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Correlates and prevalence of insufficient 25-hydroxyvitamin D status in black and white older adults: The Health ABC Study

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Abstract

Objective—Vitamin D insufficiency is associated with increased risk for age-related disease and mortality, leading to increased interest in measuring circulating 25-hydroxyvitamin D [25(OH)D]. Although blacks are more likely to have lower 25(OH)D than whites, whether the predictors of 25(OH)D are similar in blacks and whites is unclear. Therefore, we determined the prevalence and correlates of vitamin D insufficiency in black and white older adults.

Design—Cross-sectional.

Setting—Health, Aging and Body Composition (Health ABC) Study.

Participants—977 black and 1604 white adults aged 70–81 years.

Measurements—Logistic regression and classification and regression tree analysis were used to identify correlates of vitamin D insufficiency (25(OH)D <30 ng/mL) in blacks and whites separately.

Results—The prevalence of 25(OH)D insufficiency was 84% in blacks and 57% in whites. Seventy-six percent of blacks and 56% of whites did not take a multivitamin; those who did not take a multivitamin were more likely to be vitamin D insufficient [OR (95% CIs): blacks 5.17 (3.47–7.70); whites 2.56 (2.05–3.19)]. Additional risk factors for vitamin D insufficiency in blacks included vitamin D-containing supplement use, female gender and obesity while in whites included winter season, low dietary vitamin D intake, obesity, type 2 diabetes, and female gender.

Conclusion—Vitamin D insufficiency was more prevalent in blacks than whites. Not consuming a multivitamin increased the odds of vitamin D insufficiency in both blacks and whites.

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Conflicts:

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Knowledge of additional risk factors, such as dietary intake and co-morbid conditions, may help identify older adults who are likely to be vitamin D insufficient.

Keywords

vitamin D; insufficiency; race; prevalence; determinants

INTRODUCTION

Vitamin D insufficiency has been associated with increased risk for several age-related chronic diseases, impaired physical function, and mortality in older age¹⁻³. Vitamin D status is measured clinically using the circulating concentration of 25-hydroxyvitamin D [25(OH)D]. It is generally accepted that 25(OH)D concentrations of at least 20 ng/mL (50 nmol/L; to convert to nmol/L, multiply by 2.496) are needed to prevent an elevation in parathyroid hormone (PTH) and maintain skeletal health, as recommended recently by the Institute of Medicine (IOM)⁴ and others⁵⁻⁷. Since vitamin D has many physiological functions beyond bone, experts have suggested 25(OH)D concentrations higher than 30 ng/mL (75 nmol/L) should be maintained to ensure vitamin D adequacy to meet both the calcemic and non-calcemic requirements^{5;8-10}, which is supported by several reports that serum 25(OH)D $\geq$ 30 ng/mL 25(OH)D is associated with improved cardiometabolic and functional outcomes⁹⁻¹². Whether vitamin D insufficiency is defined as <30 ng/mL or <20 ng/mL of circulating 25(OH)D, the prevalence is increasing among older Americans^{13;14} and is more common in blacks than in whites.

Sunlight, the primary source of vitamin D, is synthesized in the skin upon exposure to UVB light. However, the ability to synthesize vitamin D cutaneously decreases with age, and is also reduced in African Americans^{15;16}. In addition to age and race, inadequate vitamin D intake, increased adiposity, and chronic disease also contribute to vitamin D insufficiency⁹. However, few studies have examined the determinants of vitamin D status in blacks separately from whites¹⁷⁻¹⁹ and none have specifically examined the determinants of vitamin D insufficiency in older black and white adults. Furthermore, although epidemiological evidence of the association between vitamin D insufficiency and chronic disease, physical function and mortality has accumulated^{1-3;17;20-22}, some of these associations appear to differ by race^{15;23-25}. Thus, it is important to identify the extent to which modifiable and non-modifiable factors contribute to vitamin D insufficiency in order to effectively design and implement supplementation trials to more definitively determine vitamin D's effect on health outcomes in older black and white adults and to help determine for whom 25(OH)D screening and/or vitamin D supplementation might be appropriate.

Therefore, the purpose of these analyses was to determine the prevalence and determinants of vitamin D insufficiency in community-dwelling older black and white adults separately, according to the 30 ng/mL 25(OH)D threshold of insufficiency. We also examined the prevalence and determinants of vitamin D insufficiency using 20 ng/mL 25(OH)D as the threshold, since the definition of sufficient 25(OH)D remains to be clarified, and persons with 25(OH)D below this threshold may be at even greater risk for vitamin D-related skeletal and non-skeletal co-morbidities.

METHODS

Study Population

The Health ABC cohort consists of 3075 well-functioning community-dwelling black and white older adults who were recruited between April 1997 and June 1998 from a random sample of white and all black Medicare-eligible residents of Pittsburgh, PA (40.4°N latitude)

and Memphis, TN (35.2°N latitude). At the time of enrollment, all Health ABC participants were 70–79 yrs old, reported no difficulty walking ¼ mile, climbing 10 stairs, or performing activities of daily living, were free of life-threatening illness, and planned to remain in the geographic area for at least 3 years. Unless indicated otherwise, data for these cross-sectional analyses were obtained at the 12-month follow-up visit (year 2) when dietary intake and serum 25(OH)D were measured. Participants who did not return for the year 2 visit (n=77) or were missing data on serum 25(OH)D (n= 205), dietary intake (n=103) and additional pertinent covariates (n=109) were excluded from these analyses. The final sample included 2581 participants (1604 white and 977 black). All participants provided written informed consent and all protocols were approved by the institutional review boards at both study sites.

