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Evaluating the Relationship Between Vitamin D Supplementation, Lifestyle, Social Determinants of Health, Asthma, and Respiratory Tract Infections

Yun O'Donnell
Walden University

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Walden University

College of Health Sciences and Public Policy

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Yun O'Donnell

has been found to be complete and satisfactory in all respects,
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the review committee have been made.

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Walden University
2026

Abstract

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Determinants of Health, Asthma, and Respiratory Tract Infections

by

Yun O'Donnell

MS, University of Massachusetts Dartmouth, 2014

BS, University of Massachusetts Dartmouth, 2007

Final Study Submitted in Fulfillment

of the Requirements for the Degree of

Doctor of Philosophy

Public Health- Epidemiology

Walden University

May 2026

Abstract

Hypovitaminosis D is a significant public health concern in the United States associated with inadequate sunlight exposure and insufficient dietary intake. Asthma is a chronic respiratory condition that progressively worsens over time. While asthma is typically managed through individual-level treatment approaches, population-level strategies such as vitamin D supplementation and food fortification policies have not been implemented. A five-tier Public Health Impact Pyramid theoretical foundation guided this nonexperimental quantitative cross-sectional study. Data from 2013-2014 and 2017-2018 NHANES (n = 1,456) was evaluated for relationships between vitamin D supplementation, duration of sunlight exposure, and food security index, with asthma, asthma exacerbation severity, and respiratory tract infections in individuals between 16 and 30 while controlling for race, household crowding index, and smoking. A complex sample binary logistic regression analyses indicated achieving vitamin D RDA was significantly associated with a decreased risk of asthma exacerbation severity ($B = -25.604$, $SE = 1.087$, $t(13) = -23.556$, $p < 0.001$, $OR = 2.676E-12$, $95\% CI [1.416E-12, 5.057E-12]$) and FSI was significantly associated with RTIs ($p < 0.001$). However, the nature of the relationship between FSI and RTIs could not be established using the current model. Results from this study include evidence that food fortification policies involving staple food items can change environmental contexts and decrease barriers including social determinants of health associated with hypovitaminosis D, resulting in positive social change among young adults to improve long-term respiratory health outcomes.

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Chapter 1: Introduction to the Study

Asthma is a chronic condition in which an individual experiences inflammation anywhere within their respiratory tract (National Heart, Lung, and Blood Institute, 2024). Inflammatory responses, triggered by stimuli, can promote mucus aggregation within the respiratory tract, further limiting oxygen exchange within the lungs. Physiological responses to hypoxia and inflammation result in airway remodeling of the respiratory epithelium, causing permanent hyperplastic and hypertrophic changes with subepithelial fibrosis that increase the risk of chronic obstructive pulmonary disease (COPD) and decrease overall lung function (Yamauchi & Inoue, 2007). Reduction of asthma and asthma-related illnesses in adolescence and early adulthood can significantly improve future respiratory health in later decades of life.

Increasing incidences of asthma and chronic respiratory illnesses have resulted in a decrease in quality-adjusted life years (QALY) in all populations, but more dramatically in those from lower-income communities (Scully et al., 2022). Healthy People 2030 included a goal to improve respiratory health by reducing emergency department visits for asthma. However, overall age-adjusted benchmarks associated with asthma hospitalization reduction in those between 5 and 65 have thus far failed to demonstrate statistical significance due to the minimal rate of reduction from 49.6 per 10,000 persons in 2016-2018 to 41.1 per 10,000 persons in 2019-2021 (Healthy People 2030, n.d.-a). Furthermore, there was a significantly higher number of asthma-related hospitalizations in Black individuals between 5 and 65 (147.5 per 10,000 persons in 2016-2018 and 131.4 per 10,000 persons in 2019-2021) compared with their White

counterparts (31.9 per 10,000 persons in 2016-2018 and 24.7 per 10,000 persons in 2019-2021 (Healthy People 2030, n.d.-a). Furthermore, asthma increases the risk of respiratory tract infections (RTIs) due to the inflammatory process inhibiting respiratory tract cilia from clearing mucus, allergens, and pathogenic microorganisms, and through the immune dysfunction associated with atopic and nonatopic asthma (Juhn, 2014). Recommended asthma management includes lifestyle changes and chemotherapeutics to stabilize and maintain cellular integrity of the respiratory tract (American Family Physician, 2020). However, no current recommendations exist to manage respiratory and immune function through maintaining micronutritional balance. This suggests a better understanding of micronutrients' role in immunoregulatory functions can provide a cost-effective treatment pathway in populations at a higher risk of experiencing asthma-related healthcare inequities.

Vitamin D is an endogenously produced endocrine and autocrine hormone well-linked to serum calcium and phosphate homeostasis for sustaining bone health. Additionally, vitamin D receptors (VDR) have been identified on immune system cells, suggesting that vitamin D plays an immunomodulatory role beyond bone maintenance. It is estimated 50% of the world population suffers from vitamin D insufficiency ($25(\text{OH})\text{D} = 50\text{-}75 \text{ nmol/L}$ or $20\text{-}30 \text{ ng/mL}$), and approximately 35% of adults in the United States suffer from vitamin D deficiency ($25(\text{OH})\text{D} = < 50 \text{ nmol/L}$ or $< 20 \text{ ng/mL}$ (Cleveland Clinic, 2022; National Institutes of Health, 2024). However, current clinical guidelines do not recommend routine vitamin D testing or supplementation beyond the Daily Recommended Allowance (RDA) of 600 IU per day in nonpregnant adults under 50 who

do not demonstrate hypocalcemia. Moreover, when the Endocrine Society updated its practice guidelines, it no longer recognized specific cutoff ranges to determine vitamin D status due to a lack of clinical evidence demonstrating the relationship between serum vitamin D levels and clinical outcomes (Demay et al., 2024). Removing recommended vitamin D cutoff ranges has resulted in inconsistencies in vitamin D deficiency and insufficiency reporting. Furthermore, the problem remains vitamin D testing and supplementation are not routinely recommended for individuals with asthma and recurring RTIs who do not have clinical manifestations of bone loss. Determining a relationship between risk factors and recurring acute and chronic respiratory episodes can help mitigate asthma exacerbation and future chronic respiratory conditions, thereby improving QALY of communities, decreasing respiratory health disparities, and promoting social change.

This chapter includes an overview of the study, discussion of the problem, purpose of the study, research questions and hypotheses, theoretical foundation, scope of research, and significance of the study.

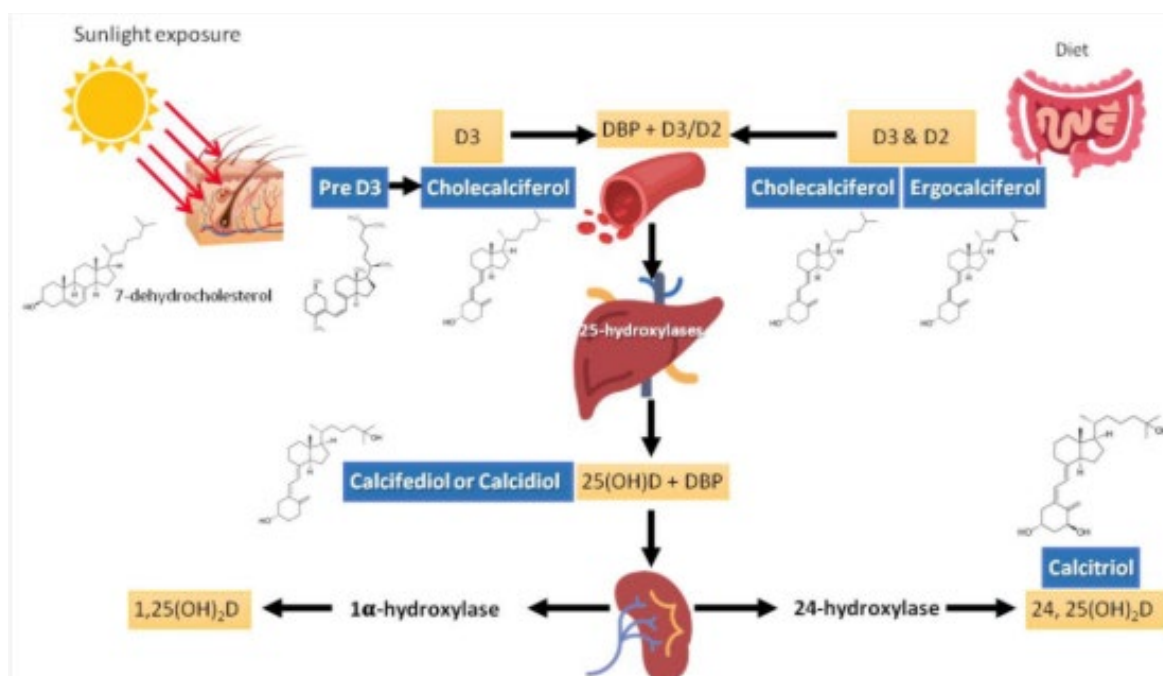
Background

Active vitamin D (1, 25-dihydroxyvitamin D or $1,25(\text{OH})_2\text{D}_3/\text{D}_2$) is an endogenously-produced endocrine and autocrine hormone. Inactive vitamin D prohormone can be acquired through plant-based sources (ergocalciferol or vitamin D_2), by irradiating yeast-produced ergosterol, or through ultraviolet B (UVB) sunlight (wavelength of 290-315 nm) conversion of 7-dehydrocholesterol (7-DHC) on the skin surface to cholecalciferol (vitamin D_3) (Alter, 2024). In addition, vitamin D_3 can also be

acquired through animal-based dietary sources, such as fatty fish, liver, milk, eggs, and vitamin D supplementation. After uptake, vitamin D₃ is transported by vitamin D binding protein (VDBP) to hepatocytes, where the first hydroxylation step occurs. Here, 25-hydroxylase converts vitamin D to 25OH vitamin D (25-hydroxyvitamin D or 25(OH)D_{2/3}). Second hydroxylation step occurs in the renal proximal tubules, where 25(OH)D-1 α -hydroxylase converts 25(OH)D to active 1,25(OH)₂D₃ or 1,25(OH)₂D₂ (see Figure 1).

Figure 1

Vitamin D Metabolic Pathway



Note. From “Vitamin D sources, metabolism, and deficiency: Available compounds and guidelines for its treatment,” by L. J. Dominguez, M. Farruggia, N. Veronese, and M. Barbagallo, 2021, *Metabolites*, 11(4), p. 3 (<https://doi.org/10.3390/metabo11040255>).

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Active $1,25(\text{OH})_2\text{D}_3/\text{D}_2$ has a serum half-life of 36-78 hours or can be stored in adipocytes, prolonging its half-life to 2 months (Tsiaras & Weinstock, 2011). $25(\text{OH})\text{D}_3$ is the predominant form found in the body, contributing the most to $25(\text{OH})\text{D}$ immunoassay testing for vitamin D sufficiency within the clinical laboratory due to its stability and low daily variation (Alter, 2024; Müller & Volmer, 2015).

Vitamin D is involved in multiple physiologic processes, from calcium and phosphate metabolism to immune regulation, thereby preventing chronic illnesses in the later decades of life (Institute of Medicine, 2011). When individuals experience hypocalcemia and/or hypophosphatemia, the parathyroid gland releases parathyroid hormone (PTH) in a negative feedback mechanism. PTH indirectly increases blood calcium and phosphate concentrations to promote $25(\text{OH})\text{D}$ conversion into active $1,25(\text{OH})_2\text{D}$ (Alter, 2024). $1,25(\text{OH})_2\text{D}$ upregulates calcium and phosphate absorption and reabsorption in the small intestines and renal tubules by binding VDRs. Until recently, vitamin D was thought to only help maintain serum calcium and phosphate homeostasis and sustain bone health. Current healthcare recommendations are still focused on preventing rickets in children and osteomalacia in adults through vitamin D supplementation (Alter, 2024).

However, more recently, vitamin D has been implicated in maintaining immune function when VDRs were found on immune cells (Aranow, 2011). When an individual is sensitized to a pathogen, antigen-presenting cells, specifically macrophages, recognize microbial surface lipopolysaccharide (LPS) through toll-like receptors (TLR). This leads to further activation of the innate immune system and potentially, the adaptive immune

system. If sufficient opsonization occurs, the immune response will elicit long-term immunity through B-cell activation. Additionally, innate immune system activation causes bactericidal phagosomes within macrophages to digest the pathogen. TLR activation increases 1α -hydroxylase and VDR expression, increasing vitamin D binding. This in turn upregulates the cathelicidin antimicrobial peptide and defensin $\beta 2$ genes to produce their respective phagosome antimicrobial proteins, cathelicidin, and beta-defensin 4 (Wang et al., 2004). Moreover, vitamin D downregulation of CD4⁺ T cell proliferation causes a shift away from production of the Th1 phenotype and towards the anti-inflammatory Th2 and Th17 phenotypes. Phenotypic shift in T cell lineages decreases production of asthma-inducing and proinflammatory IL-4, IL-5, IL-13, IL-17, and IL-21 while promoting anti-inflammatory IL-10 and immunoprotective INF- γ , resulting in vitamin D-induced immune regulation (Salmanpour et al., 2022; Aranow, 2011).

As more research supporting vitamin D's immunoregulatory effects has been reported, studies examined the relationship between vitamin D and respiratory health. Hornsby et al. (2018) found high-dose vitamin D supplementation resulted in a more robust neonatal innate immune cell response to stimuli and a significantly higher cellular expression of TLR2 and TLR4 ($p = 0.02$). Therefore, a high dose of maternal vitamin D supplementation upregulated cytokine production in neonates, which was related to a decreased frequency of respiratory infections and increased innate immune system fitness, supporting anti-inflammatory protective properties offered by sufficient vitamin D levels.

