Conclusions—Although vitamin D deficiency is associated with an unfavorable lipid profile in cross-sectional analyses, correcting for a deficiency might not translate into clinically meaningful changes in lipid concentrations; however, data from intervention trials are required to confirm these findings. (Circulation. 2012;126:270-277.)

Key Words: cholesterol • lipids • vitamin D

Vitamin D is a steroid hormone that is present in some foods but is synthesized mainly in response to ultraviolet light exposure. After ingestion or endogenous synthesis, vitamin D is hydroxylated by the liver to form 25-hydroxyvitamin D [25(OH)D], the predominant form of vitamin D in circulation. Two forms are important in humans: ergocalciferol (vitamin D₂) and cholecalciferol (vitamin D₃). Vitamin D₂ is synthesized by plants, whereas vitamin D₃ is synthesized in the skin on exposure to specific ultraviolet B rays. Foods may be fortified with, and supplements may include, either vitamin D₂ or D₃.

Epidemiological studies suggest an inverse association between circulating levels of 25(OH)D and cardiovascular risk biomarkers, including an atherogenic lipid profile. Vitamin D deficiency is highly prevalent and can be effectively treated through oral repletion. However, a role for supplementation in modifying cardiovascular risk has not been well defined, and it is unclear whether vitamin D status is causally related to disease or is merely a marker of health.

This is relevant for practitioners and the general population because of the increasing consumption of pharmacological doses of vitamin D sold over the counter.

Cross-sectional studies are unable to assess the longitudinal effects of changes in 25(OH)D levels on standard cardiovascular risk biomarkers. Although randomized clinical trials of vitamin D supplementation would provide a higher level of evidence, studies to date have shown conflicting results. These studies were limited by relatively small sample sizes, confounding effects of vitamin D with additional calcium...
supplementation, and study designs that did not specifically target vitamin D deficiency or did not use a sufficient dose of vitamin D to achieve a consensus optimal level of ≥30 ng/mL.

In the absence of definitive evidence from randomized, controlled trials (RCTs), data mining is becoming an increasingly valuable tool for rapidly and cost-effectively generating and testing hypotheses. Quest Diagnostics has the largest private database of patient laboratory test data. We analyzed deidentified results from this database to compare cross-sectional and longitudinal approaches to studying the relationship between 25(OH)D levels and blood lipids. In the cross-sectional approach, we studied the association between 25(OH)D levels and the lipid panel in a large population derived from medical practices broadly across the United States. For the longitudinal approach, we identified a cohort from the same population to determine how changes in 25(OH)D levels are related to changes in lipid levels.

Given the absence of clear evidence from RCTs, we believe our longitudinal cohort analysis introduces a novel approach to exploring these important biomarker relationships. We studied a very large national sample relatively quickly and inexpensively, whereas an analogous prospective RCT would take years to complete and would possibly be prohibitively expensive. Because vitamin D deficiency and dyslipidemia are so prevalent, it is important for clinicians to have better evidence on which to base treatment decisions in a timely manner. We believe that our longitudinal analysis fills this gap between cross-sectional reports and a resource-intensive clinical trial, the results of which would not be available for many years.

Methods

Patients

Quest Diagnostics has over 145 million annual patient encounters across the United States. Test results are stored in a private, clinical database. We selected 4.06 million patient records that included simultaneous 25(OH)D and lipid panel tests between September 2009 and February 2011 and deidentified them for analysis.

Cross-Sectional Study Population

Of these patients, 107,811 records met the following inclusion criteria: were 40 to 80 years of age; had ≥2 simultaneous 25(OH)D, lipid panels, and glucose tests within 4 and 26 weeks apart, inclusive; had triglyceride levels of <400 mg/dL and glucose levels of <200 mg/dL for both tests; and had an absolute difference between the first and second glucose values of ≥30 mg/dL (Figure 1). The glucose restrictions were intended to exclude patients who fasted inconsistently, may not have fasted, or had poorly controlled diabetes mellitus. We stratified 25(OH)D results into consensus clinical strata: deficient (<20 ng/mL; n = 25,235), insufficient (20–29 ng/mL; n = 40,406), and optimal (≥30 ng/mL; n = 42,170) 25(OH)D.

Longitudinal Study Population

From these 107,811 patients, we determined the distribution of low-density lipoprotein (LDL) cholesterol level change between the initial and final visits. To exclude patients who may have had changes in lipid-lowering therapy, the analysis was limited to patients in the second and third quartiles of the LDL cholesterol change distribution. This excluded patients whose change in LDL cholesterol measurements were ≥15 or ≤10 mg/dL. From the 54,794 patients who met this criterion, 2 subgroups were selected: group 1, the repletion group, included 6260 patients whose initial 25(OH)D concentration was <20 ng/mL and whose immediate subsequent 25(OH)D concentration was ≥30 and ≤100 ng/mL, and group 2, the “control” group, included 2332 patients whose initial and immediate subsequent 25(OH)D concentrations were both <20 ng/mL.

