among racial groups is an important contributor to disparities in adverse birth outcomes in the United States (14–17). The prediction was that there would be lower racial disparities and absolute rates of LBW and PTB among women living in areas with higher UV light exposure. Contrary to the predictions of the UVD hypothesis, there was a positive relationship between UV light exposure and absolute rates of LBW and PTB, as well as racial disparity in LBW and PTB. Because an increase in UV light availability decreases the likelihood of vitamin D insufficiency, these data do not support the UVD hypothesis.

Given the UVD hypothesis, we would expect that women who live in the South would have better birth outcomes than those living in the North. However, the present analysis suggests the exact opposite, with absolute rates—as well as racial disparities—in birth outcomes being greatest in southern states. Importantly, lower adverse birth outcomes among black mothers in areas with less UV light (higher latitudes) drives the reduction in the LBW/PTB disparity rather than higher adverse outcomes in white women who live in states with less UV light. Notably, the 2 states with the lowest racial disparity in LBW and PTB, North Dakota and Vermont, had the second and third lowest UV index scores, respectively.

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**Table 2.** Correlations Between Disparity in Rates of Low Birth Weight and Preterm Birth and Economic, Environmental, and Health Variables in the United States, 2007

<table>
<thead>
<tr>
<th>Variable</th>
<th>Low Birth Weight</th>
<th>Preterm Birth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gross state product (US dollars)</td>
<td>0.20</td>
<td>0.13</td>
</tr>
<tr>
<td>Poverty rate (%)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.34&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.18</td>
</tr>
<tr>
<td>Gini coefficient&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.40&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.36&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Latitude (°North)</td>
<td>−0.61&lt;sup&gt;b&lt;/sup&gt;</td>
<td>−0.48&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Temperature (°F)</td>
<td>0.61&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.44&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>No. of clear days/year</td>
<td>0.19</td>
<td>0.25</td>
</tr>
<tr>
<td>Smoking (%)</td>
<td>0.25</td>
<td>−0.13</td>
</tr>
<tr>
<td>Obesity (%)&lt;sup&gt;d&lt;/sup&gt;</td>
<td>0.35&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.09</td>
</tr>
<tr>
<td>Health care spending (US dollars)&lt;sup&gt;e&lt;/sup&gt;</td>
<td>−0.16</td>
<td>−0.16</td>
</tr>
</tbody>
</table>

<sup>a</sup> Data for 2009.

<sup>b</sup> $P < 0.05$.

<sup>c</sup> Gini coefficient is a measure of income inequality, with 0 equaling perfect equality and 1 equaling total inequality.

<sup>d</sup> Overweight and obesity.

<sup>e</sup> Health care spending per capita per annum.

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**Figure 3.** Relationship between disparity of the incidence of A) low birth weight and B) preterm birth across ultraviolet (UV) index scores for non-Hispanic blacks and non-Hispanic whites in the United States. UV light exposure data from the National Oceanic and Atmospheric Administration, 2007 (41); low birth weight and preterm birth data from the Centers for Disease Control and Prevention, 2007 (43).
Analysis of additional economic, social, and health variables suggests that the positive relationship between UV light exposure and birth outcomes may be confounded by variables unrelated to UV light availability. For example, poverty rate is significantly correlated with UV light exposure (Table 1) and is significantly higher in states at lower latitudes compared with those at higher latitudes (Table 2). Further, states with greater income inequality had higher disparities in LBW and PTB across the UV light spectrum (Figure 2). After we controlled for UV light availability, Gini coefficient remained a significant positive predictor of disparity in LBW and PTB. Gini coefficient and similar socioeconomic variables that covary with latitude and UV light availability in the United States are therefore likely contributing to the positive relationship we found between UV light availability and adverse birth outcomes.

The results of this analysis are supported by recent literature that calls into question the link between vitamin D status and birth outcomes. For example, a recent Cochrane review evaluated the results of 6 randomized control trials and found no association between vitamin D supplementation in pregnancy and PTB, although there was a borderline association between vitamin D supplementation and the risk of LBW in offspring (53). In studies that have reported relationships between vitamin D status and adverse birth outcomes, the results are often inconsistent among racial or ethnic groups. For example, a recently published article found an association between spontaneous PTB risk and vitamin D levels among African American and Puerto Rican mothers but not among white mothers (26), whereas another study found that vitamin D status was associated with the risk of having small-for-gestational age, it has been strongly associated with numerous long-term adverse health outcomes and, therefore, is important from the perspective of early-life programming of adult disease risk (71, 72). However, the categorical nature of the available data made calculation of small-for-gestational-age rates impossible. That said, LBW is still a useful birth outcome indicator because, even without adjustment for gestational age, it has been strongly associated with numerous short- and long-term health outcomes (73). Future studies...
would be improved by calculating the relationship between UV light exposure and LBW, as well as small-for-gestational-age infants in the United States and in other samples.

State-level health and economic data were used, and these data are limited in their ability to capture individual variability. Despite this, the fact that income inequality within each state was strongly related to disparities in rates of LBW and PTB indicates that such inequalities are important contributors to racial disparities in birth outcomes in the United States.

In summary, this analysis evaluated whether differences in UV light availability contribute to racial disparities in adverse birth outcomes in the United States. The prediction was that lower UV light availability would be associated with higher rates of LBW and PTB, as well as racial disparity in these outcomes, because vitamin D deficiency is higher in such environments. Contrary to the predictions of the UVD hypothesis, absolute rates of adverse birth outcomes, as well as racial disparities in birth outcomes, were greatest in southern states where UV light availability was highest. This argues against the hypothesis that an inability to produce sufficient vitamin D is a major contributor to birth disparities in the United States and suggests instead that other environmental factors that positively covary with UV light availability in this context, such as income inequality or heat stress, may be driving the relationship. Future research should address other social, economic, and environmental factors that follow a south-to-north gradient in the United States to explain the environmental origins of racial disparities in birth outcomes.

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