Bhat et al. (2023) indicated individuals with hypovitaminosis D were more likely to experience more severe and frequent asthma exacerbation episodes and hospitalizations compared with those who had sufficient serum 25(OH)D. School-aged children who received adequate amounts of UVB exposure throughout the day intimated sufficient dietary access to vitamin D was necessary to maintain 25(OH)D levels.

Few studies have involved evaluating the relationship between lifestyle behaviors, social determinants of health, and respiratory health in young adults between 16 and 30. The limited information about individuals transitioning to living independently and gaining nutritional autonomy, indicates a gap in terms of vitamin D and respiratory health research. Furthermore, evaluating the relationship between asthma, RTIs, and vitamin D supplementation using a five-tier Public Health Impact Pyramid (PHIP) has not been explored.

This doctoral quantitative research study involved evaluating the relationship between asthma, RTIs, and vitamin D supplementation using the five-tier PHIP framework. The PHIP framework is often used to develop public health initiatives so public health policy makers can address each level within the pyramid to achieve maximum social change in terms of decreasing health disparities. However, addressing lower levels of the PHIP can have the most significant impact on the greatest number of individuals. The specific research problem, therefore, was whether there was a relationship between vitamin D supplementation, food security index, duration of sunlight exposure, asthma, and RTIs while controlling for race, household crowding index, and smoking to help improve QALY of a community.

Problem Statement

Vitamin D insufficiency and deficiency, collectively called hypovitaminosis D, are still prominent concerns in U.S. public health systems and have been associated with insufficient sunlight exposure and dietary consumption. Cui et al. (2022) reported that in the 2001-2018 National Health and Nutrition Exam Surveys (NHANES), 65.5% of the U.S. population have hypovitaminosis D (2.6% deficient with 25(OH)D < 25 nmol/L, 22.0% moderately deficient with 25(OH)D 25-50 nmol/L, and 40.9% insufficient with 25(OH)D 50-75 nmol/L). 34.5% of the population had sufficient serum vitamin D concentrations (25(OH)D > 75 nmol/L).

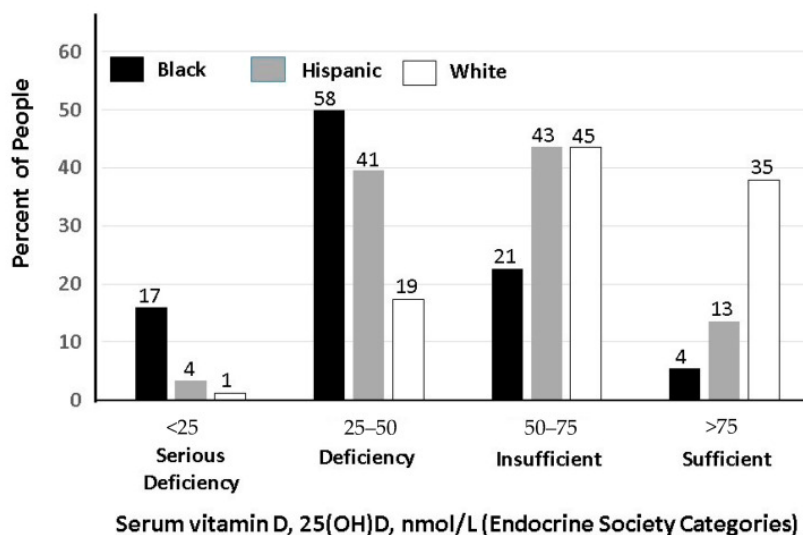
Additionally, geographic location may increase the risk of hypovitaminosis D. The solar zenith angle (SZA) is the angle of the sun in the sky related to a point that is perpendicular to the earth's surface and directly impacts the wavelength intensity of UVB (Tsiaras & Weinstock, 2011). SZA and resultant UVB peaks at midday during summer months in the United States, with diminishing SZA later in the day and during winter months. Furthermore, Tsiaras & Weinstock (2011) reported UVB intensity is insufficient to produce vitamin D₃ at latitudes greater than 35° North during the winter months. This suggests seasonal and geographic differences can impact vitamin D photoconversion.

Despite insufficient vitamin D consumption, caution must be exercised when administering vitamin D supplements. Although rare, some individuals may experience vitamin D toxicity when dosages are not adjusted appropriately based on weight (Marcinowska-Suchowierska et al., 2018). Vitamin D is fat-soluble and stored in adipose tissue. Those who consume higher than the RDA to compensate for transient seasonal or

dietary deficiencies may be at a higher risk of toxicity if significant weight loss results in decreased vitamin D sequestration. Vitamin D toxicity generally presents with clinical manifestations associated with hypercalcemia, including cognitive disturbances, gastrointestinal and renal dysfunction, and cardiovascular arrhythmias (Marcinowska-Suchowierska et al., 2018).

Due to conflicting evidence of vitamin D's immunoregulatory function, the problem remains vitamin D testing and supplementation are not clinically recommended for individuals with asthma and frequent recurring RTIs. Despite the increased consumption of vitamin D supplements, Schleicher et al. (2021) reported there were still significantly lower 25(OH)D levels in non-Hispanic Blacks compared with non-Hispanic Whites (see Figure 2), suggesting racial or cultural disparities in supplement use.

This research was necessary to understand how vitamin D supplementation, duration of sunlight exposure during winter months, and SDOH contribute to asthma, asthma exacerbation severity, and RTIs. Manousaki et al. (2017) concluded the association between 25(OH)D levels and atopic disease was confounded by various lifestyle factors not controlled for. In addition, Mendes et al. (2018) reported hypovitaminosis D was still prevalent in Brazilian populations despite the year-round availability of high-intensity UVB. Few studies have been conducted to evaluate 25(OH)D with dietary intake and sunlight exposure in the context of confounding factors. Therefore, the current study's findings added to research on improving respiratory health outcomes by providing evidence for cost-effective vitamin D supplementation for respiratory health maintenance among at-risk populations.

Figure 2*Serum 25(OH)D Levels by Race*

Note. From "Does the high prevalence of vitamin D deficiency in African Americans contribute to health disparities?" by B. N. Ames, W. B. Grant, and W. C. Willett, 2021, *Nutrients*, 13(2), p. 5 (<https://doi.org/10.3390/nu13020499>). Copyright 2021 by the authors. CC BY 4.0.

Purpose of the Study

The purpose of this quantitative study was to examine relationships between the independent variables vitamin D supplementation, duration of sunlight exposure, and food security index, with the dependent variables asthma, asthma exacerbation severity, and RTIs in individuals aged 16-30, while controlling for race, household crowding index, and smoking. Understanding the interrelated factors contributing to asthma severity and RTIs is necessary to establish potential multidimensional and multidisciplinary preventive strategies to improve respiratory health outcomes.

Research Questions and Hypotheses

The following research questions and hypotheses guided the study:

RQ1: Is there a relationship between vitamin D supplementation, food security index, duration of sunlight exposure, and the presence of asthma in participants 16-30 during the winter months in the U.S. after controlling for race, household crowding index, and smoking?

H₀1: There is no relationship between vitamin D supplementation, food security index, duration of sunlight exposure, and the presence of asthma in participants 16-30 during the fall and winter months in the U.S. after controlling for race, household crowding index, and smoking.

H_a1: There is a relationship between vitamin D supplementation, food security index, duration of sunlight exposure, and the presence of asthma in participants 16-30 during the fall and winter months in the U.S. after controlling for race, household crowding index, and smoking.

RQ2: Is there a relationship between vitamin D supplementation, food security index, duration of sunlight exposure, and the severity of asthma exacerbations in participants 16-30 during the fall and winter months in the U.S. after controlling for race, household crowding index, and smoking?

H₀2: There is no relationship between vitamin D supplementation, food security index, duration of sunlight exposure, and the severity of asthma exacerbations in participants 16-30 during the fall and winter months in the U.S. after controlling for race, household crowding index, and smoking.

H_{a2}: There is a relationship between vitamin D supplementation, food security index, duration of sunlight exposure, and the severity of asthma exacerbations in participants 16-30 during the fall and winter months in the U.S. after controlling for race, household crowding index, and smoking.

RQ3: Is there a relationship between vitamin D supplementation, food security index, duration of sunlight exposure, and having RTIs in participants 16-30 during the fall and winter months in the U.S. after controlling for race, household crowding index, and smoking?

H₀₃: There is no relationship between vitamin D supplementation, food security index, duration of sunlight exposure, and having RTIs in participants 16-30 during the fall and winter months in the U.S. after controlling for race, household crowding index, and smoking.

H_{a3}: There is a relationship between vitamin D supplementation, food security index, duration of sunlight exposure, and having RTIs in participants 16-30 during the fall and winter months in the U.S. after controlling for race, household crowding index, and smoking.

Theoretical Foundation for the Study

The five-tier PHIP was the theoretical foundation that grounded this study. As a multifaceted issue involving intrapersonal, interpersonal, community, societal, and institutional influences, frameworks underpinning the principles of PHIP are best suited to establish a more equitable healthcare system. PHIP's universal approach tackles issues upstream and can help influence a broader range of individuals (Frieden, 2010).

Unlike other health behavior models, a five-tier PHIP modifies levels evaluated by the social ecological model (SEM) and addresses five aspects of public health interventions. Frieden (2010) argued that under the five-tier PHIP, public health initiatives targeting bottom two tiers have the most effect on population health, while top three tiers require interventions on individual levels, having less effect on overall long-term health of the community (see Figure 3).

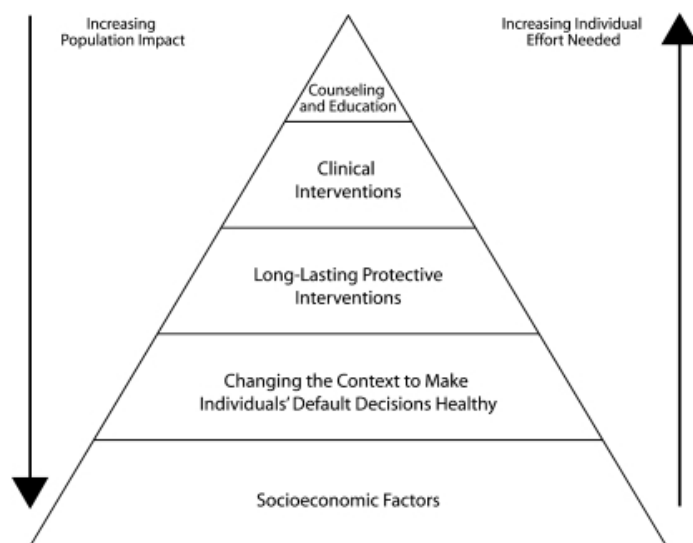
Although RCTs have explored relationships between vitamin D supplementation, immune system development, and respiratory health (Bhat et al., 2023; Denlinger et al., 2016; Hornsby et al., 2018; Manousaki et al., 2017), few studies have evaluated relationships between vitamin D status, dietary intake, duration of sunlight exposure, and risk of asthma and RTIs while controlling for known confounders (Mendes et al., 2018). Current asthma management practices focus on individual interventions. However, these practices have been unsuccessful in helping the U.S. population reach Healthy People 2030 goals. PHIP focuses on program development with a more distal influence from the individual to increase the reach of interventions. Therefore, assessing asthma and risk of RTIs using a PHIP framework focusing on interventions at the bottom two levels, such as food security and health behavior practices, would benefit long-term respiratory health maintenance.

In this study, I used the 2013-2014 and 2017-2018 NHANES datasets to evaluate the relationships between independent and dependent variables while controlling for confounders. Assessing the relationships between the variables will help determine if

vitamin D supplementation and adequate vitamin D dietary intake can decrease the risk of adverse respiratory outcomes.

Figure 3

Five-tier Health Impact Pyramid



Note. From “A framework for public health action: The health impact pyramid,” by T. R. Frieden, 2010, *American Journal of Public Health*, 100(4), 590–595 (<https://doi.org/10.2105/AJPH.2009.185652>). Copyright 2010 by the American Public Health Association. Reprinted with permission.

Nature of the Study

Specific research design included a nonexperimental quantitative cross-sectional study where I evaluated the November through April 2013-2014 and 2017-2018 NHANES data for participants between 16 and 30. Since vitamin D through UVB exposure was lower during the winter months in parts of the United States, using data for

the fall and winter months would help to capture a more accurate assessment of asthma and RTI exacerbations related to hypovitaminosis D.

Independent variables that answered the research questions were vitamin D supplementation based on total 30-day vitamin D supplementation intake, daily sunlight exposure duration estimation, and food security index using the questions predetermined by Bickel et al. (2000) to measure food security. Dependent variables were the presence of asthma as diagnosed by a healthcare provider, asthma exacerbation severity as determined by asthma-related hospitalization in those diagnosed with asthma, and the presence of RTI in participants. Confounding factors to asthma and respiratory tract infections were race, household crowding index, and participant smoking status or exposure to secondhand smoke. Descriptive statistics and binary logistic regression were used to evaluate the relationships between the independent and binary dependent variables.

Definitions

Asthma: Asthma was characterized as a positive diagnosis by a healthcare provider. An asthma diagnosis in adults may be based on clinical presentation of wheezing, shortness of breath, cough, and chest tightness that worsens in the morning and evening (American Family Physician, 2020).