Vitamin D status

Blood samples were taken at the year 2 clinic visit (1998–99) after an overnight fast and stored at –70°C until time of analysis. Serum 25(OH)D concentrations were measured using a 2-step radioimmunoassay (25-Hydroxyvitamin D 125I RIA Kit, DiaSorin, Stillwater, Minn., USA) at the University of Georgia. The inter-assay coefficient of variation was 6.78% for log-transformed values. For our primary analysis, 25(OH)D <30 ng/mL was considered insufficient based on the most recent expert consensus opinion^{5,9}. We also examined 25(OH)D <20 ng/mL.

Potential correlates of vitamin D status

At the year 2 clinic visit, dietary intake over the previous year was estimated using an interviewer-administered 108-item Food Frequency Questionnaire (FFQ), which was developed specifically for Health ABC. The FFQ food list was derived using 24-hour recall data obtained from NHANES III for non-hispanic black and white adults >65 yrs old, residing in the Northeast or South. The Health ABC FFQ was analyzed for micronutrient and macronutrient content using the Block Dietary Data System²⁶. To determine dietary supplement and medication use, participants were asked to bring to their clinic visit all medications and supplements they were currently taking. If a supplement had more than 3 vitamin or mineral ingredients, it was considered a multivitamin. If a supplement contained 3 or fewer ingredients, the individual nutrient ingredients were recorded. Vitamin D-containing supplements were defined as supplements containing 3 or fewer ingredients, one of which was vitamin D. Calcium-containing supplements were defined as supplements containing 3 or fewer ingredients, one of which was calcium. A supplement containing both calcium and vitamin D was considered as both a calcium supplement and a vitamin D supplement. Body weight and height were measured using a standard balance-beam scale and Harpenden stadiometer (Holtain Ltd., Crosswell UK), and BMI was calculated as weight (kg)/(height (m))². Physical activity was self-reported as the number of minutes per week spent walking. Information on prevalent cardiovascular disease (CVD), diabetes, osteoporosis, hypertension, and knee osteoarthritis (knee pain) was obtained from self-report, clinic data, and medication use. At the baseline clinic visit, demographic and lifestyle characteristics, including age, gender, race, education, smoking status, and alcohol intake, were ascertained using an interviewer-administered questionnaire.

Biochemical measures—Serum C-reactive protein (CRP) was measured using ELISA (Calbiochem, San Diego, CA). Serum creatinine and total cholesterol were measured using a colorimetric technique on a Johnson & Johnson Vitrols 950 Analyzer (Johnson & Johnson, New Brunswick, NJ) and used to calculate the estimated glomerular filtration rate (eGFR) using the abbreviated Modification of Diet in Renal Disease equation.

Statistical analyses

Differences in vitamin D insufficiency by race were compared using a t-test for continuous (natural log) 25(OH)D. Initially we calculated the odds ratios (95% confidence intervals) for serum 25(OH)D <30ng/mL and <20ng/mL for blacks compared to whites, adjusted for season. Because our overall aim was to determine race-specific determinants of vitamin D status and the distribution of vitamin D insufficiency in blacks and whites were disparate (Figure 1), subsequent analyses were stratified by race. The relationship between categories of serum 25(OH)D (<20 ng/mL, 20-<30 ng/mL, ≥30 ng/mL) and participant characteristics were analyzed using chi-square tests for categorical variables. Differences in continuous exposures were also examined across categories of serum 25(OH)D using general linear models. Logistic regression with backward selection was used to identify predictors of vitamin D insufficiency defined as 25(OH)D <30 ng/mL and as <20 ng/mL separately in whites and blacks. Initially, the full models contained the following predictors: age, gender, vitamin D supplement use, multivitamin use, calcium supplement use, calcium intake (<1000 mg/d or ≥1000 mg/day), vitamin D intake (<400 IU/day or ≥400 IU/day), obesity (BMI ≥30 kg/m² or <30 kg/m²), physical activity participation (none or any), current drinking (none, <1/week, 1–7/week, >7/week), smoking status (current, former, never), site (Pittsburgh, Memphis), season (Dec–Feb, Mar–May, June–Aug, Sept–Nov), kidney function (eGFR <60 ml/min or ≥60 ml/min), prevalent diabetes, cardiovascular disease, hypertension, osteoporosis, or knee osteoarthritis (knee pain), and inflammation (CRP >3 mg/L). The proportion of European ancestry (admixture %) was also included in the full model for blacks²⁷. Potential determinants were retained in the model if they were associated with vitamin D insufficiency at $p < 0.20$, and the retained predictors were included in a second backward selection logistic regression analysis. The odds ratios (95% confidence intervals) for being vitamin D insufficient associated with the final predictors were calculated. The discriminative power of each logistic regression model was evaluated using the c-statistic. Multivariable linear regression with backward elimination was also used to determine predictors of serum 25(OH)D as a continuous (natural-log transformed) outcome in black and white adults.