Laboratory Methods

The 25(OH)D measurements were performed by liquid chromatography with tandem quadrupole mass spectrometers (Thermo Fisher Scientific, San Jose, CA). This method measures the area under the curve (AUC) for 25(OH)D2, 25(OH)D3, and total 25(OH)D. The cross-sectional study reports only values based on the AUC for 25(OH)D, and if the AUC was <4.0 ng/mL, a value of 3.9 ng/mL was assigned. In the longitudinal study, total 25(OH)D and 25(OH)D2 were based on the AUC for 25(OH)D and 25(OH)D3, whereas 25(OH)D2 was the AUC for 25(OH)D minus the AUC for 25(OH)D3. In the longitudinal study, 0.3% of patients had total
25(OH)D <4.0 ng/mL, and these values were arbitrarily set to 3.9 ng/mL; 3% of patients had 25(OH)D <4 ng/mL, and these values were arbitrarily set to zero. Accuracy of testing was monitored by participation in the Vitamin D External Quality Assurance program.15

Both glucose and calcium measurements were performed on Beckman Coulter AU analyzers with the glucose hexokinase and calcium arsenazo methods, respectively (Beckman Coulter, Inc, Brea, CA). Accuracy of testing was monitored by participation in the College of American Pathologists General Chemistry Survey (College of American Pathologists, Northfield, IL). The Friedewald equation was used to calculate LDL cholesterol levels.16

Statistical Analysis
In the cross-sectional study, the least-squares means from generalized linear regression models were used to detect associations between baseline 25(OH)D and the lipid measurements. Each lipid value was regressed against initial 25(OH)D status and age. Dummy variables were used to control for sex and month of testing. Pairwise comparisons of least-squares means between the 25(OH)D groups were evaluated with the Tukey method. Statistical significance was taken as P<0.05.

In the longitudinal study, baseline characteristics for the lipid panel, 25(OH)D, glucose, calcium, creatinine, age, sex, weeks between testing, and the top 10 International Classification of Disease, Ninth Revision (ICD-9) codes, were calculated for patients in the repletion and control groups. To compare baseline statistics between the repletion and control groups, the 2-sided, unpaired Student t test was used for quantitative variables; the 2-proportion z test was used for categorical variables such as sex and top ICD-9 codes. Intergroup differences in lipid changes between the repletion and control groups were assessed by unpaired 2-sample t tests. Statistical significance was taken as P<0.05.

For additional analysis assessing the impacts of seasonality and the interval between testing on the longitudinal study, see the online-only Data Supplement.

Human Subject Protection
This study was reviewed by The Rockefeller University Institutional Review Board and Western Institutional Review Board and considered an exempt activity that required no further Institutional Review Board review.

Results
To determine the association between 25(OH)D levels and components of the lipid panel, we performed a cross-sectional analysis in a sample population stratified by consensus clinical 25(OH)D levels: those with deficient (<20 ng/mL), insufficient (20–29 ng/mL), and optimal (≥30 ng/mL) 25(OH)D levels (Figure 1). Mean 25(OH)D levels for these groups were 14.2, 24.8, and 40.0 ng/mL, respectively. Compared with the group with deficient levels, the group with optimal 25(OH)D levels had a statistically significant, healthier lipid panel: lower total and LDL cholesterol, higher high-density lipoprotein (HDL) cholesterol, and lower triglycerides (Table 1 and Figure 2). The intermediate group with insufficient 25(OH)D levels showed a directionally consistent, intermediate association with a favorable lipid panel compared with the group with deficient 25(OH)D levels. These associations were similar for both men and women.

To explore this finding further, we performed a cohort analysis to determine whether an increase in 25(OH)D from a deficient to an optimal level was associated with an improvement in the lipid panel. A total of 107 811 patients satisfied the inclusion criteria (Figure 1). To minimize the confounding effect of possible changes in lipid-lowering therapy, we further excluded individuals whose change in LDL cholesterol level was in the first or fourth quartiles of change in LDL cholesterol. From the remaining patients (n=54 794), we used changes in 25(OH)D levels to identify the repletion group (group 1; n=6 260) and the control group (group 2; n=2 332).

The average±SD age of patients in group 1 was 60.6±10.6 years compared with 58.9±10.9 years for patients in group 2 (Table 2). Both groups had a similar proportion of women (approximately two thirds). The baseline 25(OH)D level for group 1 was 14.3±3.8 ng/mL compared with 13.2±3.9 ng/mL for group 2. Baseline lipid, glucose, calcium, and creatinine levels were clinically similar between the groups, although the control group had statistically higher LDL cholesterol, lower triglycerides, and lower calcium levels 0.