Asthma Exacerbation Severity: As defined by the National Asthma Education and Prevention Program (NAEPP) Expert Panel Report 3, asthma exacerbations are defined as acute or subacute episodes of progressively increasing shortness of breath, cough, wheezing, and/or chest tightness that alters the participant's previous asthma control

status (National Asthma Education and Prevention Program, 2007). To evaluate the severity of asthma exacerbations, the participants of NHANES were asked if they were hospitalized due to asthma in the last 12 months.

Food Security Index: U.S. Department of Agriculture (2025) identifies food security as the ability for households to access enough nutritionally adequate and safe food for all household members in a socially acceptable manner. Therefore, food insecurity is defined by having limited or unpredictable access to nutritionally adequate and safe food in a socially acceptable manner. Food security index categorizes an individual's access to food and will be established using the Bickel et al. (2000) U.S. Food Security Survey module (FSSM). Sum of affirmative (i.e., yes, often, sometimes, almost every month, and some months but not every month) responses determined the participant's food security status. Based on the total of the affirmative responses to 18 food security questions, NHANES categorized participants based on answers as adult full food security, adult marginal food security, adult low food security, and adult very low food security.

Household Crowding Index: Four methods have been described to assess the household crowding index: persons per room, persons per bedroom, unit square footage per person, and persons per room by unit square footage per person (Blake et al., 2007). To facilitate data collection, the persons per room (PPR) definition was used. This measurement criterion considers the number of persons in a household per the total number of livable/finished rooms. An index of more than one PPR is considered overcrowded (Blake et al., 2007).

Respiratory Tract Infections (RTIs): RTIs are characterized by viral or bacterial infections within the respiratory tract. These infections are clinically diagnosed as a common cold, sinusitis, pharyngitis, laryngitis, bronchitis, bronchiolitis, or pneumonia. NHANES participants indicated if they were diagnosed with any RTIs within the 30 days of the medical examination center (MEC) interviews.

Smoking Status: Centers for Disease Control and Prevention (CDC, 2025) criteria for classifying current smokers, former smokers, and never smokers were used. Individuals who currently smoke cigarettes or use vaping products at the time of the survey and have also smoked at least 100 cigarettes in their lifetime were considered current smokers. Individuals who were not currently smoking cigarettes or using vape products at the time of the survey, but who had smoked at least 100 cigarettes in their lifetime were considered former smokers. Finally, individuals who were not currently smoking cigarettes or using vape products at the time of the survey and had not smoked at least 100 cigarettes in their lifetime were considered never smokers. Furthermore, secondhand smoke exposure is defined as breathing in burned tobacco products exhaled by another individual (CDC, 2024a). Secondhand smoke often contains byproducts similar to those acquired through direct exposure to smoking. Therefore, secondhand smoke exposure was evaluated with smoking status.

Social Determinants of Health: SDOH relevant to this study include the food security index, household crowding index, and race. As SDOH are considered the environment in which individuals are born, live, learn, work, play, worship, and age

(Healthy People 2030, n.d.-b), food security index, household crowding index, and race are all factors that contribute to how individuals can interact with their environment.

Sun Exposure: A significant source of unimpeded UVB can contribute to the photoconversion of ergocalciferol or 7-dehydrocholesterol to $1,25(\text{OH})_2\text{D}_3/\text{D}_2$. Therefore, the duration of sun exposure was defined as the amount of time participants were exposed to direct sunlight.

Vitamin D Supplementation: As defined by the Food and Drug Administration (FDA, 2025), dietary supplements are any substances ingested to add to the diet outside of consumed food items. These can include multivitamins or specific vitamins, such as vitamin D, that can be taken to meet the recommended daily dietary requirements to maintain health. In this study, I focused on vitamin D acquired through multivitamins or vitamin D supplementation.

Assumptions

In this study evaluating secondary data, it was assumed that participants accurately recalled supplement consumption information, duration of sunlight exposure, severity of asthma exacerbation, and RTIs. Furthermore, another assumption was that missing data were truly questions that were missing answers and not ones that were intentionally skipped.

Scope and Delimitations

The focus of this study was to provide evidence for cost-effective vitamin D supplementation to improve respiratory health outcomes in populations at risk. Bhat et al. (2023) reported that despite tropical weather and adequate sunlight exposure in study

participants, 86.7% demonstrated hypovitaminosis D. In addition, asthma symptom exacerbation and hospitalizations showed a statistically significant correlation with serum 25(OH)D levels ($p < 0.05$). However, Bhat et al. (2023) did not control for known confounders, such as smoking or exposure to secondhand smoke, food security index, or household crowding, necessitating this current doctoral study. Furthermore, exploring the interrelated factors contributing to asthma severity and RTIs is necessary to establish evidence-based multidimensional and multidisciplinary preventive strategies to improve respiratory health outcomes. PHIP underscores the necessity to address respiratory health holistically as public health initiatives move away from the traditional siloed approach to health promotion. The framework will support upstream multidisciplinary approaches to improve respiratory health maintenance.

Sample population included were individuals between 16 and 30 who participated in the November through April 2013-2014 or 2017-2018 NHANES. Individuals excluded were adolescents under 16, adults over 30, and those with weak or failing kidneys. Study generalizability was improved by using a randomly selected national survey population. However, results may not be generalizable to individuals between 16 and 30 outside of the United States with different climates and access to vitamin D supplementation.

Limitations

All efforts were made to mitigate study limitations. However, some limitations still need to be addressed. Complete data collection for at least 875 participants with varying socioeconomic backgrounds was needed to give the study adequate statistical

power. Therefore, multiple NHANES cycles were used to meet the minimum required sample for data analysis.

Another limitation was the potential for recall bias when participants were asked to remember supplementation intake and the amount of sunlight exposure in the last 30 days. Recall bias threatens internal validity and can bias the findings towards null hypothesis and statistically bias risk of an outcome. Furthermore, nonresponse bias is another important limitation when evaluating nationally collected data. For asthma status, participants were asked in the MEC questionnaire if a healthcare professional had ever told them they had asthma. A subsequent question asked if participants still had asthma. However, responses were entered for all participants regardless of answers to the former question. All respondents who had answered “no” in the former question and had missing inputs in the latter question were documented as having missing responses. Therefore, recoding of the data was necessary to provide the correct statistical data and decrease nonresponse bias.

Additionally, due to the nature of the NHANES data collection, location data for participants have been masked, making it difficult to include a control group with sufficient sun exposure and similar characteristics to the study group. With the expectation of inclement weather in northern states, MEC and biospecimen collection were restricted to southern states during the November-April data collection periods and to the northern states for the May-October periods (CDC, 2018). This was a limitation in the study as 25(OH)D demonstrates seasonal variations, especially in the winter months, in the higher latitudes. Furthermore, the questions regarding sun exposure did not include

garments worn or the approximate amount of direct unimpeded skin exposure, which can drastically impact the amount of 7-DHC photoconversion of vitamin D.

A third limitation in the study is that food security status is measured at a single time and may fluctuate based on seasonal availability of food items (Kong et al., 2025). Cross-sectional studies evaluating food security may not hold for an extended time. Since the NHANES is conducted on a nationally representative sample, this would potentially limit the errors that exist in a smaller, more homogenous sample.

Finally, when evaluating multiple cycles of NHANES, it is necessary to consider how data is collected and weighted. In the 2013-2014 NHANES, oversampling in lower-income populations used a federal income poverty level cutoff of $\leq 130\%$. However, in the 2017-2018 NHANES, the cutoff was changed to $\leq 185\%$. Changes to oversampling low-income populations must be considered during data analysis and interpretation.

Ethical considerations that may threaten participants' trust include assurance of confidentiality. Informed consent was ascertained and stored by the National Center for Health Statistics. During the informed consent process, participants were given information about how survey information had been deidentified (CDC, n.d.-a, n.d.-b). Participants then signed consent documents to agree to interviews and/or biological sample collection. All survey data were encrypted and password-protected as an additional security measure.

Significance

Cost-effective, evidence-based secondary preventive methods can positively affect development of respiratory-related decreases in QALY and improve respiratory

health outcomes in communities experiencing low sunlight and barriers to food access. Identifying vulnerable populations, SDOH contributing to the deficiency, and pathways by which hypovitaminosis D occurs can provide evidence for modifications and recommendations during regular healthcare visits and public health policies. In conjunction with patient education during healthcare visits about asthma prevention, development, and progression, culturally inclusive fortified staple food items and relevant public health education programs targeting communities with fewer resources and higher rates of food inequity can significantly improve respiratory health in at-risk communities.

Chronic asthma can lead to progressive damage to lung tissue due to the release of proinflammatory cytokines during the inflammatory process. However, with increasing prevalence of asthma, it is evident that current secondary preventive measures are ineffective at preventing asthma-associated COPD especially in communities suffering from greater health inequity (Global Initiative for Asthma, 2020).

Summary

Although asthma maintenance primarily focuses on treatment at individual levels, evidence suggests that vitamin D supplementation or increased dietary intake can help improve respiratory immune function, decrease asthma exacerbation and the risk of RTIs. Current treatment methods have minimally decreased asthma-related hospitalizations, illustrating the necessity of finding alternative, cost-effective multidisciplinary methods for mitigating adverse respiratory outcomes. To date, few studies have explored vitamin D supplementation intake in addition to asthma treatments to decrease the severity of

asthma exacerbations and RTI while considering known confounders. This research added knowledge to the research gap explored in Chapter 2.

Chapter 2: Literature Review

There is a gap in terms of finding innovative low-cost approaches for maintaining asthma and respiratory health to improve QALY of populations at risk. The purpose of this nonexperimental quantitative cross-sectional study was to determine whether there was a relationship between vitamin D supplementation, FSI, duration of sunlight exposure, asthma, asthma exacerbation severity, and RTIs in individuals aged 16-30 while controlling for race, household crowding index, and smoking. Studies have been completed to identify the relationships between vitamin D, immune system development, asthma, and RTIs. However, Endocrine Society guidelines still do not recommend vitamin D testing or higher dose supplementation to individuals under 74 who do not have signs of hypocalcemia or skeletal dysfunction. The knowledge gap underpins the need to examine the relationship between vitamin D in terms of vitamin D supplementation, sunlight exposure, asthma, and RTIs while controlling for known confounding factors.

As dietary choices are often related to societal and cultural practices (Iglesias-Vázquez et al., 2023; Ratelle et al., 2023), it is necessary to understand the independent variables of the study as they were related to the five-tier PHIP. Wills et al. (2023) noted in terms of asthma and COPD in Native Hawaiians and Pacific Islanders, increased risk of respiratory illnesses was related to social and individual factors. Additionally, socioeconomic status and historical factors may be necessary to provide the most impact in terms of decreasing respiratory health disparities, which can be evaluated using the PHIP.

In this chapter, I discuss findings from foundational and more current studies associated with vitamin D in the context of respiratory health.

Literature Search Strategy

I used the following key words: *vitamin D deficiency, vitamin d insufficiency, hypovitaminosis D, asthma, acute asthma, asthma attack, asthmatic, asthma exacerbation, respiratory health, lung function, chronic bronchitis, immune system, immune function, immunity, social ecological model, social ecological theory, public health impact pyramid, skin pigmentation, race, UV transmission, household crowding index, eating practices, transitional adolescent, food insecurity, and food insufficiency.*

The following Walden University databases were used: Google Scholar, ProQuest Central, PubMed, and EBSCOHost. In addition, CDC, USDA, U.S. Census Bureau, Mathematica Policy Research, and Health Promotion Agency web sites were searched to understand the problem.

Peer-reviewed quantitative, qualitative, mixed methods, and meta-analysis studies as well as seminal literature were evaluated that were published between 2001 and 2025 to provide a clear understanding of the topic.

Theoretical Foundation

The theoretical foundation for this study was based on the five-tier PHIP introduced by Frieden. Other similar frameworks, such as a four-tier pyramid, Grizell's six-tier pyramid, Hamilton and Bjatti's 3D population health and health promotion cube, and the maternal and child health pyramid were focused on clinical interventions to health problems and not population health improvements that target public health

infrastructures. Although individual behavior changes are necessary to yield positive health outcomes, they rely on sustained individual behavior changes.

Using Frieden's five-tier PHIP, I addressed respiratory health outcomes in vulnerable populations by focusing on the bottom two tiers: socioeconomic factors and changing context to promote health-conscious decisions. Food insecurity and availability of quality food items are strongly related with poverty. Increasing availability and affordability of food items can improve individual micronutrient balance. In addition, improving awareness of the importance of vitamin D via public health initiatives can alert individuals to affordable sources of vitamin D-rich food items in areas with lower seasonal sunlight exposure. These two strategies can have the most significant population impact as they are related to the first tier of the PHIP. Enacting mandatory vitamin D food fortification policies for staple food items (i.e., flour, rice, corn, and potatoes) can further improve access to vitamin D and change the environmental context that encourages making healthy decisions a default option. This strategy falls within the second tier of the PHIP.

In reviewing literature, the five-tier PHIP was not used to evaluate vitamin D in the context of improving respiratory health. Identifying viable cost-effective strategies for a greater population impact to improve QALY associated with respiratory outcomes is therefore worth investigating.

Literature Review Related to Key Variables and/or Concepts

Vitamin D responds to PTH to regulate calcium metabolism through renal 1α -hydroxylase (CYP27B1). Extrarenal conversion of prohormone vitamin D by immune

cells with VDRs, specifically antigen presenting macrophage and APCs, T cells and B cells, have been identified in literature due to their ability to convert 25(OH)D through CYP27B1. This latter vitamin D bioconversion is regulated by serum 25(OH)D concentration and is not regulated by the negative feedback loop associated with PTH, calcium, and phosphate metabolism (Van Etten et al., 2008). However, this extrarenal conversion is isolated in the immune cells to increase immunotolerance and regulate the immune response (Walawska-Hrycek et al., 2025). Despite the recognized relationship between vitamin D and immune regulation, testing and supplementation are not clinically recommended for individuals with asthma and recurring RTIs (Demay et al., 2024).