The predictors that were retained in the final logistic regression models for blacks and whites were entered into classification tree analysis for model verification and to explore hierarchical relationships among predictor variables. Classification and Regression Tree (CART, version 6.0, Salford Systems, San Diego, CA) is an analysis software that uses a non-parametric technique and recursive partitioning to identify optimal cut-points in the data (referred to as nodes) and generates a classification tree that identifies those at greater risk for the outcome [25(OH)D <30 ng/mL]^{28,29}. Blacks and whites were analyzed separately. For each analysis, generally the tree with the smallest misclassification rate and highest area under the curve (AUC) was considered optimum. However, a tree with a misclassification rate statistically indistinguishable from the minimum and near maximum AUC was considered optimum due to a considerable reduction in nodes used in the tree in rare cases.

RESULTS

The mean (SD) serum 25(OH)D concentration was lower in blacks compared to whites overall (21.0(10.4)ng/mL vs 29.2(10.9)ng/mL, $p < 0.001$) and during each season [March–May: blacks=21.2(12.3)ng/mL, whites=28.4(10.5)ng/mL; June–August: blacks=22.1(8.0)ng/mL, whites=30.5(8.7)ng/mL; Sept.–Nov.: blacks=21.2(8.5)ng/mL, whites=31.6(13.0)ng/mL; Dec.–Feb.: blacks=19.2(9.8)ng/mL, whites=26.6(10.4)ng/mL; all $p < 0.001$]. The distribution of serum 25(OH)D by race is shown in Figure 1. Among blacks, 84% had serum 25(OH)D <30 ng/mL, and 54% had serum 25(OH)D <20 ng/mL. Among whites, 57% had serum 25(OH)D <30 ng/mL and 18% had serum 25(OH)D <20 ng/mL. Blacks were over four times more likely to have 25(OH)D <30 ng/mL [OR(95%CI): 4.36 (3.57–5.33), adjusted for

season] and almost six times more likely to have 25(OH)D <20 ng/mL [OR(95% CI): 5.78 (4.79–6.92), adjusted for season], compared to whites.

The descriptive characteristics of black and white study participants according to serum 25(OH)D categories are shown in Tables 1 and 2. Overall, 73% of blacks and 51% of whites did not report taking multivitamins or dietary supplements that contained vitamin D. Over 90% of both black and white participants reported low dietary vitamin D intake (<400 IU/day). Following adjustment for age, gender, BMI, and season, among blacks there was a significant trend for higher dietary vitamin D intakes across the increasing 25(OH)D categories, but dietary calcium intake did not differ across 25(OH)D categories (Table 1). Among whites there were significant trends for higher vitamin D and calcium dietary intakes across increasing serum 25(OH)D categories (Table 2). Vitamin D status was associated with vitamin D-containing supplement use, season, obesity and prevalence of type 2 diabetes among blacks and whites, and with physical activity, kidney function and prevalence of CVD among whites in unadjusted analyses.

Participants who were excluded from these analyses due to missing covariate data (n=212) were more likely to be black, not take dietary supplements or participate in physical activity, and have type 2 diabetes, less than a high school education and lower mean serum 25(OH)D concentrations (23.2±10.9ng/mL vs. 26.1±11.5ng/mL, p=0.001), compared to those included in our sample.

Regression analyses

The odds ratios associated with identified predictors of vitamin D insufficiency in blacks are shown in Table 3. Among blacks, the odds of having 25(OH)D <30 ng/mL for those who did not report taking a multivitamin were more than five-fold greater than the odds for those who reported taking a multivitamin. Similarly, the odds for 25(OH)D <30 ng/mL were approximately three times higher for blacks who did not report taking a vitamin D-containing supplement compared to blacks who did. Being female, obese or living in Pittsburgh were all associated with greater odds of having 25(OH)D <30 ng/mL in blacks. Blacks were also more likely to have 25(OH)D <20 ng/mL during the winter.

The odds ratios associated with identified predictors of vitamin D insufficiency in whites are shown in Table 4. Similar to blacks, multivitamin use was identified as a primary determinant of vitamin D insufficiency, defined according to either threshold, in whites. Obesity and prevalent CVD were also associated with greater odds of being vitamin D insufficient. Being female, having diabetes, and normal kidney function were associated with a higher odds of having 25(OH)D <30 ng/mL, while prevalent osteoporosis was associated with lower odds of 25(OH)D <30 ng/mL. Vitamin D intake <400 IU/day, lack of physical activity, and having 25(OH)D measured in the winter and spring season were associated with higher odds of having 25(OH)D <30 ng/mL and <20 ng/mL.

The results of linear stepwise models were comparable to those of the logistic stepwise models. Among blacks, vitamin D-containing supplements (unstandardized beta-coefficient (unstd β)=0.24), calcium-containing supplements (unstd β =0.17), and/or multivitamin (unstd β =0.31) were positively associated with (natural log) 25(OH)D (all p<0.001), and female gender (unstd β =−0.10, p<0.001), obese BMI (unstd β =−0.06 p=0.018), winter (unstd β =−0.14, p<0.001, compared to summer), spring (unstd β =−0.05, p=0.049, compared to summer), and living in Pittsburgh (unstd β =−0.09, p<0.001) were inversely associated 25(OH)D. Among whites, use of vitamin D-containing supplements (unstd β =0.09, p<0.001), calcium-containing supplements (unstd β =0.07, p<0.001), multivitamin (unstd β =0.21, p<0.001), prevalent osteoporosis (unstd β =0.06, p=0.01), and GFR < 60 (unstd β =0.08, p<0.001) were positively associated with (natural log) serum 25(OH)D, and female

gender (unstd $\beta = -0.12$, $p < 0.001$), obese BMI (unstd $\beta = -0.07$, $p = 0.002$), calcium intake < 1000 mg/day (unstd $\beta = -0.07$, $p = 0.01$), vitamin D intake < 400 IU/day (unstd $\beta = -0.05$, $p = 0.06$), no participation in physical activity (unstd $\beta = -0.05$, $p = 0.003$), prevalent CVD (unstd $\beta = -0.06$, $p = 0.002$), prevalent diabetes (unstd $\beta = -0.06$, $p = 0.01$), high cholesterol (unstd $\beta = -0.04$, $p = 0.01$), winter (unstd $\beta = -0.16$, $p < 0.001$, compared to summer), spring (unstd $\beta = -0.09$, $p < 0.001$, compared to summer), and age (unstd $\beta = -0.01$, $p = 0.04$) were inversely associated with 25(OH)D.