Table 3 shows the frequency of the most common ICD-9 codes listed on the initial laboratory requisitions. Patients in group 1 were more likely to receive ICD-9 codes indicative of dyslipidemia and hypertension compared with the control group. However, there was no statistical difference between groups in the designation of vitamin D deficiency or the common comorbidities of diabetes mellitus and hypothyroidism.

For group 1, the repletion group, 25(OH)D levels increased an average of 27.3 ng/mL, from a mean value of 14.3±3.8 to 41.6±10.9 ng/mL (Figure 3). In contrast, initial and final mean 25(OH)D levels remained deficient in group 2, the

Table 1. Cross-Sectional Associations Between 25-Hydroxyvitamin D and Lipids

<table>
<thead>
<tr>
<th>Lipid Parameter</th>
<th>&lt;20 ng/mL</th>
<th>&lt;20 vs &lt;30 ng/mL</th>
<th>20–29 ng/mL</th>
<th>20–29 vs &gt;30 ng/mL</th>
<th>&lt;20 vs &gt;30 ng/mL</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total cholesterol, mg/dL</td>
<td>195.6</td>
<td>196.0</td>
<td>194.0</td>
<td>1.58</td>
<td>0.65 to 2.52</td>
<td>0.0002</td>
</tr>
<tr>
<td>LDL cholesterol, mg/dL</td>
<td>117.7</td>
<td>110.6</td>
<td>106.0</td>
<td>5.73</td>
<td>4.91 to 6.58</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>HDL cholesterol, mg/dL</td>
<td>56.2</td>
<td>58.1</td>
<td>62.1</td>
<td>5.88</td>
<td>6.25 to 5.52</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Triglycerides, mg/dL</td>
<td>139.0</td>
<td>137.3</td>
<td>130.5</td>
<td>8.48</td>
<td>7.01 to 9.95</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

*Cl indicates confidence interval; 25(OH)D, 25-hydroxyvitamin D; LDL, low-density lipoprotein; and HDL, high-density lipoprotein.*
control group (13.2±3.9 versus 14.1±3.7 ng/mL, an increase of only 0.9 ng/mL). Because vitamin D$_2$ is not produced endogenously, we analyzed 25(OH)D$_2$ and D$_3$ levels at the initial and final visits for both groups 1 and 2 to provide evidence that the increase in group 1 was due to supplementation. In the repletion group, 25(OH)D$_2$ levels were detectable (≥4 ng/mL) in only 4.6% of patients at baseline but in 69.2% at the final measurement. In the control group, 25(OH)D$_2$ levels increased 22.2 ng/mL of the total 25(OH)D increase of 27.3 ng/mL; in the control group, 25(OH)D$_2$ levels increased 0.6 ng/mL of the total increase in 25(OH)D of 0.9 ng/mL. Thus, 81% of the increase in 25(OH)D levels in the repletion group was due to 25(OH)D$_2$, proving a major role for exogenous supplementation. Because vitamin D$_3$ is made endogenously but can also come from supplementation, this is a minimum number.

At the final visit, total cholesterol decreased 2.04 mg/dL in the repletion group compared with a 2.81-mg/dL decrease in the control group for a relative increase of 0.77 mg/dL ($P<0.01$) in the repletion group (Table 4). An increase in 25(OH)D levels was also associated with an increase in HDL cholesterol of 0.42 mg/dL ($P=0.02$). No statistically significant intergroup differences were observed for changes in LDL cholesterol or triglycerides.

**Discussion**

We analyzed a large national clinical laboratory database to determine relationships between 25(OH)D levels and components of the lipid panel. In the cross-sectional analysis, the optimal 25(OH)D group relative to the deficient group

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**Table 2. Baseline Characteristics for the Cohort Study**