Although vitamin D intake has increased in all populations, subpopulations in the United States have not met the benchmark goal for Healthy People 2030. Moore et al. (2014) reported non-Hispanic Whites had the highest total and dietary intake of vitamin D, followed by Hispanics, and non-Hispanic Blacks. Hagenau et al. (2009) reported mean vitamin D levels were significantly higher in Caucasians compared with non-Caucasians ($p < 0.01$). Moreover, there was a 47% and 52% higher rate of consumption of vitamin D supplements in non-Hispanic Whites compared with non-Hispanic Blacks and Hispanics, respectively (Moore et al., 2014). Furthermore, Pate et al. (2021) found asthma-related emergency department (ED) and urgent care center (UCC) visits were higher among non-Hispanic Blacks and Hispanics compared with non-Hispanic Whites. Additionally, asthma mortality was higher in non-Hispanic Blacks compared with non-Hispanic Whites. Moreover, Schleicher et al. (2021) reported there were still significantly lower 25(OH)D levels in non-Hispanic Blacks compared with non-Hispanic Whites. Evidence

thus far suggests that although vitamin D supplementation and dietary consumption might have increased for all races over the last several years, there are still disparities involving respiratory health maintenance and vitamin D.

Sources of Vitamin D

Sources of vitamin D can be affected by lifestyle, nutrition, genetic and physiologic differences, and environments in which people live. Lifestyle factors contributing to serum 25(OH)D levels include exposure to sunlight, clothing choice, and coverings influenced by tradition or religion (Almelli, 2023; Patel et al., 2023). Nutritional factors contributing to vitamin D bioavailability include the consumption frequency of vitamin D-rich foods (i.e., oily fish, dairy products, vitamin D fortified foods, and the use of vitamin D supplements) (Iglesias-Vázquez et al., 2023; Schleicher et al., 2021). Additionally, genetic variations in VDR and the hydroxylating enzymes contribute to cellular vitamin D uptake in the metabolic pathway and immune development (Kandemiş et al., 2021; Murugesan et al., 2024). Furthermore, darker skin pigment, attributing to higher melanin concentrations in the epidermis, has been associated with decreased UVB absorption (Chen et al., 2007). Finally, environmental factors contributing to vitamin D status include air quality and SZA, resulting in the amount of UVB available (Rahman & Elmi, 2021; Religi et al., 2019). The following sections will further describe studies exploring the relationship between vitamin D status, individual lifestyle factors, nutrition, genetic and physiologic differences, the environment, asthma, and RTIs.

Vitamin D Concentrations Influenced by Lifestyle

Cutaneous production of cholecalciferol (vitamin D₃) contributes the most to the endogenous bioavailability of vitamin D, accounting for approximately 90% of vitamin D produced (Reichrath, 2006). 7-dehydrocholesterol (7-DHC), a precursor of cholecalciferol found in keratinocytes, is photosynthetically converted to cholecalciferol (vitamin D₃) when exposed to UVB radiation at a wavelength of 290-315 nm. Continued UV irradiation does not prolong the production of vitamin D₃. However, a steady state is reached once 10-15% of 7-DHC has been converted, which was thought to be one of the internal feedback mechanisms to prevent toxicity (Tsiaras & Weinstock, 2011).

Depending on where individuals live and local traditions, UVB radiation exposure needed to convert 7-DHC may not be sufficient to maintain bioactive vitamin D levels. Furthermore, recent studies have called into question whether sunlight exposure is as great a contributing factor to serum 25(OH)D levels as previously believed. Holick (2004) reported UVB radiation is sufficient in converting 7-DHC to vitamin D₃ year-round in regions below 35° latitude. Supporting these findings, Young et al. (2019) reported those using UVA sunscreen at their discretion on vacation spent more time in the sun. However, these participants experienced a significantly increased incidence of erythema but also had the most significant change in serum 25(OH)D levels when compared with pre-vacation values. Post-hoc analyses tested the differences between the study's groups and were statistically significant ($p < 0.001$) (Young et al., 2019). Furthermore, Feketea et al. (2021) conducted a study in Amaliada, Greece (37.7 °N) and found children who wore sunscreen had a higher mean 25(OH)D level compared with

those who did not wear sunscreen ($p \leq 0.001$). The authors inferred that children wearing sunscreen often experienced sun exposure for extended periods due to the sunscreen's ability to limit erythema, which supported previous studies (Kim et al., 2020; Pereira et al., 2019). However, Tugrul et al. (2023) found children who used sunscreen during the summer had significantly lower 25(OH)D levels during the winter compared with those who did not use sunscreen ($p = 0.001$). It is important to note that vitamin D testing did not occur when 25(OH)D levels were at their seasonal peak, but at a time when lower temperatures and less sunlight would result in less UV exposure (Tugrul et al., 2023). Therefore, 25(OH)D levels would depend more on dietary consumption than sun exposure. The results from these studies suggested a relationship between the duration of sunlight exposure and changes in serum vitamin D levels in the participants. Sunscreen did not affect these variations, which helped decrease the risk of erythema and skin damage caused by UV radiation.

Conversely, Kagotho et al. (2018) found vitamin D deficiency (< 50 nmol/L) and insufficiency in 17.4% and 42.6% of participants in Nairobi, Kenya (1° S), respectively. The participants who were vitamin D deficient did not demonstrate symptoms of hypocalcemia or hypophosphatemia. Using a multivariate regression analysis, the duration of sunlight exposure was not significantly related to serum 25(OH)D levels ($p = 0.08$). Additionally, in a review of Brazilian studies (between 5° N and 33° S), vitamin D insufficiency prevalence was between 28.5% and 57.4% among study participants (Correia et al., 2014; Premaor et al., 2008; Santos et al., 2012). Similarly, Pulungan et al. (2021) reported that 37.5% of children in Jakarta, Indonesia (6.2° S) demonstrated

hypovitaminosis D. Furthermore, Ahmed et al. (2017) reported that 45.6% of infants demonstrated hypovitaminosis D in Bangladesh's urban slums, despite the abundance of sunlight and seasonality of vitamin D measurements. These studies below 35° latitude suggests that vitamin D status may not rely on UVB exposure. Hagenau et al. (2009) hypothesized that the decreased dependency on UVB for vitamin D conversion is due to evolutionary adaptations caused by decreased sunlight exposure and latitude variations. This resulted in the inverse relationship between increasing latitude and vitamin D levels in Caucasians. However, this relationship was absent in non-Caucasian populations. In addition, the variations found in serum vitamin D levels may be due to climate, pollution, altitude, age, skin pigmentation, sex, lifestyle, government food fortification policies, and supplementation (Hagenau et al., 2009). These findings from UVB-rich regions suggested that contributing factors other than sunlight exposure affect serum vitamin D levels, indicating that future studies need to consider these factors when evaluating hypovitaminosis D.

Using the total body surface area (TBSA) criteria to estimate body surface affected for burn injury evaluations, the head and neck (both front and back) is equivalent to 9% of the body surface (State Burn Coordinating Center, 2023). Religi et al. (2019) estimated that it is necessary to have UV exposure to 22% of the body during summer months for 10-15 minutes and up to 6.5 hours of exposure of 8-10% of the body during winter months to acquire the equivalent of a 1000 IU (or 25 µg) dose of vitamin D in higher latitudes. This differed from the conclusions made by Holick (2004), which suggested the exposure of face and arms (22% TBSA) for 15-30 minutes between 11 am

and 3 pm was sufficient for adequate vitamin D conversion. The findings from Chee et al. (2022) suggested that UV exposure of $\geq 27\%$ TBSA significantly reduced the risk of hypovitaminosis D in pregnant women ($p < 0.001$). More exposure in the latter study was required due to the increased vitamin D need to maintain fetal and maternal calcium metabolism during pregnancy.

Therefore, the duration and amount of unimpeded UVB radiation exposure contribute to vitamin D photoconversion and serum 25(OH)D levels. In Homs, Syria, Almelli (2023) reported that 46.4% of participants had the lowest mean serum 25(OH)D. The prevalence of vitamin D deficiency was equally distributed between males and females (50% and 54%, respectively), while the female participants in the study demonstrated significantly lower mean serum 25(OH)D levels compared to their male counterparts. Additionally, 65% of female study participants wore the traditional veiled clothing (head scarf and covering the whole body), which was a significant contributor to vitamin D deficiency ($p < 0.0001$). However, Pulungan et al. (2021) found no significant association between hypovitaminosis D and clothing worn by female children wearing traditional Hijabs. Neither study indicated the type of fabric from which traditional coverings were made, which can contribute to the amount of UV radiation transmitted through the textile. Liu and Zhang (2015) found that UV radiation transmission through polyester was higher than with cotton, but UV transmission is also highly dependent on textile color. Darker colored cotton fabrics allowed less UVA transmission, whilst darker polyester fabrics allowed more UVA transmission (Aguilera et al., 2014).

When considering the relationship between vitamin D supplementation and serum vitamin D levels, the studies presented suggest it is necessary to consider lifestyle, duration and amount of unimpeded UVB exposure participants experience.

Vitamin D Concentrations Influenced by Nutrition

Aside from the cutaneous conversion of 7-DHC, cholecalciferol can be acquired through dietary intake of red meat, oily fish, dairy products, vitamin D-fortified foods, and vitamin D supplementation. However, dietary vitamin D intake only accounts for approximately 10% of total-body vitamin D (Ahmed et al., 2017). Furthermore, customs of different ethnic groups contribute to the variation of dietary vitamin D. Mendes et al. (2018) reported that despite experiencing sufficient UVB exposure, there is a high prevalence of vitamin D deficiency in different areas of Brazil attributed to the lack of oily fish and mushrooms in the Brazilian diet. Moreover, vitamin D food fortification is not mandated in Brazil and is an uncommon practice. Additionally, Chee et al. (2022) concluded that in a study with predominantly from West Sumatra, Indonesia (0°N), and Selangor and Kuala Lumpur, Malaysia (3°N), dietary vitamin D was below RDA due to the limited consumption of naturally occurring vitamin D-rich foods. Comparing the dietary habits of Polish and Spanish pregnant women, Iglesias-Vázquez et al. (2023) evaluated the culturally based diets and participants' micronutritional deficiencies. Spanish Mediterranean diet consisting of fruits, vegetables, whole grains, legumes, nuts, olive oil, fish, and dairy products were compared with Polish diet consisting of cereals, potatoes, vegetables, and meat. Despite the difference in dietary intake of the study's population from two countries, both groups did not meet the RDA for vitamin D

throughout their pregnancies. With varying global food fortification policies and the underconsumption of natural sources of vitamin D found in oily fish, there is a significant challenge in acquiring sufficient dietary vitamin D.

Furthermore, dietary intake and sun exposure are significant contributing factors to vitamin D status only when taking into account an individual's place of residence. In a June 2017 to February 2019 Taiwanese nutritional survey, Huang et al. (2023) used an area under the receiver operating characteristic (AUROC) curve. The authors concluded in sub-tropical regions of Taiwan, vitamin D intake contributed more towards 25(OH)D levels than sun exposure (AUROC = 0.536, $z = 51.98$, $p < 0.001$). In tropical regions, sun exposure contributed more towards 25(OH)D levels (AUROC = 0.617, $z = 54.02$, $p < 0.001$). In addition, those who were unaware of vitamin D food sources were at an increased risk of hypovitaminosis D (aOR = 4.39, $p = 0.002$) (Sakyi et al., 2021). These findings suggested that the contribution of dietary vitamin D varies by geographic location, amount of sun, cultural dietary norms, and knowledge.

Although some have argued the importance of diet on vitamin D status, Young et al. (2019) did not find significance in diet's contribution to vitamin D levels. Similarly, Gill et al. (2024) used a Spearman's correlation test to evaluate the relationship between vitamin D intake using a food frequency questionnaire and serum 25(OH)D levels. The authors reported there was a significant weak positive correlation ($r(88) = 0.764$, $p < 0.001$). However, in a multiple logistic regression, vitamin D intake was the only significant contributor to vitamin D status ($R^2 = 0.764$, $F(1, 86) = 120.618$, $p < 0.001$) compared with demographics and exposure to sun. Therefore, diet was a weak predictor

of vitamin D status. Nevertheless, Ratelle et al. (2023) reported that micronutritional deficiencies were prevalent among Dene and Métis communities in the Northwest Territories in Canada with limited UV exposure (above 60° N). Communities in these areas rely heavily on food sources, rather than sunlight exposure, for vitamin D. The authors found that those who consumed country food or traditional food (consisting of game meat, wild birds, fish, and foraged foods) had better nutritional status compared with those who did not consume these food items. Although nutritional balance was better in one group, deficiencies in vitamin D were still prevalent in both groups. Various arguments support and refute the involvement of food quality as a contributing factor to nutritional deficiencies.

