Objective: To explore a hypothesized association between vitamin D inadequacy and diabetic retinopathy.

Methods: This cross-sectional study analyzed data from individuals aged 40 years and older with diabetes mellitus who participated in the interview and medical examination components of the Third National Health and Nutrition Examination Survey conducted from October 1, 1988, through September 30, 1994. The relationship between diabetic retinopathy and serum 25-hydroxyvitamin D concentration was evaluated using regression analysis in the presence of demographic and clinical covariates, such as age, race, obesity, and persistent hyperglycemia.

Results: On the basis of the 1790 adults with diabetes who met the study’s inclusion criteria, the percentage of individuals with vitamin D deficiency increased with severity of retinopathy: no retinopathy, 27.9%; mild, 28.2%; moderate to severe, 43.2%; and proliferative, 64.6% (P=.01). Regression analysis of retinopathy severity vs serum 25-hydroxyvitamin D concentration did not demonstrate a statistically significant relationship between the two variables (P=.07).

Conclusions: This study found an association between severity of diabetic retinopathy and prevalence of vitamin D deficiency, but the findings were inconclusive about the existence of a relationship between retinopathy severity and serum 25-hydroxyvitamin D concentration. Given previous research indicating possible anti-inflammatory and antiangiogenic properties of vitamin D, the connection between vitamin D and diabetic retinopathy warrants further study.
amination Survey conducted by the National Center for Health Statistics from October 1, 1988, through September 30, 1994 (NHANES III). Certain demographic groups, including blacks and Mexican Americans, were oversampled as part of a multistage sample design. Using US Census data, NHANES III investigators first identified primary sampling units, which were predominantly large US counties, then geographic segments within each primary sampling unit, households to be screened within each segment, and finally demographic data of eligible households. Sampling rates for areas with greater concentrations of young, elderly, black, and Mexican American individuals were increased to achieve the desired number of participants with each demographic characteristic (age, sex, and ethnicity/race).18

Of the 39,695 individuals included in the NHANES III survey, 33,994 (85.6%) participated in a home interview, which was used to collect data on demographic characteristics, socioeconomic status, family medical history, current medical conditions, and use of medications. All individuals who participated in the home interview were invited to visit a mobile examination center (MEC) for a medical examination, which consisted of a physical examination and collection of blood and urine samples for laboratory testing. A total of 16,575 participants aged 20 years or older were examined in the MEC.19

INCLUSION CRITERIA

To be included in the present study, NHANES III participants must have been participants in the NHANES III home interview and MEC examination, including gradable fundus photography. Study criteria for the diagnosis of diabetes (had been told by a physician that they had diabetes [other than gestational diabetes] or had MEC laboratory test results indicative of diabetes [hemoglobin A1c ≥0.5] to [determine proportion of total hemoglobin, multiply by 0.01], fasting plasma glucose ≥126 mg/dL [to convert to millimoles per liter, multiply by 0.0555], or 2-hour oral glucose tolerance test ≥200 mg/dL) [or confirm that the patient was a nonfasting patient]); and provided a blood sample for measurement of serum 25-hydroxyvitamin D (25-OHD). Because NHANES III survey participants were eligible for fundus photography only if they were aged 40 years or older, the present study was limited to adults in that age category.

The NHANES III did not differentiate between individuals with type 1 vs type 2 diabetes. We therefore assigned the most likely diagnosis on the basis of age at first diagnosis. Participants were classified as having type 1 diabetes only if they answered “30 years or less” in response to the question, “What was your age when you were first told you had diabetes?” Participants who had been diagnosed after 30 years of age or whose NHANES III test results provided the only indication of diabetes were classified as having type 2 diabetes. This classification was used to provide a descriptive overview of the study sample, but it was not used in any of the analyses.

MEASURES

Primary Outcome Variables

Retinopathy severity and the dichotomous “retinopathy” (present or absent) served as the primary outcome variables. Retinopathy was assessed using nonmydriatic fundus photographs of 1 eye, chosen by an NHANES III randomization protocol at the time of the examination. Photographs were taken in a darkened examination room to allow for dilation of the pupil to 6 to 10 mm in diameter and graded at the Ocular Epidemiology Grading Center of the University of Wisconsin Medical School. Trained graders used the Modified Airlie House Classification scheme and the Early Treatment for Diabetic Retinopathy Study severity scale to grade the photographs as follows: no retinopathy (graded 010 or 015), mild nonproliferative retinopathy (020 or 031), moderate to severe nonproliferative retinopathy (041 or 051), or proliferative retinopathy (060, 065, or 070; or evidence of photocoagulation treatment noted outside arcades).20,21

Primary Exposure Variables

Serum 25-OHD concentration and the dichotomous “vitamin D deficiency” (present or absent) served as the primary exposure variables. Vitamin D deficiency was defined in accordance with the generally accepted standard of serum 25-OHD less than 20 ng/mL (to convert to nanomoles per liter, multiply by 2.496).22 During the NHANES III physical examination at the MECs, 100 mL of whole blood was collected, frozen at −70°C, and tested for serum vitamin D levels within 2 weeks after collection. (Because vitamin D is very stable, serum samples may be frozen at −20°C to −70°C for years before analysis.) Serum 25-OHD was measured using the Incstar 25-OHD assay (DiaSorin).23