CART Analysis

Overall, the predictors of vitamin D insufficiency identified by our logistic regression analyses were confirmed by CART analysis, with multivitamin use being identified as the main predictor in both blacks and whites. Among blacks, multivitamin and vitamin D-containing supplement use were identified as the main predictors of serum 25(OH)D < 30 ng/mL. Ninety percent of blacks who did not take a multivitamin had 25(OH)D < 30 ng/mL. Even among blacks who did take a multivitamin and/or a vitamin D-containing supplement, the prevalence of 25(OH)D < 30 ng/mL was 66% and 60%, respectively. Among whites, the prevalence of serum 25(OH)D < 30 ng/mL increased to 66% among those who did not take a multivitamin. During winter, 83% of whites who did not take a multivitamin were vitamin D insufficient, based on 25(OH)D < 30 ng/mL. Season, obesity, dietary intake of vitamin D, kidney function, and physical activity were associated with vitamin D insufficiency among whites using CART analysis. The classification trees for 25(OH)D < 30 ng/mL for black and white participants are shown as supplementary on-line Figures S1 and S2.

DISCUSSION

In our sample of well-functioning men and women aged 70–81 years, 84% of blacks had 25(OH)D < 30 ng/mL, while the prevalence among whites was 57%. Furthermore, blacks were more than four times as likely to have 25(OH)D < 30 ng/mL compared to whites. The prevalence of 25(OH)D < 30 ng/mL was lower in Health ABC compared to black and white men and women ≥ 70 years old in NHANES 2001–2004, in which the prevalence of 25(OH)D < 30 ng/mL was approximately 93% in blacks and 73% in whites³⁰. This may be due, in part, to the improved functional status and overall health of Health ABC participants.

Among blacks who reported taking a multi-vitamin or vitamin D-containing supplement, more than 60% had serum 25(OH)D < 30 ng/mL, while 38% of whites who reported taking these supplements had serum 25(OH)D < 30 ng/mL. Dietary supplement use did not appear to have been sufficient enough to increase serum 25(OH)D levels ≥ 30 ng/mL, especially among blacks. It is important to note that supplement use was queried in 1998, when most multivitamins contained 400 IU or less of vitamin D; these levels have increased and many multivitamins currently contain 800 IU. Dose-response studies in blacks and whites suggest an intake of 400 IU/day (10 μ g/d) vitamin D₃ will increase circulating 25(OH)D by 2.8 ng/mL in the absence of sun exposure^{31,32}. It was recently reported that 800 IU/day of vitamin D₃ increased circulating 25(OH)D to 35.4 ng/mL (from a mean baseline value of 12.1 ng/mL) in older adults³². However, outcomes of other studies suggest higher doses may be necessary to achieve 25(OH)D ≥ 30 ng/mL in older adults³³, and higher doses of vitamin D given daily, monthly, or as a single bolus have been shown to be safe and effective for repletion of 25(OH)D in this age-group^{34–37}. The baseline level of 25(OH)D, which is usually lower in blacks, is an important determinant of the response to supplementation, so it is plausible higher supplemental doses would have been required to raise serum levels to 30 ng/mL in the blacks in our cohort, as demonstrated by Aloia et al³⁸. Considering a recent report that a single annual dose of 500,000 IU of vitamin D₃ increased hip fracture risk in older women³⁹, the optimal dosing regimen of vitamin D supplementation for older adults merits investigation.

Consistent with younger age groups, being female and/or obese increased the odds of being vitamin D insufficient in older black adults in Health ABC^{17;19;40}. We also identified several additional risk factors for vitamin D insufficiency among whites. Whites who reported a dietary intake <400IU/day were more likely to have 25(OH)D <30 ng/mL. Season and participation in physical activity were also predictive of vitamin D insufficiency among whites. Because the cutaneous production of vitamin D is greater in whites compared to blacks, whites tend to be more susceptible to seasonal variation in vitamin D status⁴¹. Participation in physical activity was defined according to self-reported walking; thus, it is likely that those who reported walking spent more time outdoors which could influence the cutaneous synthesis of vitamin D. Being female, obese, or having type 2 diabetes was also associated with vitamin D insufficiency among whites, so these characteristics may help discriminate white older adults who are at greater risk for low vitamin D status.