Several studies indicated that older adolescents are at a higher risk of hypovitaminosis D during a time when individuals are experiencing rapid skeletal growth. Adolescents between 11 and 18 years old were found to be at a significantly higher risk of vitamin D deficiency ($p < 0.001$) (Karagol & Duyan Camurdan, 2023). Tangpricha et al. (2002) and Horton-French et al. (2021) reported that young adults between 18 and 25 living away from home were at a higher risk of hypovitaminosis D due to dietary changes occurring during the transitional time in their lives. Dong et al. (2022) reported between January and February 2019 in Coventry, United Kingdom (52.4°N), 46.3% of participating university students between 18 and 29 years old experienced hypovitaminosis D. Additionally, 87.9% did not consume the 10 µg RDA of vitamin D from food sources. Furthermore, 64.3% who were Black, African, or African-Caribbean demonstrated vitamin deficiency, almost two to three times higher than Asian and

Caucasian students, respectively (Dong et al., 2022). Using a simple logistic regression analysis, the authors found that ethnicity ($R^2 = 0.185$, $p = 0.01$) and dietary intake ($R^2 = 0.13$, $p = 0.04$) were significant predictors of vitamin D levels (Dong et al., 2022). During the recruitment process, the authors noted that participants had very little to no knowledge of the importance of vitamin D RDA, suggesting a lack of health education involving vitamin D and its multifaceted physiologic functions. Complementing these findings, Hafiz et al. (2023) reported food availability and self-confidence were barriers to healthy dietary habits in Northern Ireland university students. The authors further concluded young adults transitioning to living outside of the home are often met with newfound autonomy in food choices. However, with autonomy comes the responsibility of purchasing and preparing food. Focus group results reported although students could find information on dietary recommendations, food storage and preparation were challenges in a university setting. Furthermore, students from abroad who moved to attend university met the additional challenge of finding familiar traditional foods. In addition, other barriers to healthy eating in late adolescence included mood, dietary habits, physical activity, finances, nutritional knowledge, peer influence, class and work schedules (Klobodu & Goto, 2024). Therefore, nutritional and vitamin D education and mandatory food fortification policies are necessary and missing components of healthy dieting initiatives, especially in at-risk young adults making independent dietary choices.

Although sun exposure and dietary sources of vitamin D are necessary to maintain vitamin D levels, additional vitamin D supplementation is still necessary to maintain sufficiency. Mendes et al. (2021) found vitamin D supplementation was necessary to

maintain serum 25(OH)D levels regardless of geographic location. Both groups receiving vitamin D supplementation but in different geographic locations had increased 25(OH)D levels (with UVB group: baseline 25(OH)D = 75.1 ± 22.0 nmol/L, post-intervention 25(OH)D = 84.8 ± 21.0 nmol/L, $p = 0.004$; without UVB group: baseline 25(OH)D = 38.1 ± 15.9 nmol/L, post-intervention 25(OH)D = 55.1 ± 12.2 nmol/L, $p < 0.001$; no significant difference in placebo groups) with a significant correlation between the intervention and serum 25(OH)D levels (with UVB: $r = 0.407$, $p = 0.001$; without UVB: $r = 0.421$, $p = 0.003$). Using a hierarchical multiple regression with baseline 25(OH)D, age, BMI, and waist circumference in step 1, the model explained 62.6% of the variance in 25(OH)D levels. Using total vitamin D intake and sunlight exposure level at step 2, the model was able to explain an additional 5% of the variance in 25(OH)D levels ($F(2, 92) = 31.9$, $p < 0.001$). In the final model, only baseline 25(OH)D and vitamin D intake were significant predictors of post-intervention 25(OH)D levels ($\beta = 0.734$, $p < 0.001$; $\beta = 0.217$, $p < 0.001$, respectively). The study's findings indicate that vitamin D supplementation significantly predicts vitamin D levels, while exposure to UVB was not as much of an influencing factor.

Moreover, individuals reported that limited knowledge of vitamin D and appropriate supplementation dosage are significant barriers to vitamin D supplementation use. Boland et al. (2015) found 8% of participants between 20 and 39 at a Canadian university could identify the correct vitamin D RDA, however 38.9% took some vitamin supplementation that included vitamin D. Additionally, Day et al. (2019) indicated parents in the United Kingdom were unaware of the health effects associated with

hypovitaminosis D or were discontent with the amount and quality of information provided about vitamin D recommendations during gestation, postnatally, and during early childhood. 64% knew the role of vitamin D in maintaining bone health, and 39% were aware of the role of vitamin D in supporting immune health. Furthermore, 70% stated that if they knew more about vitamin D and the health implications of hypovitaminosis D, would have motivation to include supplementation and dietary vitamin D in their child's diet. Likewise, Kalliokoski et al. (2021) reported culturally sensitive vitamin D education was provided for both the study's Somali and Swedish target groups. Initial findings indicated that four months post-intervention, the Somali target group significantly increased consumption of dietary vitamin D ($p < 0.05$) while the Swedish target group did not demonstrate significant dietary changes ($p > 0.05$). However, 10 months post-intervention, the Somali target group only continued the increased consumption of cheese, but not in the other sources of foods (milk and fish). During the focus group sessions for the Somali target group, Kalliokoski et al. (2021) found participants reported better understanding of vitamin D sources but demonstrated varying sustained behavioral changes. Although application of behavioral changes did not occur, there was an increase in vitamin D confidence due to the educational intervention. Furthermore, Zaremba and Conduit-Turner (2025) reported knowledge of vitamin D was poor in the Scottish population. 15.1% of participants correctly identified the recommended dose of vitamin D supplementation but only 7.4% were taking the daily RDA.

In populations that have demonstrated increases in vitamin D supplementation, there is still a racial disparity in vitamin D knowledge and use. Schleicher et al. (2021) found in the 2007-2010 and 2011-2014 NHANES, frequency of individuals taking any vitamin D supplement has increased by 2.9% ($p = 0.0314$) and high-dose vitamin D by 8.6% ($p < 0.001$). However, after adjusting for age, sex, Hispanic race, time of season, BMI, 24-hour dietary vitamin D intake, and vitamin D supplementation, the difference in the serum 25(OH)D levels was not significant ($p = 0.09$). Of note, non-Hispanic Blacks had vitamin D levels 22 nmol/L lower than non-Hispanic Whites. Therefore, clear and precise nutritional education about vitamin D functions, an appropriate dosage of vitamin D supplementation consensus, and food sources of vitamin D are necessary in promoting vitamin D health.

Vitamin D Concentrations Influenced by Genetic and Anthropometric Variations

UVB conversion for biosynthesis of vitamin D and vitamin D intake significantly influences vitamin D status. However, biological differences can affect how vitamin D is converted and transported throughout the body. Melanin absorbs electromagnetic radiation throughout the UV spectrum. Those with a higher qualitative Fitzpatrick phototype measurement of skin pigmentation (Fitzpatrick VI) have more melanocytes and melanin, resulting in competition between melanin and 7-DHC for UVB radiation (Tsiaras & Weinstock, 2011). Chen et al. (2007) reported that when a light skin sample was placed in sunlight for 30 minutes, 3% of 7-DHC was converted. In contrast, when a darker skin sample was evaluated in the same experiment, it had converted 0.3% of 7-DHC. Those with Fitzpatrick I and II phototypes have a lower erythema dose but a higher

UV penetrance to promote conversion of 7-DHC (Raymond-Lezman & Riskin, 2023). Furthermore, Chee et al. (2022), concluded that Malaysian and Indonesian participants with predominantly Fitzpatrick phototype IV and V skin color, experienced a higher burden of hypovitaminosis D. Religi et al. (2019) indicated that in the summer, skin phototype II individuals need up to 10 minutes of UV exposure to achieve 1,000 IU of vitamin D. However, in skin phototype III individuals, UV exposure must be extended 4 minutes to achieve 1,000 IU of vitamin D, which is still below the exposure time to induce erythema (estimated at 36-37 minutes). However, Pulungan et al. (2021) reported that those with Fitzpatrick phototype IV demonstrated a lower prevalence of hypovitaminosis D than type III due to the extra time spent outdoors, resulting in darker tans among Indonesian children. In contrast, Tugrul et al. (2023) and Gill et al. (2024) did not find statistical significance between skin phototype and vitamin D levels. Charoenngam and Sriussadaporn (2021) also noted that individuals with darker skin spent more time in the sun than those with lighter skin due to a lower risk of erythema and were, therefore, at a lower risk of developing hypovitaminosis D ($OR_{\text{dark skin}} = 0.263$, $p = 0.026$; $OR_{\text{medium skin}} = 0.369$, $p = 0.067$). Although there is controversy on skin pigmentation and UV vitamin D photoconversion, the fact remains that many studies still suggest that those with darker skin will need prolonged UVB exposure compared with those with lighter colored skin to acquire the same amount of vitamin D, a probable contributing factor to higher rates of hypovitaminosis D in non-Hispanic Blacks.

Vitamin D hydroxylation and bioactivation require cytochrome enzymes at different gene loci. CYP2R1 (encoding 25-hydroxylase) converts previtamin D to

25(OH)D. The second vitamin D hydroxylation step depends on the renal and extrarenal production of 1α -hydroxylase by the CYP27B1 gene. Therefore, individuals with chronic kidney disease (CKD) have decreased renal function, resulting in decreased production of the enzyme. Furthermore, CKD results in phosphate retention, which inhibits CYP27B1 activity (Tsiaras & Weinstock, 2011). Finally, CYP24A1 catabolizes 25(OH)D to be eliminated. Single-nucleotide polymorphism (SNP) variants have been evaluated in the context of vitamin D metabolism. Pillai et al. (2011) concluded CYP24A1 SNP rs2248137 was a risk factor for hypovitaminosis D in those who had asthma ($p = 0.006$). CYP2R1 SNP rs10766197 AA genotype was associated with asthma ($p = 0.044$), and VDR SNP rs2228570 was associated with more severe nighttime asthma exacerbation episodes ($p = 0.04$), but neither SNP variation demonstrated significant associations with vitamin D concentrations ($p > 0.05$).

Moreover, Das et al. (2022) concluded SNPs in the CYP27B1 gene were positively associated with vitamin D deficiency ($\beta = 1.61, p = 0.008$). The AA wildtype was protective against hypovitaminosis D, while the CC SNP was a risk factor for hypovitaminosis D. Furthermore, vitamin D metabolism is dependent on the activity of VDR. Although Pillai et al. (2011) did not find an association between VDR SNP and vitamin D concentrations in the cohorts with asthma, Munkhbayarlakh et al. (2019) reported participants with SNP rs2228570 GG genotype was significantly associated with having asthma in a multifactorial logistic regression (OR = 3.77, $p = 0.012$) with the AG or AA genotype being more prevalent in those without asthma. Hypovitaminosis D was significantly associated with asthma (OR = 38.94, $p < 0.0001$). Likewise, Kandemiş et al.

(2021) conducted a study on the four most common VDR polymorphisms. The authors found the rs2228570 C > T variant was significantly associated with lower vitamin D levels ($p = 0.029$). Moreover, individuals with both hypovitaminosis D and the SNP rs2228570 GG genotype were at a significantly increased risk of having bronchial asthma (OR = 147.3, $p < 0.0001$) while having the AG or AA genotype and hypovitaminosis D had a lesser degree of increased risk (OR = 34.7, $p < 0.0001$) (Munkhbayarlakh et al., 2019). The genetic variability in enzymes and receptors involved in vitamin D metabolism must be considered a potential barrier to achieving vitamin D sufficiency in those with sufficient dietary vitamin D and sun exposure.

Another factor affecting vitamin D metabolism is abdominal adiposity. Various studies reported vitamin D levels were inversely related to BMI (Tsiaras & Weinstock, 2011). Studies looking at relationships between independent variables such as sun exposure, dietary and supplementation intake, control statistical analysis for BMI due to the small effect adiposity has on 25(OH)D levels. Pulungan et al. (2021) did not find a significant relationship between BMI and vitamin D levels under univariate and multivariate tests (OR_{univariate} = 0.919, $p = 0.094$; OR_{multivariate} = 0.908, $p = 0.095$). Likewise, Huang et al. (2023) reported that BMI did not significantly contribute to vitamin D levels in pregnant women using a multiple logistic regression analysis (OR_{obese} = 0.87, $p = 0.397$). However, in a study on 25(OH)D concentrations in children with asthma, Bindow (2021) found children who were vitamin D deficient had a significantly higher BMI compared with those with insufficient or sufficient levels of 25(OH)D. Furthermore, in a post-hoc analysis on a randomized, double-blinded, placebo-controlled

trial of 2,000 IU per day vitamin D supplementation, Tobias et al. (2023) concluded those who were classified as underweight, normal weight, overweight, with obese class I, and obesity class II, the increase in total 25(OH)D were lower with increasing BMI (treatment effects were 13.5, 12.7, 10.5, and 10.0, respectively; $p < 0.001$). The data analyzed indicated that adiposity diminished the effect of vitamin D supplementation on serum levels. This trend was similar to serum 25(OH)D, free vitamin D, and bioavailable vitamin D data in the same multivariable-adjusted mean analysis of the treatment groups. The author's findings suggest that BMI is a significant modifier contributing to 25(OH) levels and should be considered when developing vitamin D education to improve health outcomes.

Vitamin D Concentrations Influenced by Environmental Factors

Although evidence suggests that sufficient sun exposure is necessary to produce approximately 90% of the bioavailable vitamin D in the body, the intensity of UV radiation significantly contributes to photosynthetic vitamin D conversion. Although Hagenau et al. (2009) reported that there was no significant contribution of latitude to vitamin D levels. However, the meta-regression analysis was conducted in a highly heterogeneous sample from countries with different dietary, cultural, and fortification practices. Recent studies have provided information on UVB intensity and vitamin D based on geographic location. Khanna et al. (2022) evaluated dermal vitamin D conversion (D-UVB) wavelengths in 46 European capitals and found that there was up to a five-fold difference in mean UVB based on locations between 35 to 64 °N latitudes (mean annual D-UVB_{Nicosia} = 5.57 kJ/m²; mean annual D-UVB_{Reykjavik} = 1.16 kJ/m²).