<table>
<thead>
<tr>
<th></th>
<th>Group 1 (Repletion)</th>
<th>Group 2 (Control)</th>
<th>$P$</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>6260</td>
<td>2332</td>
<td></td>
</tr>
<tr>
<td>Age, y</td>
<td>60.6±10.6</td>
<td>58.9±10.9</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Female sex, %</td>
<td>66.0</td>
<td>66.7</td>
<td>0.40</td>
</tr>
<tr>
<td>Time between measurements, wk</td>
<td>17.6±5.3</td>
<td>17.3±5.7</td>
<td>0.01</td>
</tr>
<tr>
<td>Initial 25(OH)D, ng/mL</td>
<td>14.3±3.8</td>
<td>13.2±3.9</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Total cholesterol, mg/dL</td>
<td>178.8±37.9</td>
<td>180.2±39.5</td>
<td>0.18</td>
</tr>
<tr>
<td>LDL cholesterol, mg/dL</td>
<td>98.8±32.5</td>
<td>101.4±33.4</td>
<td>0.001</td>
</tr>
<tr>
<td>HDL cholesterol, mg/dL</td>
<td>53.5±15.6</td>
<td>53.5±15.9</td>
<td>0.53</td>
</tr>
<tr>
<td>Triglycerides, mg/dL</td>
<td>133.5±63</td>
<td>128.0±63</td>
<td>0.0001</td>
</tr>
<tr>
<td>Glucose, mg/dL</td>
<td>101.8±20.2</td>
<td>101.0±21.1</td>
<td>0.13</td>
</tr>
<tr>
<td>Calcium, mg/dL</td>
<td>9.41±0.40</td>
<td>9.35±0.45</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Creatinine, mg/dL</td>
<td>0.92±0.34</td>
<td>0.92±0.43</td>
<td>0.74</td>
</tr>
</tbody>
</table>

25(OH)D indicates 25-hydroxyvitamin D; LDL, low-density lipoprotein; and HDL, high-density lipoprotein. Values are mean±SD.
association studies cannot be used to infer causality. Indeed, in contrast to cross-sectional data, the longitudinal analysis showed that increasing 25(OH)D levels from the deficient to the optimal range (repletion group) compared with remaining in the deficient range (control group) was associated with small and clinically minimal effects on total cholesterol (0.8-mg/dL increase) and LDL cholesterol (0.4-mg/dL increase) and no significant changes in LDL cholesterol or triglycerides levels. These longitudinal data contrast with the purported benefits of vitamin D repletion on the lipid profile inferred from cross-sectional studies.17–20

These novel findings and approach provide a different type of evidence for clinical practice guidelines than existing association studies. Clinicians are still awaiting the results of large, randomized, placebo-controlled outcome trials of vitamin D supplementation.21 In the absence of clinical trials, this novel, inexpensive approach fills a gap for quickly examining the effect of vitamin D repletion on the lipid panel, a major predictive biomarker of cardiovascular risk. Moreover, and particularly important for patient-oriented research, the data were obtained from patient encounters in settings reflective of true clinical practice across the United States.

Our cross-sectional analysis is concordant with other vitamin D/lipid association studies showing that higher 25(OH)D levels are associated with a healthier lipid profile.17–20 This validates the use of the Quest Diagnostics database because it replicated the known associations between 25(OH)D and the lipid profile found in other cross-sectional studies. For example, the largest published association study (n = 15 088), based on National Health and Nutrition Examination Survey (NHANES) III, found that mean 25(OH)D levels were lower in subjects with hypertriglyceridemia and hypercholesterolemia.17 The same study also compared the age-, sex-, and race-adjusted prevalence rates of cardiovascular risk factors between the highest (≥92.4 nmol/L [≥37 ng/mL]) and lowest (<52.4 nmol/L [<21 ng/mL]) quartiles of 25(OH)D levels and found that hypertriglyceridemia was more prevalent in the lowest quartile of 25(OH)D levels. Using a similar approach to stratifying by 25(OH)D levels, we were able to supplement the findings of the NHANES III analysis by also identifying trends in LDL and HDL cholesterol levels.

Given the large size of our database, we were able to control for patient age, sex, and month of testing. We had enough patient records to match patients into clinically relevant strata of 25(OH)D levels: <20, 20 to 29, and 30 to 100 ng/mL. Therefore, we were able to achieve higher statistical power to identify clinically significant relation-

### Table 3. Most Common International Classification of Disease, Ninth Revision, Diagnosis Codes for the Cohort Study

<table>
<thead>
<tr>
<th>Rank</th>
<th>ICD-9 Code</th>
<th>Description</th>
<th>Group 1 (Repletion)</th>
<th>Group 2 (Control)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>272</td>
<td>Disorders of lipid metabolism</td>
<td>56</td>
<td>49.1</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>2</td>
<td>401</td>
<td>Essential hypertension</td>
<td>37.9</td>
<td>33.5</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>3</td>
<td>250</td>
<td>Diabetes mellitus</td>
<td>25.8</td>
<td>25.9</td>
<td>0.48</td>
</tr>
<tr>
<td>4</td>
<td>780</td>
<td>General symptoms</td>
<td>12.6</td>
<td>11.3</td>
<td>0.04</td>
</tr>
<tr>
<td>5</td>
<td>V70</td>
<td>General medical examination</td>
<td>11.6</td>
<td>10.7</td>
<td>0.11</td>
</tr>
<tr>
<td>6</td>
<td>244</td>
<td>Acquired hypothyroidism</td>
<td>11.4</td>
<td>10.1</td>
<td>0.04</td>
</tr>
<tr>
<td>7</td>
<td>268</td>
<td>Vitamin D deficiency</td>
<td>9.7</td>
<td>9.5</td>
<td>0.42</td>
</tr>
<tr>
<td>8</td>
<td>V58</td>
<td>Other and unspecified aftercare</td>
<td>6.8</td>
<td>5.9</td>
<td>0.05</td>
</tr>
<tr>
<td>9</td>
<td>790</td>
<td>Non-specific findings on examination of blood</td>
<td>5.9</td>
<td>6</td>
<td>0.48</td>
</tr>
<tr>
<td>10</td>
<td>733</td>
<td>Other disorders of bone and cartilage</td>
<td>5</td>
<td>4.3</td>
<td>0.07</td>
</tr>
</tbody>
</table>

