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Research Article

The Interrelationships of Vitamin D, Inflammation and Obesity in a Middle Eastern Population - A Pilot Study

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Abstract

Background: The prevalence of obesity and its health implications have risen to undesirable levels across genders and ages worldwide. Genetic, environmental, and behavioral factors are known to influence the development of obesity. Vitamin D deficiency is also linked to central obesity, which has public health implications.

Objectives: The study was conducted to determine the relationship between obesity, and inflammation on Vitamin D levels.

Methods: A cross-sectional study was conducted using sixty subjects, aged 19-65. Informed consent was obtained to access their medical records for Vitamin D levels, body mass index (BMI) and socio-demographic data. The inflammatory cytokines associated with obesity, Tumor necrosis factor-alfa (TNF-α), Interleukin 6 (IL-6) and C-reactive protein (CRP), were measured.

Results: A significant association between IL-6 (β = -3.12, SE = 1.39, P = 0.031), TNF-α (β = 5.64, SE = 2.18, P = 0.014), and CRP (β = -0.32, SE = 0.14, P = 0.031) with Vitamin D was observed, after adjusting for demographics. The correlation of IL-6, CRP and Vitamin D was significant irrespective of age or gender. Dietary intake of cod liver or fish oil contributed significantly to Vitamin D sufficiency.

Conclusion: In this study, inflammatory markers TNF-α, IL-6, and CRP were significantly associated with Vitamin D levels. Dietary intake was also significantly associated with Vitamin D levels. Obesity was associated with increased levels of inflammatory markers TNF-α, IL-6, and CRP. Furthermore, the findings of this study suggest that intake of cod liver or fish oil significantly improved blood Vitamin D levels, especially in obese subjects.

Keywords: *Vitamin D Deficiency; 25-Hydroxyvitamin D; Obesity; Inflammation Markers; Tumor Necrosis Factor-α; Interleukin 6; C-Reactive Protein; Cod Liver*

Abbreviations

BMI: Body Mass Index; CRP: C-Reactive Protein; IL-6: Interleukin-6; TNF-α: Tumor Necrosis Factor Alpha; GLM: Generalized Linear Regression Model

Introduction

Obesity is a worldwide epidemic associated with comorbidities, including metabolic syndrome (MetS) [1,2]. Approximately five hundred million adults worldwide are classified as obese, and about 1.5 billion are considered overweight [3]. Increased mortality, morbidity, and healthcare costs are related to higher BMI [4]. In the United States, the estimated annual medical cost of obesity and related diseases was $173 billion in 2019 dollars. Accordingly, Medical costs for adults who had obesity were $1,861 higher than medical costs for people with a healthy weight [5].

Vitamin D, identified as a fat-soluble prohormone, plays essential roles in numerous physiological processes [6]. Serum 25(OH)D levels, enhanced by Vitamin D consumption, correlate inversely with BMI [7]. Vitamin D deficiency is a pervasive global concern, associated with diverse diseases, with 30-80% reported prevalence rates in children and adults [8-10]. This deficiency has been notably linked to obesity. A pivotal study by Wortsman., *et al*. (2000) highlighted the limited bioavailability of Cholecalciferol in obese individuals due to its sequestration in adipose tissue [11]. In a contemporary context, the CDC (2020) has indicated a heightened risk for severe COVID-19 outcomes in obese individuals [12]. The limited sunlight exposure for the obese population due to less skin exposure might contribute to this deficiency [13-16]. Chronic low-grade inflammation, marked by raised levels of cytokines, typifies obesity. This inflammatory cascade, including IL-6, TNF-α, and CRP, underscores the obesity-inflammation nexus [17,18]. CRP, especially its high-sensitive form (Hs-CRP), stands out as a hallmark inflammatory marker in obesity [19]. Yet, the intricate role of Vitamin D, especially concerning Hs-CRP elevation in metabolic syndrome patients, remains an area of ongoing research [4,20]. Recent insights suggest Vitamin D's potential to modulate adipogenesis, support immune functions, and dampen adipose inflammation [21]. Inflammation is, by design, a protective response leading to tissue repair. However, chronic inflammation and Vitamin D deficiency are major underlying causes of many diseases, including heart disease and diabetes [22]. There is a paucity of data on the inter-relationship between obesity and inflammatory cytokines on Vitamin D in the United States. To assess their relevance to potential morbidity, we conducted a cross-sectional study of body mass index (BMI) and inflammatory cytokines on Vitamin D in a subpopulation of Middle Eastern descent. In addition, this study examined the effect of dietary sources and lifestyle factors on Vitamin D levels.