Confounder Variables and Effect Modifiers

The following covariates were evaluated as potential confounders as well as effect modifiers: age, sex, race, socioeconomic status (yearly income <$20,000, $20,000-$49,999, or ≥$50,000), duration of diabetes, persistent hyperglycemia (glycosylated hemoglobin ≥6.5%), hypertension (systolic blood pressure ≥140 mm Hg or diastolic blood pressure ≥90 mm Hg), obesity (body mass index [calculated as weight in kilograms divided by height in meters squared] ≥30), hypercholesterolemia (total serum cholesterol >240 mg/dL [to convert to millimoles per liter, multiply by 0.0259]), hypertriglyceridemia (serum triglycerides >150 mg/dL [to convert to millimoles per liter, multiply by 0.0113]), and compromised kidney function (serum creatinine >1.2 mg/dL for men and >1.0 mg/dL for women [to convert to micromoles per liter, multiply by 88.4]).3-5,17,24

STATISTICAL ANALYSIS

Descriptive statistics provided an overview of the sample population (eg, distributions of age, sex, ethnicity/race, educational level, and insurance). Vitamin D levels were compared by race, region, season, and retinopathy severity using subgroup (domain) regression analyses. Weighted prevalences and 95% CIs of vitamin D deficiency (serum 25-OHD <20 ng/mL) and insufficiency (serum 25-OHD <32 ng/mL) overall and by sex and race were also calculated. The relationships between severity and presence of diabetic retinopathy and (1) the prevalence of vitamin D deficiency and (2) the serum 25-OHD concentration were evaluated using ordinal and logistic regression analyses, respectively, controlling for covariates. Any covariate introduced into the regression model that changed the regression coefficient (β) of the primary exposure variable by 10% or more was identified as a potential confounding variable; any covariate introduced into the regression model that rendered a statistically significant interaction term (P<.05) was identified as a potential effect modifier.25

All analyses were performed using the survey analysis procedures of SAS, version 9.2 (SAS Institute, Inc).26 This version of the software allows the user to specify sample weights that take into account the number of persons in the population represented by a given individual in the sample to ensure accurate estimates of variance. Sample weights are necessary to account for unequal probability of selection (among such
subgroups as age, sex, and ethnicity/race), oversampling techniques, and differential nonresponse (to reduce biases arising from the fact that nonrespondents may differ from respondents). To account for the cluster design of NHANES III, sampling parameters and weights provided in the NHANES III data set were specified in all steps of the analysis.

The mean (SD) serum 25-OHD concentration in 1522 participants with or without retinopathy did not differ significantly in mean (SD) age (61.6 [9.7] years vs 60.9 [12.0] years). The prevalence of retinopathy did not differ significantly between the two groups (71.5%, mild nonproliferative; 24.9%, moderate nonproliferative; and 12.1%, proliferative). The relationship between vitamin D deficiency and retinopathy severity was statistically significant (Table 2).

RESULTS

A total of 1790 NHANES III participants met the study’s inclusion criteria. Their mean (SD) age was 62.7 (11.1) years, and 53.6% were women (Table 1). The distribution of participants by region and season of vitamin D testing is shown in Table 2.

VITAMIN D

The 1790 study participants had a median (interquartile range) serum 25-OHD concentration of 25.8 (17.9-31.1) ng/mL. Non-Hispanic blacks (n=467) and Mexican Americans (n=547) had median vitamin D levels significantly lower than non-Hispanic whites (n=708): 18.5 ng/mL and 21.3 ng/mL vs 27.5 ng/mL (P < .01). Participants residing in the western United States at the time of measurement (Pacific and Mountain states) had the lowest levels of vitamin D (23.9 ng/mL vs 26.0 ng/mL in other regions; P < .05), as did participants measured from January through March (23.4 ng/mL vs 26.0 ng/mL during the remaining months; P < .01).

Weighted prevalences (95% CIs) of vitamin D deficiency and insufficiency among participants were 28.6% (25.0%-32.1%) and 74.0% (70.0%-78.1%), respectively. The prevalence of vitamin D deficiency was greater in women (34.9% vs 21.3%; P < .01) and higher among non-Hispanic blacks (56.0%) and Mexican Americans (42.7%) compared with non-Hispanic whites (23.2%) (P < .01). Similarly, vitamin D insufficiency was higher in women (78.1% vs 69.3%; P < .01) and higher among non-Hispanic blacks (89.2%) and Mexican Americans (89.5%) compared with non-Hispanic whites (69.4%) (P < .01).