ICD-9 indicates International Classification of Disease, Ninth Revision.

### Figure 3. Changes in 25-hydroxyvitamin D [25(OH)D] levels in the cohort study. The graph displays the mean and ±SD 25(OH)D values. To convert values of 25(OH)D to nanomoles per liter, multiply by 2.496.

### Table 4. Changes in Lipid Parameters for the Repletion and Control Groups

<table>
<thead>
<tr>
<th>Lipid Parameter</th>
<th>Group 1 (Repletion)</th>
<th>Group 2 (Control)</th>
<th>Intergroup Difference</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total cholesterol, mg/dL</td>
<td>−2.04</td>
<td>−2.81</td>
<td>0.77</td>
<td>0.18 to 1.36</td>
</tr>
<tr>
<td>LDL cholesterol, mg/dL</td>
<td>−2.00</td>
<td>−2.32</td>
<td>0.32</td>
<td>−0.01 to 0.66</td>
</tr>
<tr>
<td>HDL cholesterol, mg/dL</td>
<td>0.23</td>
<td>−0.19</td>
<td>0.42</td>
<td>0.08 to 0.76</td>
</tr>
<tr>
<td>Triglycerides, mg/dL</td>
<td>−1.48</td>
<td>−1.51</td>
<td>0.04</td>
<td>−2.16 to 2.23</td>
</tr>
</tbody>
</table>

CI indicates confidence interval; LDL, low-density lipoprotein; and HDL, high-density lipoprotein.
ships, which show a stepwise association of higher 25(OH)D levels with better lipid panel results. Furthermore, compared with NHANES III, our data contained a greater proportion of patients with hypertension (32.5% versus 28.4%) and diabetes mellitus (29.9% versus 8.4%), which is more reflective of the patient population at increased cardiovascular risk and those seeking medical care.17

The difference in lipid levels between the optimal and deficient vitamin D groups in our cross-sectional study suggests a possible 12% reduction in the imputed relative risk of cardiovascular disease.22-23 Association studies, however, do not prove cause and effect.

RCTs have been published to investigate a causal relationship between vitamin D supplementation and changes in the lipid panel.5-9,11 The largest was the Women’s Health Initiative (WHI). A subgroup analysis of 1191 women found no effect of vitamin D supplementation on lipids over a 5-year period.7 However, the WHI highlights many pitfalls common to prior studies, preventing a definitive conclusion of the effect of vitamin D repletion on lipids.24 First, many study participants were not vitamin D deficient at baseline. Furthermore, the dose of vitamin D (400 IU/day) was likely too small to meaningfully separate treatment and placebo groups, especially when subjects in both arms were allowed to take nonstudy vitamin D supplements. A third limitation was the coadministration of calcium supplements, which may have confounded the effect of vitamin D. There was also relatively poor compliance; only 60% of participants took >80% of the study drug. Other trials suffered from small sample sizes that lacked sufficient statistical power.5-14,25 Thus, there are no intervention studies that clearly address the effect of vitamin D repletion on lipid levels.

A new generation of vitamin D supplementation trials may provide more definitive evidence of vitamin D supplementation on heart disease outcomes.21 These well-powered trials use a higher dose of vitamin D than the WHI and will test the effect of vitamin D without calcium. However, they do not specifically target vitamin D deficiency, and the results will not be available for several years.

In the absence of rigorous RCTs, we used the Quest Diagnostics database to conduct a retrospective cohort analysis. This method has several advantages over association studies. Foremost, it presents a different type of evidence by analyzing changes in 25(OH)D over time to directly test the effect of raising 25(OH)D from deficient to optimal levels. The database was large enough to identify 8592 individuals who met the specified inclusion criteria. The longitudinal patient cohorts were derived from the cross-sectional patient pool. As a surrogate for active intervention, we identified large changes in 25(OH)D levels in serial measurements over a relatively short time period (between 4 and 26 weeks, inclusive). Although season and diet can influence 25(OH)D levels, the almost tripling of mean 25(OH)D levels is best explained by pharmacological intervention. This is supported by the large rise in 25(OH)D2, which is derived exclusively from exogenous sources. To better approximate a controlled trial in which changes in lipid-lowering therapy would be precluded, we excluded individuals in the first and fourth quartiles of changes in LDL cholesterol level. Our cohort analysis showed that the magnitude and direction of the changes in serial lipid values were remarkably inconsistent with the association data. Therefore, vitamin D repletion may fail to mimic the change in the lipid panel expected from association studies. To the best of our knowledge, this is the first time this discordance has been shown.