Methods

Study design and participants

The Howard University Institutional Review Board (IRB) approved this protocol. Informed consent was obtained from all participants to use data from their medical records. A cross-sectional study was conducted with sixty participants, aged 19-65 years, recruited at a local healthcare clinic over a 6-month period. Subjects were classified into three BMI groups according to the CDC criteria**:** normal (18.5-24.9 kg/m^2), overweight (25.0-29.9 kg/m^2), and obese (30.0 kg/m^2 or higher). Waist circumference was used to assess central obesity. Vitamin D levels, inflammatory cytokines (IL-6, CRP and TNF-α) and gene expression were assessed using blood samples obtained during routine participant doctor's visits.

Participants were asked to complete an interview questionnaire to collect information relevant to Vitamin D intake, obesity, and socio-demographic data (including age, gender, ethnicity, and education level) as well as dietary patterns. Participants' data were stripped of all identifiers and were assigned specific identification numbers.

Serum sample preparation

Blood samples were drawn (4 - 6 ml) in a red-topped tube to allow blood clotting (15 - 30 minutes) at room temperature. The serum was separated by centrifugation at 1,000-2,000 g for 10 minutes. The samples were apportioned into 0.5 ml aliquots, transported on dry ice, and stored at -80°C until used.

RNA extraction and reverse transcriptase procedures

Total RNA was extracted from clotted blood samples using Trizol-Reagent following the manufacturer's (Thermo Fisher Scientific, MA, USA) instructions. The total RNA quality and concentration were determined with a Multichannel Nanodrop 1000 Spectrophotometer (Thermo Fisher Scientific, MA, USA). cDNA first strand was generated from a 10 ng/µL RNA sample using the High-Capacity cDNA Reverse Transcription (RT) Kit in a 20 µL reaction buffer (Thermo Fisher Scientific, MA, USA). Real-time PCR was used for the polymerization reaction. The cDNA was stored at -20 to -30°C for eventual gene expression studies.

Gene expression by quantitative real-time polymerase chain reaction

The extent of C-reactive protein, IL-6, and TNF-α gene expressions was assessed using the TaqMan gene expression assay system with 2x TaqMan Master Mix and a 20x FAM-MGM labeled probe (Applied Biosystems, City, State). The 20x FAM-MGM labeled target gene-specific probe Assay IDs: Hs00174128_m1, Hs00174131_m1, Hs00265004_m1, and Hs99999905_m1 were used for TNF-α, IL-6, CRP and GAPDH as controls. Reactions were conducted in Applied Biosystems ViiA™ 7 Real-Time PCR instrument in duplicates on all control and experimental groups and normalized against GAPDH as a baseline control. The quantification of gene expression was performed using the $2^{(-\Delta\Delta CT)}$ relative expression method.

Measurement of IL-6, TNF-α, and CRP by mesoscale diagnostics

IL-6 and TNF-α were measured using a Custom Human Biomarkers Kit by Mesoscale Diagnostics Catalog Number K151A9H-1, Reference Number K0080545 using V-PLEX™ Plus in MSD'S Multi-SPOT 96-well plate format. Human proinflammatory panel 1 assay was used to measure IL-6 and TNF-α. All samples and standards were read in duplicates.