When evaluating seasonal differences in D-UVB intensity, there was a median 10- to 525-fold difference between peak and trough intensities (mean July D-UVB_{London} = 5.49 kJ/m²; mean December D-UVB_{London} = 0.11 kJ/m²). Mean D-UVB intensity in different capital cities in winter months also demonstrated variations (mean November to February D-UVB_{Nicosia} = 1.63 kJ/m²; mean November to February D-UVB_{Reykjavik} = 0.03 kJ/m²). Therefore, participants living above the 40 ° latitude were at a significantly higher risk of developing hypovitaminosis D compared with those living below 40 ° latitude ($p = 0.006$) (Karagol & Duyan Camurdan, 2023). Although evidence indicates a difference in UVB intensity attributed to SZA (affected by latitude, season, and time of day), Hagenau et al. (2009) have recommended that studies focus on more homogenous samples when evaluating vitamin D status and health outcomes.

Another environmental contributing factor to vitamin D through UVB photoconversion is air quality. Gaseous and particulate components found within the atmosphere can attenuate UVB transmission. Furthermore, Ahmed et al. (2017) found an increased risk of hypovitaminosis D in the urban slums of Bangladesh, attributed to air pollution. Mothers with higher education levels attempted to protect their children from inhaling particulate matter by limiting the time spent outdoors, resulting in pediatric hypovitaminosis D. Components that have been proposed to affect UVB intensity by dispersing or absorbing photons include ozone (O₃), carbon monoxide (CO), nitrogen oxides (NO_x), sulfur oxides (SO_x), and particulate matter (PM_x). Rahman and Elmi (2021) reported that in a four-year study conducted in Kuwait, O₃, NO, SO₂, and PM₁₀ were negatively associated with UVB ($\beta = -0.23, -0.11, -0.10, \text{ and } -0.002$, respectively).

Furthermore, the authors stated atmospheric NO concentrations were highest in the morning hours when inhabitants of Kuwait are more likely to spend time outside before daily temperatures peak. As a result, individuals receive lower intensity UVB exposure in the morning due to increased SZA and atmospheric pollutants. In addition, an extensive population-based prospective study using the U.K. biobanks data found that in models adjusted for demographic, location and seasonality, lifestyle (smoking, alcohol use, physical activity, and hormone replacement therapy), dietary factors (vegetables, fruits, fish, processed meat, beef, lamb, pork, milk, and coffee), and dietary supplements (calcium supplements and vitamin D supplements), air pollution concentrations at the higher quintiles were significantly associated with increased fracture hazard risk ($HR_{PM_{2.5}} = 1.18, p < 0.01$; $HR_{PM_{10}} = 1.06, p = 0.03$; $HR_{NO_2} = 1.22, p < 0.01$; $HR_{NO_x} = 1.19, p < 0.01$) (Qi et al., 2023). Furthermore, 25(OH)D was a mediator for the association of air pollution and fractures. Increases in $PM_{2.5}$, PM_{10} , NO_2 , and NO_x were significantly associated with hypovitaminosis D ($\beta = -9.66, -1.36, -1.19, \text{ and } -0.71$, respectively). 25(OH)D accounted for 5.96, 2.55, 4.09, and 5.45% of the estimated effects of pollutants and fracture risk, respectively ($p < 0.001$). These findings confirm the notion that air quality contributes to UVB transmission and affects cutaneous photoconversion of vitamin D into 25(OH)D.

Vitamin D and Immune Development

Vitamin D has been well-linked to calcium and phosphate homeostasis. Recently VDRs have been found on immune and respiratory cells, suggesting that vitamin D is involved in developing and maintaining the respiratory immune system. Bioactive

1,25(OH)₂D₃ modulates the immune system and activates the production of toll-like receptor (TLR) coreceptor CD14 to promote the phenotypic expression of human cathelicidin antimicrobial peptide (*camp*) and defensin β2 (*defβ2*) in response to bacterial and viral infections. This process occurs through VDR stimulation of vitamin D response elements (VDRE) (Koivisto et al., 2020; Wang et al., 2004). Furthermore 1,25(OH)₂D₃ promotes antigen-presenting cell (APC) maturation (specifically monocytes to macrophages), increasing the cell's phagocytic and oxidative burst capabilities (Sanlier & Guney-Coskun, 2022; Van Etten et al., 2008). Liu et al. (2006) reported that TLR activation of macrophages by *Mycobacterium tuberculosis* upregulated VDR expression, CYP27B1 activation, and VDRE (specifically *camp*), helping to reduce susceptibility to the intracellular pathogen and supporting innate immune health. Furthermore, APCs, dendritic cells, T cells, and B cells contain CYP27B1, suggesting that adaptive immune cells are also sensitive to 25(OH)D and can produce 1,25(OH)₂D₃, which are regulated by IFN-γ, LPS, or viral infections (Van Etten et al., 2008).

Vitamin D was found to affect the differentiation of CD4⁺ T-helper (Th) cells into Th1, Th2, Th17, and regulatory T cell (Treg) subsets. Th1 and Th17 cells produce IFN-γ, IL-2, IL-3, and TNF-α, which are necessary in protecting cells against intracellular pathogens and autoimmune changes (Boonstra et al., 2001; Sanlier & Guney-Coskun, 2022). Th2 cells produce IL-4, IL-5, IL-9, IL-10, IL-13, IL-14, and TGF beta needed to prevent extracellular parasitic infections and induction of allergic reactions (Boonstra et al., 2001; Salmanpour et al., 2022; Sanlier & Guney-Coskun, 2022). In addition, vitamin D contributes to CD4⁺ cell differentiation by controlling the

expression of genes, such as GATA-binding protein 3 gene (GATA3), that are involved in cellular differentiation and maintaining Th1 and Th2 balance (Erfanian et al., 2022). Therefore, the fate of the CD4⁺ cells depends on the phenotypic expression of specific VDR activated transcription factors. Vitamin D binding to cellular receptors acts as a transcription factor in promoter regions of genes affecting differentiation and maturation of immune cells (Boonstra et al., 2001). Th2 and Treg cells are anti-inflammatory, while Th1 and Th17 cells are pro-inflammatory. Maintaining sufficient 1,25(OH)₂D₃ promotes upregulation in Th2 and Treg maturation and the GATA3 gene (Erfanian et al., 2022; Sanlier & Guney-Coskun, 2022). Additionally, dendritic cells can become more immunotolerant when 1,25(OH)₂D₃ reduces MHC II and CD40, CD80, and CD86 expression, leading to a lower secretion of IL-12 and increased tolerogenic IL-10 (Prietl et al., 2013; Walawska-Hrycek et al., 2025).

These studies concluded that although vitamin D has not demonstrated a causal relationship with preventing respiratory illnesses, there is a strong association between vitamin D concentrations and anti-inflammatory tolerogenic cellular profiles in both the innate and adaptive immune systems. This relationship is necessary to explore when evaluating serum 25(OH)D levels in the context of asthma and RTIs.

Hypovitaminosis D and Respiratory Health

Respiratory system development begins *in utero* and reaches developmental peak in early adulthood. After 25, respiratory functions begin to gradually decline as demonstrated by routine spirometry forced expiratory volume in 1 second (FEV1), forced vital capacity (FVC), and FEV1/FVC ratio values (Melén et al., 2024). In addition,

modifiable exposure to environmental factors, such as tobacco smoking and exposure to secondhand smoke (SHS), interfere with respiratory maturation rate and decrease peak lung function, thereby decreasing lung function throughout all stages of life. Moreover, chronic asthma significantly restricts respiratory tract development and diminishes respiratory function. Asthma treatment focuses on improved patient education and treatment with glucocorticoids to decrease asthma exacerbation frequencies, with limited focus on asthma prevention in at-risk populations.

Studies evaluating the relationship between vitamin D and respiratory health demonstrated conflicting results, obfuscating the clinical use of vitamin D to improve respiratory resilience. In a meta-analysis, Liu et al. (2022) concluded that vitamin D supplementation in those with asthma did not significantly improve respiratory health outcomes based on the asthma control test (ACT) scores ($p = 0.87$), but did significantly reduce asthma exacerbations ($RR = 0.69, p < 0.01$). However, the sample sizes of several studies in the meta-analysis were too small to support reliable conclusions. In contrast, Anand et al. (2021) found that there was a strong inverse relationship between 25(OH)D and asthma ($p < 0.001$) in children. Likewise, Alkhatatbeh et al. (2021) reported that 90.5% of adults who had asthma had 25(OH)D < 50 nmol/L compared with 65.3% of controls without asthma ($p < 0.001$). Furthermore, using a binary logistic regression analysis, the authors concluded that asthma was found to be significantly associated with decreased 25(OH)D concentrations ($OR = 0.86, p < 0.01$). Association between hypovitaminosis D and asthma prevalence was further supported in 2023 studies which reported that individuals with more severe cases of asthma had significantly lower

25(OH)D levels than those with mild to moderate asthma ($p < 0.05$) and with the highest 25(OH)D levels seen in controls without asthma (control = 115 nmol/L, mild asthma = 80 nmol/L, moderate asthma = 54 nmol/L, severe asthma = 47 nmol/L, $p < 0.0001$) (Malheiro et al., 2023; Nazneen & Usmani, 2023). In addition, Malheiro et al. (2023) concluded vitamin D concentrations were weakly correlated to lung function test results as determined by Spearman's correlation coefficient (FEV1: $r = 0.223$, $p < 0.05$; FEF_{25-75%}: $r = 0.175$, $p < 0.05$). There was no differences in the means of 25(OH)D concentrations based on seasonality in those with controlled and uncontrolled asthma ($p > 0.05$).

To further investigate the relationship between vitamin D and asthma prevalence, randomized controlled trials (RCTs) have determined if vitamin D has a direct effect on asthma. In a study of adults with asthma and hypovitaminosis D, Andújar-Espinosa et al. (2021) administered 16,000 IU/week calcifediol supplementation in the treatment group for 6 months. Although lung function did not show a significant difference between the intervention and control groups ($p_{FEV1} = 0.26$, $p_{FVC} = 0.20$, and $p_{FEV1/FVC} = 0.40$) there was a significant improvement in the intervention group's primary outcome compared to the placebo group ($p < 0.001$). The secondary outcome also indicated a significant yet small difference in the intervention group compared with the placebo group ($p < 0.001$). Furthermore, other secondary outcome measurements also demonstrated minor significant differences favoring the intervention group, including the decreased use of asthma corticosteroid treatments ($p = 0.02$), the number of asthma attacks ($p = 0.04$), and the number of unscheduled primary care visits due to asthma ($p = 0.02$). However, in a

study with in children with asthma and hypovitaminosis D, Jat et al. (2021) concluded there was no significant difference between the groups in the proportion of children who scored higher than a 20 on the ACT ($p = 0.625$) after treatment with 1,000 IU/day of vitamin D for nine months in the intervention group. Conflicting results suggest that the relationship between hypovitaminosis D and asthma is still unclear.

As asthma is a multifaceted chronic disorder requiring treatment and management to mitigate asthma exacerbation episodes, studies thus far have considered evaluating vitamin D levels and asthma exacerbation severity. Anand et al. (2021) and Jat et al. (2021) found no significant difference in the number of asthma exacerbations between the vitamin D intervention and placebo groups and those with hypovitaminosis D ($p = 0.431$, $p = 0.075$, respectively). Similarly, Alkhatatbeh et al. (2021) reported no significant association between the level of asthma control, BMI (OR = 0.98, $p = 0.74$), smoking (OR = 0.22, $p = 0.25$), and 25(OH)D levels (OR = 1.05, $p = 0.59$). In addition, Swangtrakul et al. (2021) reported children with well-controlled asthma demonstrated no significant difference between 25(OH)D concentrations in treatment and placebo groups.

However, other studies have suggested that 25(OH)D levels are associated with asthma-associated hospitalizations. Keskin and Seremet Kürklü (2020) concluded 25(OH)D levels in patients with uncontrolled asthma were significantly lower than those with controlled asthma ($p = 0.002$). Additionally, there was a weak positive association between 25(OH)D levels and ACT scores ($r = 0.295$, $p = 0.001$), suggesting that there is relationship between 25(OH)D levels and asthma control. Moreover, Herrera et al. (2023) found in children with asthma, those requiring hospitalization had 2.8 times higher risk of

having vitamin D deficiency compared with those who were treated as outpatients (OR = 2.8, $p < 0.05$). In addition, participants with lower sunlight exposure were found to be at 3.3-3.7 times greater risk of vitamin D deficiency in hospitalized patients. Similarly, Feketea et al. (2024) reported that children with recurrent wheezing episodes had a significantly lower 25(OH)D concentration compared with those experiencing their first wheezing episode and controls ($p < 0.001$). The authors concluded that asthma exacerbation was significantly associated with hypovitaminosis D (RR = 1.49, $p = 0.02$). On the other hand, in children with more than four wheezing episodes per year unrelated to viral infections, Bhat et al. (2023) discovered participants with hypovitaminosis D had higher rates of daytime asthma exacerbations ($p = 0.012$), higher incidences of evening symptoms ($p = 0.037$), and higher hospitalization rates ($p = 0.048$). Among those with hypovitaminosis D, the participants who were vitamin D deficient had increased use of rescue inhalers ($p = 0.008$) and poor asthma control ($p = 0.001$), suggesting a relationship between asthma exacerbation severity and 25(OH)D levels.