It is unclear why vitamin D supplementation appears not to improve the lipid profile. The simplest explanation may be that vitamin D has no effect on lipid metabolism. Vitamin D status may be a surrogate marker of health without a causal role. For example, obesity in particular has been independently associated with low 25(OH)D levels and dyslipidemia.26-27 Indeed, weight loss raises 25(OH)D levels and improves the lipid profile.28,29 Because vitamin D is fat soluble, adipose tissue may serve as a site of sequestration of vitamin D, effectively trapping it and lowering circulating levels of 25(OH)D. This phenomenon may explain the associations between 25(OH)D levels and the lipid profile and the failure of 25(OH)D repletion to improve the lipid profile. Another possibility is that the lipid profile influences vitamin D levels and not the converse; dyslipidemia itself may lower vitamin D levels. Alternatively, reports have demonstrated that rosuvastatin, atorvastatin, simvastatin, and lovastatin can lead to a significant rise in 25(OH)D levels over a period of weeks.30-33 Therefore, statin use may contribute to a healthier lipid profile and higher 25(OH)D levels without a direct effect of vitamin D on lipids. Finally, vitamin D absorbed through the gut may have different effects on lipid metabolism from vitamin D synthesized in the skin. Intestinal epithelium possesses 25-hydroxylation and 1-a-hydroxylase activity.34-36 Oral vitamin D can be converted locally to the active 1,25-dihydroxyvitamin D metabolite and induce autocrine signals within enterocytes. Indeed, vitamin D is known to stimulate Fgf15 production by intestinal epithelia, which alters bile acid homeostasis in mice.37 How changes in FGF19 (the human homolog of Fgf15) in response to vitamin D supplementation may affect cholesterol, the precursor of bile acids, remains to be studied.

There are limitations to our methods. Patient medical records were unavailable, which may have led to inadequate recognition of factors that influence the lipid panel such as diabetes mellitus and dietary history, as well as potential confounders including body mass index, physical activity, sun exposure, or medications. In addition, although we were unable to evaluate the impact of ethnicity, there are no ethnicity-specific thresholds for 25(OH)D deficiency or treatment. When possible, we developed database rules to approximate exclusion criteria that RCTs might use to explore the causal relationship between vitamin D repletion and the lipid panel. We attempted to eliminate patients with poorly controlled diabetes mellitus and patients who may not have been adequately and consistently fasting by imposing criteria related to glucose levels. Similarly, we attempted to limit the confounding effects of statin therapy by restricting the study population to patients who did not have large changes in LDL cholesterol between the 2 visits.

Our specific method limited the study population to the middle 2 quartiles of changes in LDL cholesterol, excluding patients on either end of the distribution. We assessed the
sensitivity of our results to this exclusion criterion by replicating the analysis for each of the 4 quartiles (data on request). For 3 of the 4 quartiles (second, third, and fourth), we found no meaningful association of vitamin D repletion with changes in the lipid profile. Only in individuals with the largest decreases in LDL cholesterol (quartile 1, defined as patients who had a decrease of >15 mg/dL in LDL cholesterol within a 4- to 26-week period) was there an association of vitamin D repletion with lowering LDL cholesterol and triglycerides. The mean decrease in LDL cholesterol for patients in this quartile was −42 mg/dL, highly suggestive of medical intervention. In addition, the vitamin D–attributable change in LDL cholesterol was <14% (−5.8 mg/dL) of the total observed change (−42.0 mg/dL). Patients in this first quartile were most likely confounded by statin therapy; the sharp changes in LDL cholesterol are more likely to be due primarily to changes in statin therapy rather than vitamin D supplements. Therefore, we believe our sensitivity analysis validates the use of database rules to exclude patients who are most likely affected by large, first-order confounding effects outside the scope of the scientific inquiry being pursued.

In addition, we do not know the clinical reason why these patients underwent vitamin D and lipid testing, which may represent other confounding factors. We explored the sensitivity of our results to potential confounding, latent effects that might have been present in baseline characteristics. We developed a propensity score model to define the repletion and control groups. We built a logistic regression model that tries to explain membership in the repletion group using available baseline characteristics. Statistically significant predictors included age, initial 25(OH)D result stratum, initial LDL cholesterol level, initial triglycerides level, abnormal calcium results (predefined reference laboratory reference range), and ICD-9 code evidence of dyslipidemia (ICD-9 code 272). Stratification matching with balancing verification was used to match control group results to repletion group results. The results (data on request) are highly consistent with the findings presented here.