CRP was measured using the Human Vascular Injury Panel 2 kit V-PLEX by Mesoscale Diagnostics Catalog Number K151STD-1. The measurements were conducted according to the manufacturer's instructions. All samples and standards were read in duplicates.

Dietary intake, exposure to sun, and vitamin D status

The source of vitamin D was determined using a validated questionnaire that collected information on dietary intake and exposure to sunlight. This questionnaire assessed participants' Vitamin D status, diet-related practices, and sun exposure. Blood Vitamin D concentrations, measured as 25-(OH)D, were obtained with consent from participants' medical records.

Statistical analysis

Statistical analyses were performed using SAS version 9.3 [23] and Statistical Analysis and Graphics, NCSS 9.0.7 [24]. Participants' baseline demographic and clinical characteristics associated with the BMI categories (normal, overweight, and obese) were assessed using descriptive statistics. A minimum of ten participants in each group of BMI categories was set as a prerequisite to fulfilling the scope of the study. For categorical variables, the count (proportions) was obtained and evaluated for significance among BMI categories using chi-square and Fisher's exact tests. Differences in mean baseline characteristics among BMI categories were evaluated using analysis of variance (ANOVA) for continuous variables. A Wilcoxon's rank-sum test was applied to compare non-normally continuously distributed data. Scatterplots were performed to assess inter-relationships between Vitamin D, BMI, and inflammatory cytokines. Boxplots were also presented to show the five-number summary with the median line represented in the middle of the box.

Pearson correlations between Vitamin D, BMI, and inflammatory cytokines were also computed to assess linear associations. Distribution of Vitamin D among BMI categories was also performed to assess potential differences in median values and trends in Vitamin D levels. A Generalized Linear Regression analysis assessed the relationships between inflammatory cytokines, and BMI on Vitamin D levels, adjusting for demographic factors. The relationship between Vitamin D and inflammatory cytokines was also explored among the various categories of BMI. The association of Vitamin D levels with dietary and lifestyle factors was explored among the different BMI categories. P-values less than 0.05 were considered statistically significant, and confidence intervals (CI) were calculated at a 95% level.

Results

Demographic characteristics of participants

The demographic characteristics of study participants are summarized in table 1. The mean age for the study participants was 37.62 (SD = 14.44), and the proportion of female participants was 51.67%. The mean age among BMI groups was significantly different, with the obese group having a higher mean age than the other groups (p = 0.020). There were no differences in gender distributions among the BMI categories. Of the sixty participants, thirteen were in the normal BMI range; twenty participants were overweight, and twenty-seven were obese. A total of 61.67% of the study population reported having earned either some college credits or a college degree.

Demographic Factors	All Participants	Normal (18.5 - 24.9 kg/m^2)	Overweight (25.0 - 29.9 kg/m^2)	Obese (≥ 30 kg/m^2)	P value
Age	37.62 (14.44)	30.31 (14.03)	35.20 (13.93)	42.93 (13.42)	0.020
Gender					
Male	29 (48.33%)	7 (53.85%)	9 (45.00%)	13 (48.15%)	0.884
Female	31 (51.67%)	6 (46.15%)	11 (55.00%)	14 (51.85%)	
Race					
African American	10 (16.67%)	0 (0.00%)	2 (10.00%)	8 (29.63%)	0.273
Asian	10 (16.67%)	4 (30.77%)	3 (15.00%)	3 (11.11%)	
Caucasian	5 (8.33%)	2 (15.38%)	1 (5.00%)	2 (7.41%)	
Hispanic	15 (25.00%)	2 (15.38%)	6 (30.00%)	7 (25.93%)	
Other	20 (33.33%)	5 (38.46%)	8 (40.00%)	7 (25.93%)	
Education					
High School	12 (20.00%)	3 (23.08%)	4 (20.00%)	5 (18.52%)	0.792
Some College	15 (25.00%)	5 (38.46%)	3 (15.00%)	7 (25.93%)	
Bachelor's	16 (26.67%)	4 (30.77%)	5 (25.00%)	7 (25.93%)	
Master's	6 (10.00%)	0 (0.00%)	3 (15.00%)	3 (11.11%)	
Other	11 (18.33%)	1 (7.69%)	5 (25.00%)	5 (18.52%)	
Values are mean (SD) for continuous variables and count (%) for categorical variables. P values computed using Non-parametric tests Kruskal-Wallis test for continuous variables, chi-square test for categorical variables.					