Discrepancies in the relationship between vitamin D and asthma exacerbation may be explained by genetic variations associated with asthma control and vitamin D metabolism. Mahboub et al. (2021) noted that NR3C1 (glucocorticoid receptor gene) was upregulated on Th2 and NK cells in those with severe asthma. Additionally blood VDR was high, suggesting a relationship between vitamin D insufficiency and glucocorticoid hyporesponsiveness in those with poor asthma control. Those with steroid-resistant asthma demonstrated an anti-inflammatory cellular profile with IL-17 inhibition and IL-10 upregulation with increased vitamin D intake (Walawska-Hrycek et al., 2025). In

adults with mild to moderate persistent asthma and healthy adults who do not take vitamin D supplementation, IgE levels were significantly higher in those with allergic asthma compared with those with non-allergic asthma (Bastyte et al., 2023). Six VDR and two VDBP gene polymorphisms were evaluated in the study, and there were no differences between the groups regarding VDR polymorphism. However, the authors reported that in the VDBP gene variant rs4588, the GT genotype was less common and the TT genotype was more common in those with non-allergic asthma ($p < 0.05$). Furthermore, 25(OH)D was significantly lower in those with asthma compared with healthy participants ($p < 0.01$). Similar to the relationship between hypovitaminosis D and asthma prevalence, the contradictory findings about hypovitaminosis D and asthma exacerbation and severity lead to unclear clinical evidence.

Vitamin D plays a vital role in respiratory immune system maturation and upregulates the production of cathelicidin, resulting in an increased innate immune response against respiratory tract pathogens. The upregulation of Th2 and Treg activity and decreased Th1 activity during infections decreases pro-inflammatory responses while increasing anti-inflammatory responses. This in turn reduces pulmonary vasoconstriction and acute respiratory distress syndrome associated with asthma and respiratory tract infections (Sanlier & Guney-Coskun, 2022). Ginde et al. (2009) concluded 25(OH)D levels are significantly associated with recent RTIs (OR = 1.24-1.36, $p < 0.001$), with a stronger relationship in those with asthma (OR = 5.67). Urashima et al. (2010) reported vitamin D supplementation significantly decrease the incidence of influenza A and asthma exacerbation episodes in children previously diagnosed with asthma (RR = 0.58,

$p = 0.04$; $RR = 0.17$, $p = 0.006$). In a later study, Bergman et al. (2012) determined that the overall infectious score in the intervention group receiving 4,000 IU per day of vitamin D for a year was significantly lower compared with the placebo group ($p = 0.04$). Furthermore, the intervention groups experienced fewer positive bacterial cultures ($p = 0.023$) and a lower number of days on antibiotics compared with the placebo group ($\beta = 0.365$, $p = 0.023$). Similarly Dąbrowska-Leonik et al. (2018) concluded hypovitaminosis D was found in 85.9% of pediatric participants, with 15% experiencing suboptimal IgG concentrations (Dąbrowska-Leonik et al., 2018). Those with below normal IgG concentrations had significantly lower 25(OH)D levels ($p < 0.05$), suggesting vitamin D inhibition of B lymphocytes proliferation and plasmacytic differentiation.

In contrast, Denlinger et al. (2016) found no significant effect on cold symptoms severity between one-time 100,000 IU load plus 4,000 IU per day intervention and placebo groups ($p = 0.39$) and no difference in the rate of colds between groups ($RR = 1.2$, $p = 0.15$) in adults with mild to moderate asthma and vitamin D deficiency. Moreover, Shimizu et al. (2018) also reported low-dose vitamin D supplementation (10 $\mu\text{g}/\text{day}$) did not significantly reduce the incidence of upper RTIs, physical severity scores, or quality of life scores between intervention or placebo groups. Likewise, Loeb et al. (2019) concluded 14,000 IU per week vitamin D supplementation for 8 months did not reduce the incidence of influenza in the intervention group ($HR = 1.18$, $p = 0.64$). However, vitamin D supplementation significantly reduced non-influenza respiratory viral infections ($HR = 0.76$, $p = 0.01$). Furthermore, Harrison et al. (2021) did not find significant evidence that vitamin D oral supplementation or solar simulated radiation

during the wintertime reduced the incidence of RTIs in treatment groups compared with placebo groups ($p > 0.05$). Although supplementation did decrease the severity and duration of self-reported infections among the treatment groups ($p < 0.05$). In addition, vitamin D sufficiency at baseline significantly reduced physician-diagnosed RTIs by 40% (OR = 0.6, $p < 0.05$), and participants were half as likely to have RTIs (OR = 0.05, $p < 0.05$), suggesting that maintained vitamin D sufficiency could mitigate the likelihood of developing RTIs.

As vitamin D aids in decreasing the duration of respiratory tract infections, it is necessary to evaluate this relationship in the current study. Asthma increases the risk of developing RTIs with prolonged durations due to an abnormal immune response to pathogens. Therefore, finding cost-effective methods to mitigate asthma, asthma exacerbations, and RTI duration can significantly improve respiratory outcomes.

Smoking, SDOH, and Respiratory Tract Outcomes

When evaluating the relationship between vitamin D and asthma, confounding factors associated with increased asthma prevalence in those with disproportionately higher risk, such as smoking, exposure to SHS, and SDOH must be considered. Kong et al. (2025) reported that food insecurity was significantly associated with race, tobacco exposure, and smoking status ($p < 0.001$). After adjusting for annual household income, insurance, family history of asthma, BMI, tobacco exposure, smoke status, and medications, food insecurity remained significantly associated with asthma (aOR = 1.41, $p < 0.001$) and wheezing (aOR = 1.72, $p < 0.001$). However, the authors concluded that smoking status was not significantly associated with current asthma and wheezing ($p =$

0.67 and 0.11, respectively). Furthermore, Yao et al. (2024) reported that adolescents who currently used cigarettes or cigars had higher odds of wheezing at follow-up (aOR = 1.88, $p < 0.01$). In addition, participants who were identified as other tobacco users (i.e., those who were former users of cigarettes, cigars, or e-cigarettes, and users/former users of pipes, hookah, snus, smokeless tobacco, dissolvable tobacco, bidis, and kreteks) had higher odds of newly diagnosed asthma (aOR = 1.91, $p < 0.01$). Moreover, those with exposure to SHS had higher odds of wheezing (aOR = 1.22, $p = 0.01$). Ginde et al. (2009) further identified that smoking significantly increases RTIs (OR = 1.81, $p < 0.05$). These findings suggest that there is a positive association between smoking, SHS, and respiratory tract outcomes.

Food security, or insecurity, is an important consideration in assessing asthma. Barriers to accessing sufficient nutritious healthy food options significantly impact nutritional balance. Tarazona-Meza et al. (2020) concluded food insecurity was not associated with asthma in resource-poor settings (aOR = 1.23, $p = 0.28$). However, food-insecure participants had higher odds of having uncontrolled asthma (OR = 2.01, $p = 0.02$). With each one-unit increase in food insecurity score (as categorized using the Household Food Insecurity Access Scale), there was 8% higher odds of uncontrolled asthma (OR = 1.08, $p < 0.01$). These findings were further supported by Clemens et al. (2021), who did not find a relationship between food insecurity and the incidence of asthma in children ($p = 0.051$). However, when food insecurity was disaggregated into moderate and severe food insecurity, children from households experiencing severe food insecurity were at an increased risk of developing asthma (HR = 2.32, $p = 0.028$). Grande

et al. (2023) also noted adults experiencing high food insecurity were at a significantly higher risk of uncontrolled asthma (aOR = 2.11, $p < 0.01$). By providing more access to vitamin D fortified foods through government policies, healthy, low-cost staple food items would become the default option, thereby changing the environmental context.

Household crowding characteristics is another SDOH that increases the risk of poor respiratory outcomes. Tse et al. (2016) reported household crowding, characterized by more than one person per room, significantly increased the risk of severe chest infections and asthma in children under two (OR = 1.51, $p = 0.01$). Furthermore, increased household crowding was associated with decreased household income. In addition, Islam et al. (2021) reported that compared with those in the lowest household income quintile, children from households with the highest income quintile had half the risk of hospitalization for respiratory tract infections ($p = 0.033$). Compared with children from households with lower household crowding, children living in households with higher household crowding had a significantly higher risk of hospitalization due to respiratory tract infections (OR = 3.61; $p < 0.001$).

As asthma-related hospitalizations are disproportionately higher in non-Hispanic, non-White individuals, race is an important confounding factor when evaluating the relationship between vitamin D and respiratory health outcomes. Wills et al. (2023) reported the importance of disaggregating ethnicities in national surveys when evaluating populations with historically low participation rates. Disaggregated Native Hawaiian/Pacific Islander populations in the 2016 and 2018 BRFSS led to results indicating Native Hawaiians had a significantly higher risk of asthma ($p < 0.05$).

Furthermore, the authors reported that in the 2018 survey, exposure to SHS was a significant mediator of developing asthma in Native Hawaiians ($p = 0.01$), Filipinos ($p = 0.03$), and Pacific Islanders ($p = 0.02$).

SDOH, such as food security and household crowding, are significant contributors to chronic respiratory disorders including asthma. Furthermore, race and smoking are contributing factors to increased asthma prevalence. These factors are necessary confounders to consider when evaluating the relationship between vitamin D, asthma, and RTIs.

Summary and Conclusions

Although the depth and breadth of the current literature provided a significant amount of information in understanding the immunoregulatory roles of vitamin D in respiratory health outcomes, there is a significant amount of conflicting findings dependent on the seasonality of studies, amount of sunlight exposure experienced by participants, vitamin D intake through dietary recall and supplementation questionnaires, and variability of recommended vitamin D supplementation dosages. Future studies with more homogenous populations with participants from similar geographic areas, accessibility to similar foods, and experiencing similar UV intensity would help fill the knowledge gap.

In summary, there is a lack of clear information about vitamin D and respiratory status in the U.S. in adolescents and young adults between 16 and 30, making evidence-based nutrition recommendations and policy changes impacting the bottom two tiers of the five-tier PHIP difficult to support. In chapter 3, I conducted a complex sample binary

logistic regression analysis using the 2013-2014 and 2017-2018 NHANES to evaluate relationships between vitamin D supplementation, food security index, duration of sunlight exposure, asthma, asthma exacerbation severity, and RTIs during the winter month survey cycle (November to April) after controlling for the known confounders of race, HCI, and smoking. The findings can be used as evidence to support vitamin D fortification policies in staple foods that are more accessible to adolescents and young adults experiencing food insecurity, thereby addressing the gap in the target population.

Chapter 3: Research Method

Studies involving micronutritional balance and respiratory health among adolescents and adults have not explored variables associated with vitamin D maintenance. As respiratory health peaks during the second decade of life, lack of evidence in literature regarding vitamin D and respiratory health is an important gap to explore. The purpose of this nonexperimental quantitative cross-sectional study was to determine whether there is a relationship between independent variables vitamin D supplementation, duration of sunlight exposure, and FSI, with dependent variables asthma, asthma exacerbation severity, and RTIs among individuals between 16 and 30 while controlling for the confounders race, HCl, and smoking.

In this chapter, I explain the rationale for the selected research design, identify the target population, elaborate on the NHANES complex multistage random sample selection process, discuss the minimum sample size, inclusion and exclusion criteria, and operationalization of variables, and explain the data analysis plan, threats to validity, and ethical procedures associated with NHANES data collection and secondary data analysis.

Research Design and Rationale

I used binary logistic regression to evaluate the relationship between dichotomous dependent variables and independent variables using a categorical scale of measurement. Binary dependent variables were presence of asthma, severity of asthma exacerbation, and reported RTI within 30 days of the dietary recall interview. Independent variables were vitamin D supplementation dosage, FSI, and duration of sunlight exposure. Covariates in the study were race, HCl, and smoking status. I selected binary logistic

regression to determine odds ratios that demonstrated whether there was an increased risk of having asthma or RTI in the presence of independent risk factors and covariates.

Using the merge file command in SPSS, 2013-2014 and 2017-2018 NHANES datasets were joined at the individual level according to the NHANES recommendation. Advantages of using multiple years of NHANES datasets include accessibility of publicly available data with a national randomized sample, large number of participants, and cost-effectiveness. However, some data such as geographic region and urbanicity were restricted and unavailable for use in this study. The design choice was consistent with the overall purpose of the study, which was to evaluate relationships between independent and dependent variables, thus providing evidence for population-scale policies via the five-tier PHIP.

Methodology

In this quantitative study, I analyzed publicly available secondary data from the 2013-2014 and 2017-2018 NHANES. Data for the nationally representative noninstitutionalized civilian population from 50 U.S. states and the District of Columbia (DC) were used to improve reliability and external validity of the study.

Population

Target population for this study consisted of participants in the 2013-2014 and 2017-2018 NHANES between 16 and 30 who did not have a history of kidney disease during the winter months (November through April). Individuals between 16 and 30 are considered to be transitional adolescents and adults who are making independent dietary decisions, and are considered to be at a higher risk of developing hypovitaminosis D

(Dong et al., 2022; Hafiz et al., 2023; Klobodu & Goto, 2024). A minimum of 875 participants were needed to generate sufficient power for statistical analysis.