Although the longitudinal study was designed as an efficient alternative to a resource-intensive RCT, it is an observational study. Therefore, although the results from this large data-mining analysis show that an increase from deficient to optimal 25(OH)D status is not associated with an improvement in the lipid profile, a definitive conclusion on the effect of vitamin D supplementation on lipids should await the results of large RCTs. However, until such results are available, this study challenges the utility of extrapolating the cross-sectional associations between vitamin D and lipids into a rational for treating patients with vitamin D supplements to improve the lipid profile.

The epidemiological evidence, based largely on association studies, suggests a role for higher 25(OH)D levels in protecting against cardiovascular disease. However, this level of evidence does not prove a causal relationship, and until compelling evidence is available to inform clinical practice, longitudinal analyses of large patient laboratory databases are valuable tools for studying unresolved health questions. With the benefit of serial testing in clinical practice, we now present evidence of an uncoupling between vitamin D and lipids for association versus intervention. In contrast to the cross-sectional association between 25(OH)D levels and a healthier lipid profile, raising 25(OH)D levels from deficient to optimal in a cohort neither improved nor worsened the lipid profile. This suggests that a higher level of 25(OH)D may simply be a passive marker of better cardiovascular health.

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Disclosures
X. Huang, M.A. Odeh, and Dr Kaufman are employees of and own stock in Quest Diagnostics. The other authors report no conflicts.

References
Vitamin D deficiency is common. Low levels of serum 25-hydroxyvitamin D \([25(OH)D]\), the biomarker of vitamin D status, are associated with cardiovascular risk factors, including dyslipidemia. However, clinical trials have yet to show a role for vitamin D repletion in reducing cardiovascular disease or improving the lipid profile. Prospective trials of vitamin D supplementation are underway but will take years to complete and are extremely expensive. We analyzed the Quest Diagnostics clinical database as an expedient and cost-effective method of investigating the relationship between 25(OH)D levels and blood lipids. This study provided data from a clinically relevant, “real-world” setting to verify the cross-sectional associations between 25(OH)D deficiency and the lipid profile. In the same population, we explored whether changes in 25(OH)D from the deficient range (\(<20\) ng/mL) to the optimal range (\(30–100\) ng/mL) were associated with beneficial effects on blood lipids. Our cross-sectional analysis found that higher 25(OH)D levels strongly correlated with a healthier lipid profile: lower total and low-density lipoprotein cholesterol, higher high-density lipoprotein cholesterol, and lower triglycerides. In contrast, our longitudinal analysis found that raising 25(OH)D levels from \(<20\) to \(>30\) ng/mL did not have an effect on low-density lipoprotein cholesterol or triglycerides, whereas total and high-density lipoprotein cholesterol both increased \(<1\) mg/dL. Thus, it is misleading to conflate the epidemiological association of low 25(OH)D levels and dyslipidemia with a presumed benefit of vitamin D supplementation. Until long-term studies are available, clinicians should be cautious and should not expect that vitamin D supplementation will treat hypercholesterolemia in patients who are vitamin D deficient.
Vitamin D May Not Improve Lipid Levels: A Serial Clinical Laboratory Data Study
Manish P. Ponda, Xiaohua Huang, Mouneer A. Odeh, Jan L. Breslow and Harvey W. Kaufman

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The online version of this article, along with updated information and services, is located on the World Wide Web at:
http://circ.ahajournals.org/content/126/3/270

Data Supplement (unedited) at:
http://circ.ahajournals.org/content/suppl/2012/06/20/CIRCULATIONAHA.111.077875.DC1

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Supplemental Analysis

To control for the potential effects of seasonal variation and differences in the interval between testing, regression analyses were applied to the longitudinal study population. Seasonal adjustments to all four lipid measurements (total, LDL and HDL cholesterol and triglycerides) were made using Berliner Verfuhren (BV) trend-cycle technique with age and gender as covariates. The study population data spanned an 18 month period – which was insufficient for detecting seasonal patterns. Instead, we estimated the BV trend-cycle parameters using a random sample of 10 million lipid panel results from the larger Quest Diagnostics database measured over 36 months (January 2008 to December 2010). The BV trend-cycle decomposition regression is reported in supplemental Table S1. Seasonality was detected for all lipid panel components. Comparisons of actual and fitted mean values are illustrated in supplemental Figure S1.