Table 1: *Demographic characteristics of participants and clinical factors of participants by BMI category. Total of 60 participants, female (n = 31), and male (n = 29). Normal weight (n = 13), overweight (n = 20), obese (n = 27).*

Clinical characteristics of participants

The clinical characteristics of participants by BMI category are summarized in table 2. Participants categorized as normal body weight had higher mean serum Vitamin D levels (29.51 ± 13.09) compared to overweight (22.08 ± 6.92) and obese participants (21.95 ± 9.18). Still, the mean differences were not statistically significant (Figure 1) among the three BMI categories (p = 0.060). The Vitamin D median was in the normal range (30-100 ng/mL) in participants with normal BMI, while obese participants showed deficient vitamin D levels (< 20 ng/mL). There were no significant mean differences in Serum Calcium, TNF-α, and CRP levels among the BMI categories. Waist circumference was significantly different among the BMI categories (p < 0.0001), with obese participants having a mean value of 42.47 (SD = 4.66) compared to the overweight group with a mean of 35.00 (SD = 3.38) and the normal group with a mean of 29.79 (SD = 2.98).

Clinical Factors	All Participants	Normal (18.5 - 24.9 kg/m^2)	Overweight (25.0 - 29.9 kg/m^2)	Obese (≥ 30 kg/m^2)	P value
Serum Vitamin D (ng/mL)	23.61 (9.78)	29.51 (13.09)	22.08 (6.92)	21.95 (9.18)	0.060
Serum Calcium (mg/ml)	9.66 (0.36)	9.84 (0.30)	9.61 (0.37)	9.61 (0.37)	0.142
IL-6 (pg/mL)	1.28 (1.21)	0.74 (0.28)	0.88 (0.55)	1.79 (1.58)	0.018
TNF- α (pg/mL)	2.69 (0.84)	2.62 (1.18)	2.51 (0.69)	2.85 (0.81)	0.445
CRP (mg/L)	7.09 (10.67)	2.68 (3.21)	7.19 (12.27)	8.74 (10.63)	0.344
Waist Circumference (inch)	37.24 (6.44)	29.79 (2.98)	35.00 (3.38)	42.47 (4.66)	<0.0001
Values are Mean (SD) for continuous variables and count (%) for categorical variables. P values computed using Non-parametric tests Kruskal-Wallis test for Continuous Variables; Chi-square test for Categorical Variables.					

Table 2: *Association of clinical factors of participants by body mass index category.*

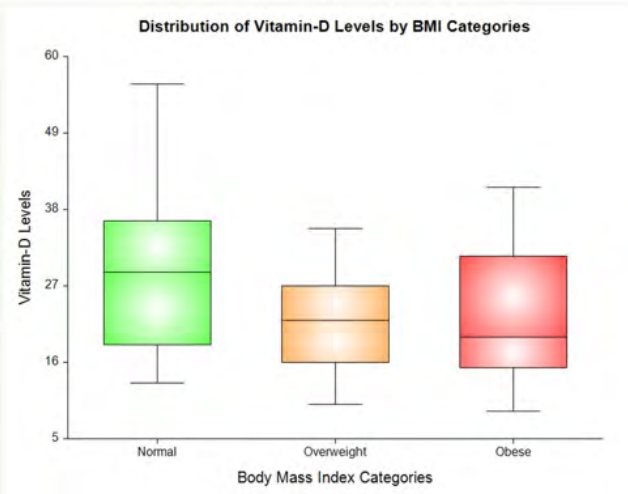

Figure 1: *Inter-relationships between vitamin D levels and body mass index on markers of inflammation. Regression line included to show relationship between factors. An inverse relationship between serum vitamin D levels, IL-6 and CRP. A positive relationship between serum vitamin D level and TNF-α.*