RETNOPATHY

The weighted prevalence (95% CI) of retinopathy was 12.1% (9.5%-14.7%). Among the sample with retinopathy, weighted prevalences of retinopathy severity were as follows: 71.8%, mild nonproliferative; 24.9%, moderate to severe nonproliferative; and 3.4%, proliferative. Participants with or without retinopathy did not differ significantly in mean (SD) age (61.6 [9.7] years vs 60.9 [12.0] years). The prevalence of retinopathy did not differ significantly between men and women (11.5% and 12.7%, respectively) but was greater among non-Hispanic blacks and Mexican Americans compared with non-Hispanic whites (16.3% and 18.0% vs 11.4%; P < .05).

RELATIONSHIP BETWEEN VITAMIN D AND RETINOPATHY

The percentage of individuals with vitamin D deficiency increased with severity of retinopathy: no retinopathy, 27.9%; mild, 28.2%; moderate to severe, 43.2%; and proliferative, 64.6% (β = 1.3, P = .01, unadjusted; and β = 1.2, P = .01, adjusted for age and obesity status given their clinical significance). The Figure shows actual serum 25-OHD concentration (median [interquartile range]) as a function of retinopathy severity score. Regression analysis of these data did not demonstrate a statistically significant relationship between the 2 variables (β = −0.04, P = .07, unadjusted; and β = −0.03, P = .13, adjusted).

Covariates found to be independently associated with retinopathy severity included duration of diabetes, persistent hyperglycemia, and compromised kidney function. More specifically, combined with vitamin D deficiency, these variables raised the probability of more severe retinopathy as follows: 1-year increase in duration of diabetes, β = 0.3, P < .01; hyperglycemia, β = 2.8, P < .01; and compromised kidney function (as measured by elevated creatinine), β = 1.4, P < .01. The relationship between vi-
The overall prevalence of retinopathy among adults with diabetes was 12%, with almost two-thirds representing the mildest form of the complication. The prevalence among non-Hispanic blacks and Mexican Americans was approximately 30% greater than among whites, but the prevalence did not differ significantly between men and women. Participants with more severe forms of retinopathy had greater prevalences of vitamin D deficiency. Vitamin D deficiency combined with longer duration of diabetes, persistent hyperglycemia, or compromised kidney function increased the risk of more severe retinopathy beyond the risk associated with vitamin D deficiency alone.

The 28.6% prevalence of vitamin D deficiency derived from the NHANES III sample of adults with diabetes is significantly greater than the 22.2% prevalence in the general population (P < .05). This is not surprising because other studies have also reported lower vitamin D levels in patients with diabetes. The discrepancy would not have a bearing on the results of the present investigation, which is limited to individuals with diabetes.

The distribution of study participants with type 1 vs type 2 diabetes (1.4% vs 98.6%) differs from the distribution in the general population (approximately 5% vs 95%). The most likely reason for the discrepancy is that individuals younger than 40 years—a group with a relatively high prevalence of type 1 diabetes—were excluded from the present study.

In conclusion, this study revealed a higher prevalence of vitamin D deficiency in adults with diabetes compared with the general adult population. The study also found an association between severity of diabetic retinopathy and prevalence of vitamin D deficiency, but the findings were inconclusive about the existence of a relationship between retinopathy severity and absolute se-

Table 2. Proportion of 1790 Participants by Region and Season at Time of Vitamin D Measurement

<table>
<thead>
<tr>
<th>Season</th>
<th>Northeast (n = 241)</th>
<th>Midwest (n = 322)</th>
<th>South (n = 836)</th>
<th>West (n = 391)</th>
<th>Total by Region</th>
</tr>
</thead>
<tbody>
<tr>
<td>January-March</td>
<td>0.0 (n = 23)</td>
<td>0.0 (n = 84)</td>
<td>13.0 (n = 74)</td>
<td>5.3 (n = 14)</td>
<td>18.3 (n = 32)</td>
</tr>
<tr>
<td>April-June</td>
<td>0.2 (n = 7)</td>
<td>10.8 (n = 84)</td>
<td>3.3 (n = 4)</td>
<td>13.1 (n = 5)</td>
<td>27.4 (n = 22)</td>
</tr>
<tr>
<td>July-September</td>
<td>14.2 (n = 5)</td>
<td>13.1 (n = 84)</td>
<td>2.1 (n = 4)</td>
<td>2.2 (n = 5)</td>
<td>31.6 (n = 22)</td>
</tr>
<tr>
<td>October-December</td>
<td>5.7 (n = 5)</td>
<td>0.3 (n = 84)</td>
<td>16.6 (n = 4)</td>
<td>0.1 (n = 5)</td>
<td>22.7 (n = 22)</td>
</tr>
<tr>
<td>Total by region</td>
<td>20.1 (n = 1522)</td>
<td>24.2 (n = 168)</td>
<td>35.0 (n = 88)</td>
<td>20.7 (n = 12)</td>
<td>100.0 (n = 744)</td>
</tr>
</tbody>
</table>

a Weighted proportions.
rum 25-OHD concentration. Given recent evidence about the role of vitamin D in vascular health, the connection between vitamin D and diabetic retinopathy warrants further study.

Submitted for Publication: March 11, 2011; final revision received December 5, 2011; accepted December 12, 2011.

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Author Contributions: Dr Patrick had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

Financial Disclosure: None reported.

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