Low dietary vitamin D intake (<400 IU/day) was identified as an important determinant of 25(OH)D <30 ng/mL among whites in Health ABC, but not as a primary determinant among blacks, although dietary intake has been identified as determinant of 25(OH)D in blacks by others^{17;19;40}. In our analyses, we dichotomized vitamin D intake as <400 or ≥400 IU/day because only 6 black and 8 white participants reported dietary intakes ≥800 IU/day and less than 2% of Health ABC participants (15 black and 30 white) reported dietary intakes ≥600 IU/day. In NHANES III (1988–1994), no more than 2% of adults over age 70 met the requirement for vitamin D intake from food alone, which at the time was 600IU/day⁴². The prevalence of dietary vitamin D intake <400 IU/day was similar among blacks (90%) and whites (92%). The IOM recently recommended adults over 70 years old consume 800IU/day of vitamin D and 1200 mg/day of calcium⁴. The overall median (interquartile range) of vitamin D intake in Health ABC was 198(164) IU/day in whites and 159(157) IU/day in blacks and of calcium intakes was 739(444) mg/day in whites and 681(480) mg/day in blacks. Furthermore, 63% of blacks and 51% of whites in Health ABC reported a dietary vitamin D intake <200IU/day. Therefore, to meet the 800IU/day recommendation it is likely black and white older adults will require dietary supplementation.

Whites with type 2 diabetes and CVD were more likely to have 25(OH)D <30ng/ml. These results are consistent with previous analyses of NHANES III that found vitamin D status to be associated with prevalence of type 2 diabetes among whites and Hispanics, but not in blacks, which the authors attributed to blacks being less sensitive to the effects of vitamin D and related hormones²⁵, as has been suggested by others¹⁵. It is plausible the associations between vitamin D status and disease outcomes differ by race because low vitamin D levels are reported to contribute to the increased risk for certain cancers (such as colorectal) and cancer-related mortality in blacks, but not in whites^{24;43;44}. In Health ABC, both black and white participants with osteoporosis were less likely to have insufficient vitamin D. The majority (70%) of participants diagnosed with osteoporosis were on medication to treat osteoporosis, which likely included advisement to take a vitamin D-containing supplement.

Although several have suggested ≥30 ng/mL are needed to meet skeletal and non-skeletal needs for vitamin D^{5;8–10}, ≥20 ng/mL have been considered sufficient to maintain skeletal health⁴, and the concentration of 25(OH)D that is considered sufficient remains controversial^{5;8;9}. We also examined the prevalence and correlates of 25(OH)D <20 ng/mL. Over half of black participants in Health ABC had 25(OH)D <20 ng/mL, while the prevalence among the whites was 18%. Overall, the determinants of 25(OH)D <20 ng/mL were similar to those of 25(OH)D <30 ng/mL. However, some differences were noted. Among blacks, season was associated with 25(OH)D <20 ng/mL, but not <30 ng/mL. Those measured during winter were over twice as likely to have 25(OH)D <20 ng/mL, supporting others who have suggested that winter season contributes to more severe vitamin D insufficiency among blacks⁴⁰. Among whites, the odds of having 25(OH)D <20 ng/mL

were 85% higher among those who did not participate in any physical activity and among those who consumed <1000 mg/day of calcium. Although 25(OH)D <20 ng/mL is not considered to be frank vitamin D deficiency, 9% of black and 2% of white participants had 25(OH)D <10ng/mL which has been considered deficient¹³. Approximately 80% of blacks and whites with 25(OH)D <10 ng/mL were female (Chi square $p<0.001$). Sixty-eight percent of blacks with 25(OH)D <10ng/mL were measured in spring or winter (Chi square $p=0.01$) and 96% of whites below 10 ng/mL reported calcium intakes < 1000 mg/day (Chi square $p=0.02$). Although Health ABC participants with 25(OH)D <10 ng/mL did not significantly from those with ≥ 10 ng/mL in any other way, it is plausible additional differences would have been detected with a larger number of participants with 25(OH)D below this threshold. Since the evidence of vitamin D's role in age-related disease continues to mount, identifying older adults at risk for more severe vitamin D insufficiency or deficiency may be important clinically.

This study has several notable strengths and certain limitations to consider. Importantly, we were able to describe the prevalence and determinants of vitamin D insufficiency in a large sample of black and white adults aged ≥ 70 years to provide insight into which older adults are at risk for vitamin D insufficiency. Although the determinants of vitamin D insufficiency among older adults have been previously described^{17;45;46}, the factors that are associated with specific thresholds of serum 25(OH)D in black and white adults aged ≥ 70 years has not yet been reported. Our results may assist geriatricians in identifying older adults to screen and treat for vitamin D insufficiency as well as researchers who need to identify vitamin D insufficient participants for supplementation trials. In Health ABC, dietary supplement use was not based on self-report. Rather, all participants were asked to bring all medications and supplements they were currently taking to the yearly clinic visit, which were then inventoried and recorded by study personnel. However, the quantity of vitamin D and/or calcium contained in the supplements is not available, so we are unable to determine associations between supplement dose and vitamin D insufficiency. It is likely that the high prevalence of vitamin D insufficiency even among those who reported taking a multivitamin or vitamin D-containing supplement may be because the supplement dose was not high enough to improve 25(OH)D concentrations to ≥ 30 ng/mL. However, we were unable to test this formally. Although we were able to adjust for latitude/location (Memphis vs Pittsburgh) and participation in physical activity, we did not have more specific measures of sunlight exposure and/or use of sunscreen, which have been identified as determinants of 25(OH)D in older adults in other population-based studies^{45;46}. Such measures would have likely explained more of the variability in 25(OH)D in Health ABC and would provide additional pertinent information with respect to additional risk factors for vitamin D insufficiency in older adults. Also, fewer blacks were recruited during the summer (June–August) at the Memphis field center which may have contributed to the association between season and vitamin D insufficiency we observed in whites compared to blacks. Substantial variation in the measurement of serum 25(OH)D, because of different assay methodology, laboratory experience, and differences between assays to recognize the vitamin D₃ and D₂ form equally⁴⁷ make it difficult to make comparisons across studies.