Inter-relationships between vitamin D, body mass index, and markers of inflammation

In this study, we observed an inverse relationship between Serum Vitamin D and BMI (r = -0.212, p = 0.117) as shown in figure 2. In addition, an inverse relationship was observed between Serum Vitamin D levels and IL-6 (r = -0.196, p = 0.191), as well as CRP Levels (r = -0.276, p = 0.064). On the other hand, we observed a positive relationship between serum vitamin D and TNF-α, though not

significant (Figure 2). In table 3, we present a Generalized Linear Regression Model to assess the association between BMI and markers of inflammation on Serum Vitamin D. In the unadjusted model, only C-reactive protein trended towards an association with Vitamin D ($p = 0.064$). In the adjusted model, including age and gender as potential covariates, we observed a significant association between IL-6 ($\beta = -3.12$, SE = 1.39, $p = 0.031$), TNF-α ($\beta = 5.64$, SE = 2.18, $p = 0.014$) and C-Reactive Protein ($\beta = -0.32$, SE = 0.14, $p = 0.031$).

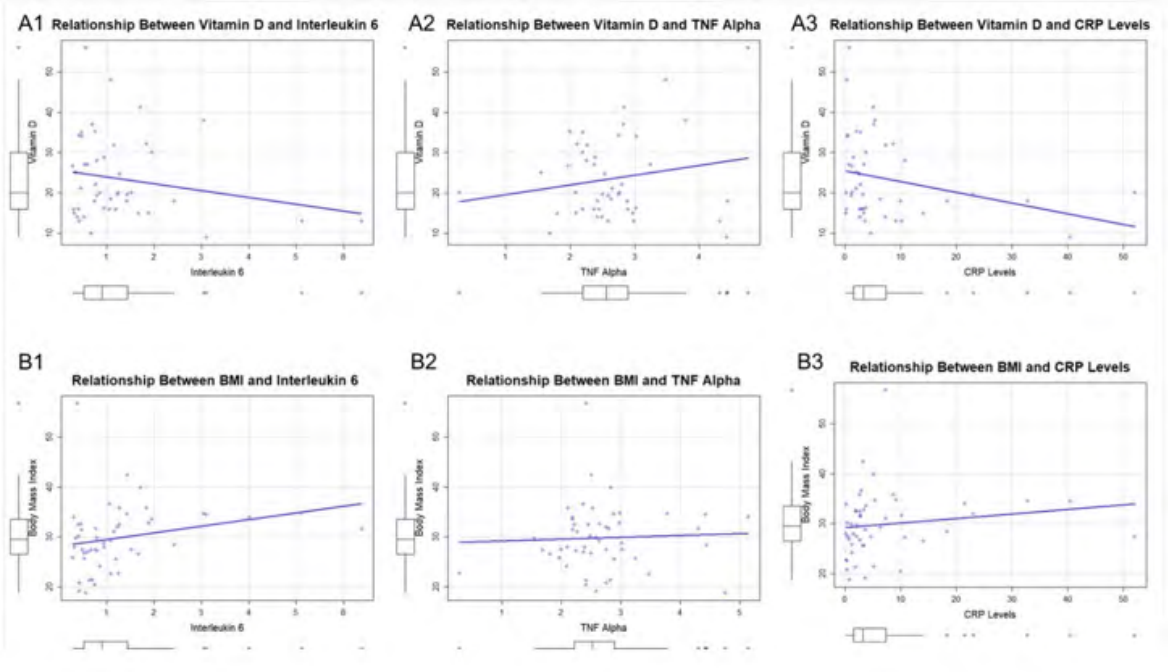

Figure 2: *Distribution of vitamin D among BMI categories. Boxplots represents the five number summary with median line represented in the middle of the boxes. Decline in median vitamin-D levels from normal through overweight to obese participants.*