The measured trend-cycle component was then subtracted from the actual lipid profile measurements for each visit of the study population. The resulting values are age-, gender-, trend-, and seasonally-adjusted lipid measurements (“adjusted lipid values”). Changes in the adjusted lipid values were regressed against dummy variables indicating repletion or control group status, as well as the number of weeks between the initial and final tests, which varied from 4 to 26 weeks. Dependencies in lipid measurements implied by the Friedewald equation were accommodated using a three-staged system fit regression model that explicitly accounted for covariance in the lipid measurements. The statistical significance of differences in the parameter estimates measuring lipid changes for the repletion and control groups was assessed using two-sample, unpaired t-tests with
unequal variances (Table S2). The seasonally-adjusted inter-group differences were not statistically significant when accounting for the interval between testing ($P<0.05$). Therefore, the findings that vitamin D repletion has minimal clinical impact on lipid profile and implied cardiovascular risk hold even after correcting for seasonality and the interval between testing.

References for Supplemental Analysis:


Supplemental Table S1

Table S1. BV trend-cycle decomposition regression equation and parameter estimates

<table>
<thead>
<tr>
<th>Lipid Parameter (mg/dl)</th>
<th>Intercept</th>
<th>Trend</th>
<th>Age</th>
<th>Gender</th>
<th>cos(2πt/12)</th>
<th>sin(2πt/12)</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Cholesterol</td>
<td>222.86</td>
<td>-0.008</td>
<td>-0.479</td>
<td>-16.41</td>
<td>1.298</td>
<td>-0.023</td>
<td>0.056</td>
</tr>
<tr>
<td>LDL Cholesterol</td>
<td>140.073</td>
<td>-0.012</td>
<td>-0.535</td>
<td>-6.867</td>
<td>1.125</td>
<td>0.094</td>
<td>0.035</td>
</tr>
<tr>
<td>HDL Cholesterol</td>
<td>55.244</td>
<td>0.029</td>
<td>0.029</td>
<td>-11.448</td>
<td>0.140</td>
<td>0.159</td>
<td>0.124</td>
</tr>
<tr>
<td>Triglycerides</td>
<td>137.704</td>
<td>-0.121</td>
<td>-0.121</td>
<td>9.604</td>
<td>0.125</td>
<td>1.397</td>
<td>0.005</td>
</tr>
</tbody>
</table>

* All parameter estimates reported are significant at p < 0.05 level.

\[
y_{i,t} = \alpha_i + \lambda_i \tau + \omega_i^1 \cos\left(\frac{2\pi t}{12}\right) + \omega_i^2 \sin\left(\frac{2\pi t}{12}\right) + \beta_i^1 \text{AGE} + \beta_i^2 \text{GENDER} + \epsilon_{i,t}
\]

where \( y \) = dependent variable

\( l \in \{ \text{Total cholesterol, LDL cholesterol, HDL cholesterol, Triglycerides} \} \)

\( t \in \{1, 2, ..., 36\} = \text{month of testing} \)

\( \alpha = \text{intercept} \)

\( \lambda_i \tau = \text{linear trend component} \)

\( \omega_i^1 \cos\left(\frac{2\pi t}{12}\right) + \omega_i^2 \sin\left(\frac{2\pi t}{12}\right) = \text{monthly cycle (seasonal) component} \)

\( \text{AGE} \in \{40 - 80 \text{ years}\} \)

\( \text{GENDER} = \begin{cases} 
0 \text{ if female} \\
1 \text{ if male} 
\end{cases} \)

\( \epsilon = \text{random error term} \)
Supplemental Table S2

Table S2. Three Stage System Fit Regression Results Measuring Changes in Lipid Values (mg/dl) for Repletion and Control Groups

<table>
<thead>
<tr>
<th>Lipid Parameter (mg/dl)</th>
<th>Group I (Repletion)</th>
<th>Group II (Control)</th>
<th>Inter-group Difference</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Cholesterol</td>
<td>-4.02</td>
<td>-4.91</td>
<td>0.90</td>
<td>(-0.43, 2.23)</td>
</tr>
<tr>
<td>LDL Cholesterol</td>
<td>-2.76</td>
<td>-3.26</td>
<td>0.50</td>
<td>(-0.28, 1.27)</td>
</tr>
<tr>
<td>HDL Cholesterol</td>
<td>0.13</td>
<td>-0.37</td>
<td>0.49</td>
<td>(-0.28, 1.26)</td>
</tr>
<tr>
<td>Triglycerides</td>
<td>-6.96</td>
<td>-6.44</td>
<td>-0.52</td>
<td>(-5.08, 4.43)</td>
</tr>
</tbody>
</table>

Supplemental Figure 1. Comparison of actual vs fitted mean lipid measurements

- To convert values of total cholesterol, LDL cholesterol, and HDL cholesterol to mmol/l multiply by 0.02586
- To convert values of triglycerides to mmol/l multiply by 0.1129