The importance of vitamin D's role in health and disease is becoming more evident, and older adults have been identified as a group for whom the prolonged effects of vitamin D insufficiency may be exacerbated^{14;14;48}. We have identified that the determinants of vitamin D insufficiency differ in black and white older adults. Knowledge of supplement use, dietary intake, physical activity and/or prevalence of co-morbidities such as obesity, type 2 diabetes and/or cardiovascular disease may provide additional pertinent information to identify older adults who are at risk for vitamin D insufficiency and, thus, for whom 25(OH)D screening and/or vitamin D supplementation might be appropriate.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Figure 1.
Distribution of vitamin D status in older black and white adults in Health ABC.

Table 1

Characteristics of black participants (n=977) by serum 25(OH)D concentration [n (%)*, unless indicated otherwise]

	< 20 ng/mL	20–< 30 ng/mL	≥ 30 ng/mL	p-value [†]
Serum 25(OH)D (mean(±SD)ng/mL)	14.8 (±3.7)	24.3 (±2.8)	37.1 (±13.8)	
Age (mean(±SD) yrs)	n(%)	292 (30%)	153 (16%)	
	74.6 (±2.9)	74.3 (±2.9)	74.5 (±2.8)	0.47 [‡]
Female	311 (58.5%)	170 (58.2%)	74 (48.4%)	0.07
Dietary Vitamin D intake <400 IU/d	497 (93.4%)	268 (91.8%)	138 (90.2%)	0.37
mean(±SD) vitamin D intake (IU/d) [§]	185 (±146)	197 (±139)	211 (±140)	0.03 [‡]
Dietary Calcium intake <1000 mg/d	417 (78.4%)	229 (78.4%)	115 (75.2%)	0.68
mean(±SD) calcium intake (mg/d) [§]	736 (±413)	776 (±415)	774 (±416)	0.17 [‡]
No Multivitamin supplement use	471 (88.5%)	199 (68.2%)	73 (47.7%)	<0.001
No Vitamin D-containing supplement use	523 (98.3%)	271 (92.8%)	130 (85.0%)	<0.001
No Calcium -containing supplement use	504 (94.7%)	250 (85.6%)	116 (75.8%)	<0.001
Inflammation: CRP [¶] >3mg/L	315 (59.2%)	149 (51.0%)	81 (52.9%)	0.06
mean(±SD) CRP [¶] (mg/L) [§]	7.3(±2.4)	6.4 (±9.5)	6.8 (±8.7)	0.59 [‡]
Cholesterol ≥200 mg/dl	285 (53.6%)	165 (56.5%)	70 (45.8%)	0.09
mean(±SD) cholesterol (mg/dl)	206 (±41)	209 (±40)	200 (±39)	0.20 [‡]
Obese BMI [¶] (≥30 kg/m ²)	216 (40.6%)	94 (32.2%)	33 (21.6%)	<0.001
mean(±SD) BMI [¶] (kg/m ²)	29.3 (±5.9)	28.2 (±5.2)	27.1 (±4.2)	<0.001 [‡]
Impaired kidney function				
(eGFR [¶] <60 mL/min)	78 (14.7%)	49 (16.8%)	18 (11.8%)	0.36
mean(±SD) eGFR [¶]	77 (±18)	76 (±19)	76 (±16)	0.29 [‡]
No Physical activity (0min/wk)	270 (50.8%)	157 (46.9%)	72 (47.1%)	0.50
Education:				
<High school	230 (43.2%)	117 (40.1%)	55 (36.0%)	0.19
High school graduate	166 (31.2%)	88 (30.1%)	44 (28.8%)	
>High school	136 (25.6%)	87 (29.8%)	54 (35.3%)	
Alcohol intake:				
≥7 /week	36 (6.8%)	13 (4.5%)	8 (5.2%)	0.25
1–7/week	55 (10.3%)	36 (12.3%)	23 (15.0%)	
<1/week	33 (6.2%)	17 (5.8%)	15 (9.6%)	

	< 20 ng/mL	20–< 30 ng/mL	≥ 30 ng/mL	
Smoking:				
None	408 (76.7%)	226 (77.4%)	107 (70.0%)	
Never	229 (43.1%)	146 (50.0%)	67 (43.8%)	0.08
Current	91 (17.1%)	30 (10.3%)	25 (16.3%)	
Former	212 (39.9%)	116 (39.7%)	61 (39.9%)	
Season:				
Sep–Nov	141 (26.5%)	93 (31.9%)	43 (28.1%)	0.006
Dec–Feb	149 (28.0%)	50 (17.1%)	30 (19.6%)	
Mar–May	166 (31.2%)	90 (30.8%)	48 (31.4%)	
Jun–Aug	76 (14.3%)	59 (20.2%)	32 (20.9%)	
Prevalent disease				
CVD	159 (29.9%)	74 (25.3%)	44 (28.8%)	0.38
Diabetes	161 (30.3%)	64 (21.9%)	42 (27.5%)	0.04
Osteoporosis	29 (5.2%)	12 (3.7%)	12 (7.7%)	0.26
Hypertension	375 (70.5%)	205 (70.2%)	107 (70.0%)	0.99
Knee pain/Osteoarthritis	151 (28.4%)	90 (30.8%)	40 (26.1%)	0.56
Site: Memphis	231 (43.4%)	137 (46.9%)	74 (48.3%)	0.44
Pittsburgh	301 (56.6%)	155 (53.1%)	79 (51.6%)	
Admixture % (mean (±SD))	21.9 (±15.3)	24.0 (±16.5)	23.0 (±16.0)	0.40 [‡]

* percents indicate prevalence within 25(OH)D category

[†] p-values are unadjusted based on chi-square analysis, unless otherwise indicated

[‡] p-values are p-for trend based on general linear models, adjusted for age, gender, BMI and season (unless analyzed on that variable); means(±SD) are presented unadjusted

[§] a natural log-transformation was applied to the outcome for formal analysis, however means(±SD) are presented in original scale.