Relationships between vitamin D and dietary/lifestyle factors

We also examined the association between Vitamin D, dietary, and other lifestyle factors (Table 4). We considered both an unadjusted and adjusted analysis with age and gender in the model. A questionnaire assessed dietary intake and sun exposure related to Vitamin D status. In the unadjusted analysis, Vitamin D was significantly associated with Cod Liver or Fish Oil ($p < .0001$). The result showed that participants who consumed Cod Liver or Fish Oil had increased serum vitamin D levels by 10.91 ng/mL compared to those who did not. In addition, there was a significant effect of Multivitamin intake on Vitamin D in the unadjusted analysis ($p < 0.009$); participants who took Multivitamins daily had an increase in serum Vitamin D levels by 6.97 ng/mL compared to participants who did not. However, the effect of multivitamins on Vitamin D was not significant when adjusted for demographic factors and body weight ($p = 0.209$). In the adjusted analysis, cod liver or fish oil intake was still significantly associated with Vitamin D ($p = 0.006$). The data showed that consuming Cod Liver or Fish Oil significantly increased the median Vitamin D levels, especially in obese participants (Figure 3). Other factors, including Vitamin D supplements, sunscreen, suntan, and tanning booths, had no significant effect on Vitamin D in both adjusted and unadjusted analyses.

	Dietary and Lifestyle Factors	Estimate	SE	P value
Unadjusted Analysis	Cod Liver or Fish Oil (Q2)	10.91	2.51	<.0001
	Multivitamins (Q3)	6.97	2.58	0.009
	Vitamin D Supplement (Q4)	2.95	2.72	0.284
	Sunscreen (Q5)	-1.68	2.67	0.531
	Suntan – Past 12 Months (Q6)	1.17	2.72	0.668
	Tanning Booth (Q8)	-3.36	4.24	0.432
Adjusted Analysis	Cod Liver or Fish Oil (Q2)	8.61	2.98	0.006
	Multivitamins (Q3)	3.51	2.76	0.209
	Vitamin D Supplement (Q4)	1.20	2.61	0.648
	Sunscreen (Q5)	-1.75	2.44	0.477
	Suntan – Past 12 Months (Q6)	1.72	2.65	0.520
	Tanning Booth (Q8)	-3.23	3.96	0.419
GLM regression analysis of vitamin D, body mass index, markers of inflammation, dietary and lifestyle factors				

Table 4: *Vitamin D levels, dietary and lifestyle factors. Significant effect of cod liver or fish oil intake on serum vitamin D Levels observed in unadjusted analysis and adjusted analysis. Significant effect of multivitamins on vitamin D in the unadjusted analysis.*

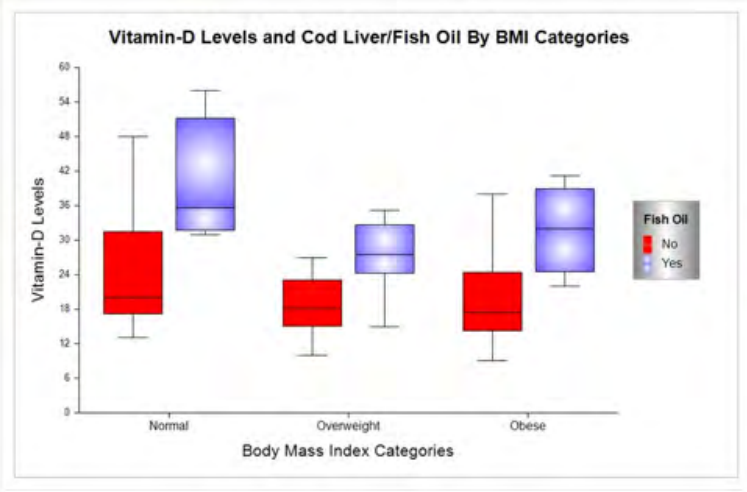

Figure 3: *Distribution of vitamin D and cod liver/fish oil among BMI categories. Boxplots represents the five number summary with median line represented in the middle of the boxes. Decline in median vitamin-D levels among those without fish oil compared to those with fish oil intake.*

Discussion

In the current study, individuals with higher Serum Vitamin D levels tended to have lower levels of CRP. These observations suggest that Vitamin D may be protective against inflammation, and it is in concordance with the findings of Yu., *et al.* (2018), who reported that Vitamin D supplementation lowered hs-CRP [25].