[¶] CRP= C-reactive protein; BMI = body mass index, eGFR= estimated glomerular filtration rate

Table 2

Characteristics of white participants (n=1604) by serum 25(OH)D concentration [n (%)*, unless indicated otherwise]*

	< 20 ng/mL	20–< 30 ng/mL	≥ 30 ng/mL	p-value [†]
Serum 25(OH)D (mean (±SD)ng/mL)	16.6 (±3.5)	25.3 (±2.8)	38.5 (±9.2)	
Age (mean (±SD)) yrs	n (%)	614 (38%)	696 (43%)	
	74.8 (±2.9)	74.9 (±2.9)	74.6 (±2.8)	0.15 [‡]
Female	155 (52.7%)	285 (46.4%)	323 (46.4%)	0.15
Dietary Vitamin D intake <400 IU/d	274 (93.2%)	563 (91.7%)	607 (87.2%)	0.004
mean (±SD) vitamin D intake (IU/d) §	178 (±122)	219 (±127)	235 (±149)	<0.001 [‡]
Dietary Calcium intake <1000 mg/d	248 (84.4%)	465 (75.7%)	506 (72.7)	<0.001
mean (±SD) calcium intake (mg/d) §	719 (±344)	795 (±353)	847 (±430)	<0.001 [‡]
No Multivitamin Supplement use	243 (82.7%)	361 (58.8%)	301 (43.3%)	<0.001
No Vitamin D-containing supplement use	281 (95.6%)	536 (87.3%)	567 (81.1%)	<0.001
No Calcium-containing supplement use	255 (86.7%)	451 (73.5%)	449 (64.5%)	<0.001
Inflammation: CRP [¶] >3mg/L	141 (48.0%)	285 (46.4%)	309 (44.4%)	0.55
mean (±SD) CRP [¶] (mg/L) §	5.6 (±9.4)	5.2 (±10.0)	5.3 (±8.9)	0.64 [‡]
Cholesterol ≥200 mg/dl	163 (55.4%)	309 (50.3%)	328 (47.1%)	0.06
mean (±SD) cholesterol (mg/dl)	207 (±40)	202 (±38)	200 (±35)	0.05 [‡]
Obese BMI [¶] (≥30 kg/m ²)	73 (24.8%)	122 (19.9%)	84 (12.1%)	<0.001
mean (±SD) BMI [¶] (kg/m ²)	27.6 (±4.6)	26.7 (±4.0)	25.7 (±3.8)	<0.001 ^{††}
Impaired kidney function (eGFR [¶] <60 mL/min)	76 (25.9%)	129 (21.0%)	193 (27.7%)	0.02
mean (±SD) eGFR [¶]	71 (±16)	71 (±14)	69 (±14)	0.002 [‡]
No Physical activity (0 min/wk)	140 (47.6%)	190 (30.9%)	205 (29.5%)	<0.001
Education:				
<High school	40 (13.6%)	71 (11.6%)	77 (11.1%)	0.17
High school grad	109 (37.1%)	209 (34.1%)	216 (31.0%)	
>High school	145 (50.0%)	334 (54.5%)	403 (57.9%)	
Alcohol intake:				
≥7 /week	37 (12.6%)	69 (11.2%)	74 (10.6%)	0.79
1–7/week	73 (24.8%)	164 (26.7%)	190 (27.3%)	
<1/week	20 (6.8%)	46 (7.5%)	63 (9.1%)	

	< 20 ng/mL	20–< 30 ng/mL	≥ 30 ng/mL	
Smoking:				
None	164 (55.4%)	335 (54.6%)	369 (53.0%)	
Never	114 (38.8%)	279 (45.4%)	304 (43.7%)	0.13
Current	24 (8.2%)	34 (5.5%)	33 (4.7%)	
Former	156 (53.0%)	301 (49.0%)	359 (51.6%)	
Season:				
Sep–Nov	52 (17.7%)	138 (22.5%)	208 (30.0%)	<0.001
Dec–Feb	120 (40.8%)	196 (31.9%)	141 (20.3%)	
Mar–May	99 (33.7%)	170 (27.7%)	201 (28.9%)	
Jun–Aug	23 (7.8%)	110 (17.9%)	146 (21.0%)	
Prevalent disease				
Cardiovascular disease	100 (34.0%)	177 (28.8%)	171 (24.6%)	0.01
Diabetes	59 (20.1%)	102 (16.6%)	82 (11.8%)	0.002
Osteoporosis	36 (12.2%)	70 (11.4%)	107 (15.4%)	0.09
Hypertension	162 (55.1%)	313 (51.0%)	331 (47.6%)	0.09
Knee pain/osteoarthritis	83 (28.1%)	145 (23.6%)	164 (23.6%)	0.25
Site: Memphis	146 (49.7%)	311 (50.7%)	353 (50.7%)	0.95
Pittsburgh	148 (50.3%)	303 (49.4%)	343 (49.3%)	

* percents indicate prevalence within 25(OH)D category

[†] p-values are unadjusted based on chi-square analysis, unless otherwise indicated.