Elevated C-reactive protein (CRP) levels, a marker of systemic inflammation, have been linked to increased fat mass [26] and the severity of metabolic syndrome [27]. Obesity leads to a chronic low-grade inflammatory state, evidenced by raised CRP levels due to adipose tissue's active secretion of pro-inflammatory substances [28]. Furthermore, as metabolic syndrome severity increases, marked by conditions like central obesity and hyperglycemia, CRP levels concurrently rise [29]. This relationship underscores the role of inflammation in obesity and its associated metabolic disturbances.

There has been an increased scientific interest in the relationship between Vitamin D, inflammation, and obesity. Central to this interest are the role of inflammation in obesity, immune system interaction in obesity, and the potential long-term health effects of these relationships in humans. Despite an expanding body of literature on the subject, the precise mechanisms through which Vitamin D modulates inflammatory cytokines and oxidative stress remain debatable. Elevated levels of proinflammatory markers such as IL-6, TNF-α, and hs-CRP are often found in individuals with suboptimal Vitamin D concentrations [30-32]. As a result, a deficiency in Vitamin D is increasingly viewed as a potential precursor to obesity and Type 2 Diabetes Mellitus (T2DM) [33]. This study primarily aims to scrutinize the influence of Vitamin D levels on the inflammatory markers IL-6, TNF-α, and hs-CRP, thereby indirectly elucidating Vitamin D's association with the intricate signaling mechanisms governing inflammation and oxidative stress.

Deficiency of Vitamin D in individuals with heightened adiposity can be attributed to multiple factors: decreased dietary intake, behavioral patterns limiting cutaneous synthesis, impaired intestinal absorption, altered Vitamin D metabolism, and its sequestration in fat tissues leading to diminished bioavailability in obesity [16,34-36] posited that reduced serum 25(OH)D levels in those with obesity stem from the volumetric dilution of vitamin D within expansive adipose reservoirs. This is consistent with findings from Savastano., *et al.* (2017), noting a 1.00% decrease in 25(OH)D for every BMI unit increase [34]. Interestingly, this research did not identify any correlation between serum Vitamin D concentration and calcium levels, aligning with Sedrani's (1984) observations, and further studies by Burt., *et al.* (2018) [37,38].

In our study, participants with a standard BMI exhibited typical Vitamin D levels, whereas obese individuals notably presented with deficient serum Vitamin D levels (< 20 ng/mL). This observation mirrors the results of Tosunbayraktar., *et al.* (2015), who found diminished serum 25(OH)D concentrations in overweight and obese subjects compared to controls ($p < 0.05$) [39]. Further subgroup analysis revealed that variations in Vitamin D supplementation's dosage and duration did not significantly influence TNF-α and IL-6 concentrations, aligning with the findings of Yu., *et al.* (2018) [25]. The exact molecular pathways through which Vitamin D affects inflammatory cytokines and oxidative stress remain elusive in this study. Hence, more extensive research is imperative to unravel the intricate mechanisms underpinning Vitamin D's interplay with cytokines.

An observed correlation between elevated IL-6 levels and the degree of overweight was observed in the current study, suggesting a potential regulatory role of Vitamin D in interleukin-6 dynamics in humans. Following adjustments for factors like age and gender, our findings underscored a noteworthy relationship between Vitamin D levels and both CRP and IL-6. Wang., *et al.* (2018) have echoed this, delineating an inverse association between serum Vitamin D and IL-6 as well as hs-CRP [40]. Similarly, Laird., *et al.* (2017) highlighted that diminished Vitamin D levels correlate with heightened inflammatory markers, including IL-6, TNF-α, and hs-CRP [41]. Furthermore, De Vita., *et al.* (2014) presented compelling evidence of the significant association ($p < 0.05$) between lower 25(OH)D levels and elevated IL-6 and CRP [30]. Yet, our research, mirroring the study by Azizieh., *et al.* (2016), did not establish a substantial relationship between

Vitamin D and TNF-α, reaffirming some previous findings that showed no discernible correlation between Vitamin D levels and certain serum cytokine profiles [42].

A significant observation in this study suggests that participants across varying BMI categories - normal, overweight, and obese - demonstrated enhanced Vitamin D levels upon consuming cod liver or fish oil. Furthermore, our data indicated that the positive impact of cod liver or fish oil on Vitamin D levels was approximately 1.5 times greater than that achieved through the consumption of Vitamin D supplements or multivitamins, with this effect being particularly pronounced among obese individuals. This underscores the pivotal role of Vitamin D's source, a notion also posited by Bouillon (2001) [43]. Reinforcing this, recent studies, including one by Borel., *et al.* (2015) and another by Smith., *et al.* (2016), have underscored that food-derived 25-hydroxyvitamin D is more efficiently absorbed in comparison to the cholecalciferol and ergocalciferol forms found in supplements [44,45].

In 2011, the National Institutes of Health reported that sunlight exposure for 5 - 30 minutes between 10:00 a.m. to 3:00 p.m. at least twice a week to the face, arms, legs, or back without sunscreen protection resulted in sufficient Vitamin D synthesis, Similarly, using tanning beds emitting 2% - 6% UVB radiation can be effective in moderate amounts [46,47]. Notably, being overweight or obese can influence the skin's ability to synthesize vitamin D [48,49]. However, in our investigation, factors like sunscreen usage, sun tanning, or tanning booths did not significantly influence Vitamin D levels across various BMI ranges. Furthermore, we observed that the influence of sun exposure on Vitamin D levels was contingent upon individual BMI categories.

Conclusion and Limitations

Our research reinforces the complex relationship between obesity and vitamin D deficiency, highlighting its significance as a global health concern. We've found compelling evidence of a two-way relationship between vitamin D levels and body weight, with inflammation playing a crucial mediating role. While the exact mechanisms remain unclear, our findings show that people with low vitamin D typically have higher levels of inflammatory markers like IL-6, TNF-α, and hs-CRP [30-32].

This study's primary contribution is the identification of a clear inverse relationship between vitamin D levels and BMI, as well as the demonstration of significant associations between inflammatory markers and vitamin D status. The findings suggest that optimizing vitamin D status through dietary sources, as recommended by public health agencies, may offer superior protection against inflammation and be more effective in preventing obesity compared to supplementation. This approach is supported by emerging epidemiological data and a strong biological hypothesis, highlighting the potential benefits of acquiring vitamin D from food rather than supplements in obesity prevention. Overall, these findings enhance our understanding of the interactions between vitamin D deficiency, obesity, and inflammation, potentially paving the way for new therapeutic strategies.

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Availability of Data and Materials

Data used to prepare this article can be made available upon request.

Author Contributions

WFA and TVF conceived, designed, and conducted the research. WFA and OEN performed all biomarker and gene expression analyses. WFA, OEN, JSN and TVF performed statistical analysis, interpretation of the results, provided subject matter and wrote the paper. WFA and TVF were primarily responsible for the final content. All authors read and approved the final manuscript.

Conflict of Interest

The authors have no commercial associations that might be a conflict of interest in this article.

Consent for Publication

All authors in the manuscript have consented to the publication of the text, tables and figures relating to the research, to be published in the Journal of Nutrition and Health.

Ethical Approval

The Institutional Review Board (IRB) of Howard University approved this protocol. Informed consent was obtained for all participants to use data from their medical records.

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