[‡] p-values are p-for trend based on general linear models, adjusted for age, gender, BMI and season (unless analyzed on that variable); means(±SD) are presented unadjusted

[§] a natural log-transformation was applied to the outcome for formal analysis, however means(±SD) are presented in original scale.

[¶] CRP = C-reactive protein; BMI = body mass index, eGRF= estimated glomerular filtration rate

Table 3

Correlates of 25(OH)D insufficiency among black participants (n=977)*

	<30 ng/ml		<20 ng/ml	
	Odds ratio (95%CI)	p-value	Odds ratio (95%CI)	p-value
No Multivitamin use	5.17 (3.47–7.70)	<0.001	5.10 (3.58–7.26)	<0.001
No Vitamin D-containing supplement use	2.96 (1.32–6.66)	0.008	3.18 (1.28–7.87)	<0.001
No Calcium-containing supplement use	1.75 (0.96–3.46)	0.07	2.35 (1.30–4.27)	0.005
Female	2.03 (1.34–3.09)	0.001	1.52 (1.12–2.06)	0.008
Season Dec–Feb (vs Jun–Aug)	†		2.19 (1.39–3.45)	<0.001
Mar–May	†		1.30 (0.86–1.97)	0.21
Sep–Nov	†		0.97 (0.64–1.48)	0.89
Obese (BMI [‡] ≥30 kg/m ²)	1.84 (1.18–2.88)	0.007	1.56 (1.14–2.12)	0.005
Site (Pittsburgh)	1.51 (1.02–2.22)	0.03	1.57 (1.17–2.10)	0.003
High cholesterol	1.48 (1.01–2.19)	0.05	†	
Smoking – current (vs never)	†		1.84 (1.19–2.84)	0.02
former	†		1.25 (0.92–1.71)	0.61
Calcium intake <1000 mg/d	1.39 (0.89–2.16)	0.15	†	
Prevalent osteoporosis	0.46 (0.21–1.00)	0.05	†	
Type 2 Diabetes	†		1.25 (0.90–1.72)	0.18
Impaired kidney function (eGFR [‡] <60 mL/min)			0.78 (0.53–1.15)	0.21
% Admixture (per 10% increase)	†		0.93 (0.85–1.02)	0.11
c statistic	0.78		0.74	

* Based on logistic regression with backwards elimination; predictors were retained if overall p<0.20;

† indicates predictor did not meet p<0.20 threshold for inclusion

‡ BMI = body mass index, eGFR= estimated glomerular filtration rate

Table 4

Correlates of 25(OH)D insufficiency among white participants (n=1604)*

	< 30 ng/ml		<20 ng/ml	
	Odds ratio (95%CI)	p-value	Odds ratio (95%CI)	p-value
No Multivitamin use	2.56 (2.05–3.19)	<0.001	4.49 (3.19–6.31)	<0.001
Season: Dec–Feb (vs Jun–Aug)	2.45 (1.77–3.41)	<0.001	3.96 (2.39–6.56)	<0.001
Mar–May	1.40 (1.02–1.92)	0.04	3.05 (1.83–5.01)	<0.001
Sep–Nov	0.90 (0.65–1.25)	0.55	1.55 (0.90–2.67)	0.11
Vitamin D intake <400 IU/d	1.85 (1.29–2.64)	<0.001	†	
Obese (BMI [‡] ≥30 kg/m ²)	1.86 (1.37–2.51)	<0.001	1.37 (0.98–1.93)	0.08
Female	1.70 (1.31–2.19)	<0.001	1.90 (1.38–2.61)	<0.001
Impaired kidney function (eGFR [‡] <60 mL/min)	0.62 (0.48–0.79)	<0.001	†	
Prevalent Diabetes	1.45 (1.06–1.99)	0.02	1.30 (0.90–1.89)	0.17
No calcium-containing supplement use	1.42 (1.05–1.93)	0.02	1.81 (1.16–2.85)	0.01
No vitamin D-containing supplement use	1.34 (0.92–1.96)	0.13	2.26 (1.13–4.50)	0.02
Prevalent osteoporosis	0.70 (0.50–0.99)	0.04	†	
No Physical activity (0 min/week walk time)	1.27 (1.00–1.58)	0.05	1.85 (1.39–2.46)	<0.001
Prevalent Cardiovascular disease	1.32 (1.03–1.69)	0.03	1.44 (1.06–1.96)	0.02
High cholesterol	1.22 (0.98–1.52)	0.08	1.30 (0.97–1.73)	0.08
Age (per year)	1.05 (1.01–1.09)	0.01		
Calcium intake <1000 mg/d	†		1.85 (1.39–2.66)	<0.001
Smoking – current (vs never)	†		1.73 (0.98–3.06)	0.11
former	†		1.21 (0.89–1.65)	0.66
c statistic	0.72		0.78	

* Based on logistic regression with backwards elimination; predictors were retained if overall p<0.20;

† indicates predictor did not meet p<0.20 threshold for inclusion

‡ BMI = body mass index, eGFR= estimated glomerular filtration rate