Sampling and Sampling Procedures

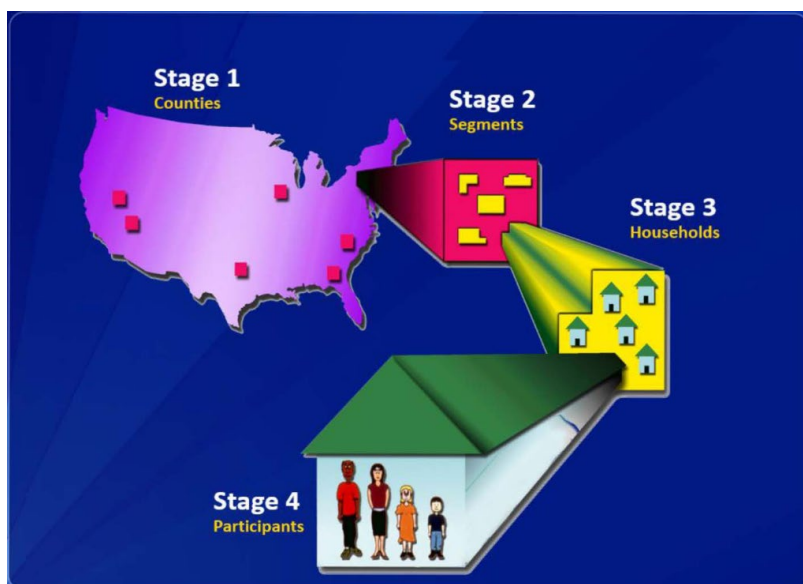
The CDC began collecting national health information from 1959-1962 with the NHES I through probability sampling of individuals between 18 and 79. After various cycles of data collection through NHES II (1963-1965), NHES III (1966-1970), NHANES I (1971-1974), NHANES II (1976-1980), NHANES III (1988-1994), and Hispanic HANES (1982-1984), the CDC began the continuous NHANES, which is the current iteration. The 1999 continuous NHANES oversampled adolescents between 12 and 19, adults over 60, those with low-income, Blacks, and Mexican-Americans. In 2011, NHANES began to oversample additional populations to include individuals who are Hispanic, non-Hispanic Asians, and non-Hispanic races other than Black, Asian, or White. In addition, beginning in 2015, the low-income cutoff point was modified from $\leq 130\%$ to $\leq 185\%$ of Health and Human Services guidelines. Oversampling of subgroups increases reliability and precision of estimates for underrepresented populations, so applying sample weights gives a more accurate national estimate of health outcomes (CDC, 2018). The NHANES uses a stratified multistage probability sample design to obtain a nationally representative sample of approximately 5,000 participants in 15 out of 3,100 U.S. counties. As the CDC recommended, data from one NHANES cycle may not be sufficient when subsamples are evaluated with low-prevalence outcomes. Therefore, combining two NHANES cycles was recommended. The CDC recommended using adjacent NHANES 2-year cycle data when combining datasets. However, due to variable

data that were needed for this study, which were incompletely collected during the 2015-2016 cycle, 2013-2014 and 2017-2018 NHANES data were used instead to provide a nationally representative sample from the U.S. population.

The NHANES uses a complex four-stage sample selection process in which random selection occurs during each step (see Figure 4).

Figure 4

Continuous NHANES Four-Stage Sample Selection Strategy



Note. From “National Health and Nutrition Examination (NHANES)” by K. S. Porter, 2015, *2015 National Conference on Health Statistics*, p. 18

(https://www.cdc.gov/nchs/ppt/nchs2015/Porter_Monday_SalonE_A6.pdf). In the public domain.

In the first stage, individual U.S. counties or adjacent counties were assigned to a stratum based on urbanicity of counties. This was considered the primary sampling unit (PSU). Each PSU is selected with probabilities proportionate to size (PPS), where the

measure of size (MOS) is predetermined based on desired information for each particular NHANES cycle. The MOS is a weighted average of population counts within the PSU (CDC, 2020). Essentially, PSUs with larger populations were more likely to be randomly selected than those with smaller populations. Some counties have MOS that are large enough to be considered as certainty PSUs, which were separated from noncertainty PSUs before county selection using noncertainty PSU stratification. Four and two certainty PSUs were included in 2013-2014 and 2017-2018 NHANES sample selection designs, respectively.

The noncertainty PSU stratification process included state groups, major, and minor strata. The state group level grouped states with similar calculated health index into A (healthiest states) through D (least healthy states) (CDC, 2020). The 2013-2014 NHANES included California as a fifth group (CDC, 2014). Within each state group, there were three or four major strata (13 in 2013-2014 and 14 in 2017-2018) defined by the census geographic region and proportion of those living in rural areas. Each major strata was divided into four minor ones (52 in 2013-2014 and 56 in 2017-2018). Thirty PSUs were sampled per NHANES cycle. Within each selected PSU and in the second stage of sample selection, secondary sampling units (SSU) or segments were created using census blocks or combinations of blocks with PPS to produce 24 segments containing approximately 50 to 100 dwelling units (DUs) within each noncertainty PSU. The segment size was determined using preestablished sampling rates and applying those to the listed DU. Segment samples were then selected using implicit stratification by minority density and geography.

In the third stage of sample selection, DUs from sample segments were selected to help identify potential sample individuals to participate in the interviews and examinations. The fourth and final stage of sample selection was to select the sample person from selected households to participate in the NHANES cycle based on rates established to ensure that the target sample sizes by subdomain were met. Sample selection was further randomized, and computer-generated numbers were assigned to each DU selected. Using secondary data from the NHANES database allowed me to use weighted data from a nationally representative sample to increase the generalizability of the findings.

For sample size estimation, a power analysis was conducted in G*Power (Version 3.1). Based on previous studies that determined the proportion of those with asthma and those without asthma who had hypovitaminosis D (0.57 and 0.32, respectively) (Han et al., 2017; Isaza, 2022). To identify a clear relationship between the variables, the expected R-squared was used to determine *a priori* sample size, dependent on a strong association using the Demidenko (2007) criteria (R^2 other X = 0.81). With a significance criterion of $\alpha = 0.05$ and power = 0.90 to provide evidence to support or refute vitamin D supplementation as a cost-effective method of addressing asthma and RTIs, the minimum sample size needed was 875 for running a binary logistic regression analysis (see Figure 5). The datasets were collected and analyzed after the institutional review board (IRB) approval. The datasets were then exported from the sources as XPT files. After importing the files into IBM SPSS Statistics (Version 29), variables that did not apply to the study were deleted from the files. Inclusion criteria included all individuals between 16 and 30

who completed the initial NHANES screening interview and the follow-up MEC examination and interview between November 1 and April 30. Participants included were not told by a medical professional that they had weak or failing kidneys. Exclusion criteria included individuals under 16 and over 30, individuals between 16 and 30 who had their screening and MEC interviews between May 1 and October 31, and individuals between 16 and 30 who had been told that they had weak or failing kidneys by a healthcare professional (see Figure 6).

Figure 5

*G*Power Sample Size Determination*

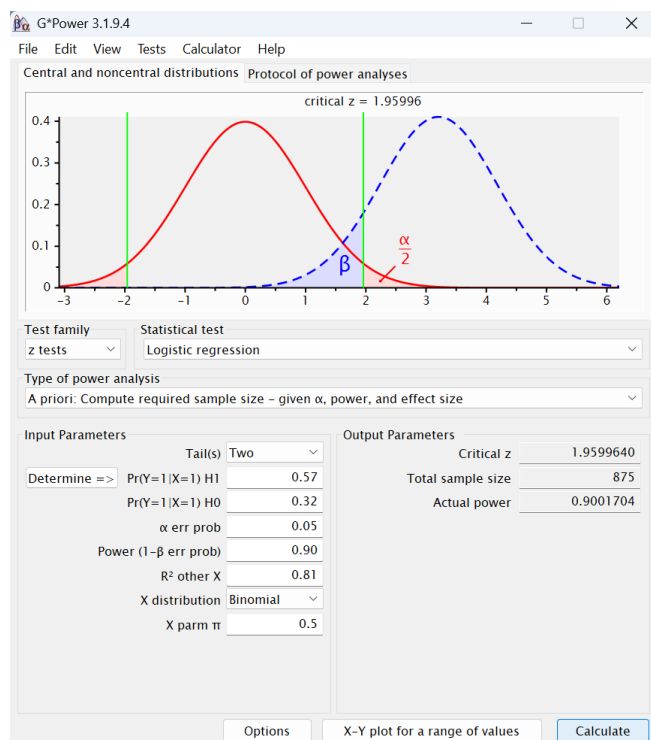
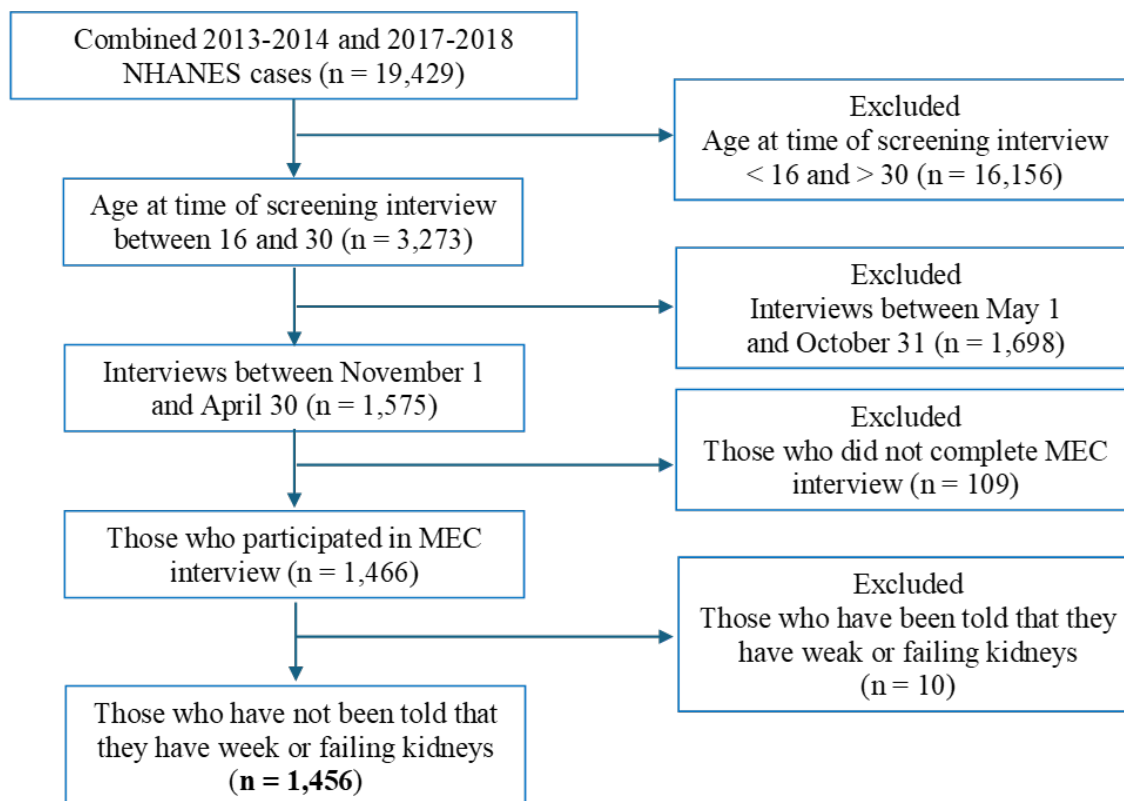


Figure 6

Flow Chart of Inclusion and Exclusion Criteria for Sample Selection



The estimated sample size was adequate to test the study hypothesis (IBM Corporation, 2024). It should be noted that in the available datasets, the comparison between variables was based on unequal sample sizes within each category, as there were more participants without asthma than participants with asthma, but the unit of analysis remained consistent.

Instrumentation and Operationalization of Constructs

To organize the variables for each research question, I created tables with the variables included and the rationale for inclusion in Appendices B-D.

Study Population

Using the NHANES datasets to identify the samples from the study population, I used the following variables. Variable RIDAGEYR: "What is {your/{NAME}'s} birthdate?" was the participant's age in years at screening, which was calculated based on the participant's date of birth. If the birthdate was unknown, the participant's age was entered into the computer-assisted personal interviewing (CAPI) system. This was a continuous variable used to filter for participants aged 16-30. Variable RIDEXMON was the six-month period in which participation in the NHANES interview and MEC exam occurred. This categorical variable was filtered for those who participated from November 1 through April 30. Variable HSQ500 indicated participation in the MEC interview. This categorical variable was used to filter for participants who completed the MEC intake. Finally, variable KIQ022: "{Have you/Has SP} ever been told by a doctor or other health professional that {you/s/he} had weak or failing kidneys? Do not include kidney stones, bladder (bladd-er) infections, or incontinence (in-kon-ti-nens)" determined if participants had pre-existing kidney disease that would impede vitamin D metabolism. This categorical variable was filtered for those who reported "No" to having been told that they had weak or failing kidneys.

Independent Variables

The first categorical independent variable was vitamin D supplementation. The variable DSD010: "The next questions are about {your/SP's} use of dietary supplements, and medications during the past month. {Have you/Has SP} used or taken any vitamins, minerals, or other dietary supplements in the past month? Include those products

prescribed by a health professional such as a doctor or dentist, and those that do not require prescription," was used to determine if participants took dietary supplements. For those who answered "yes," the supplement name(s) were recorded along with the serving size taken by the participant. The names of the products and dietary supplement data were coded to display individual dietary components found within the supplements. Additionally, variable DSD103: "In the past {30 DAYS/NUMBER AND UNIT}, on how many days did {you/SP} take {PRODUCT NAME}?" determined the number of days the supplement was taken. Finally, variable DSQTV D was the calculated total amount of vitamin D (D2 and D3) supplement intake for the past 30 days based on the supplement type and dosage. Using DSQTV D, the average daily vitamin D intake was calculated by dividing the value by 30 to provide a new continuous variable (VDDS) for assessing vitamin D supplementation intake. The continuous VDDS variable was then categorized into below RDA (daily intake less than 10 µg), achieving RDA (10 – 19 µg), and above RDA (greater than 19 µg).

The second independent categorical variable was food security index, which was established based on participant (18+) responses to a set of 10 food security questions (FSQ032a-c, FSQ041, FSQ052, FSQ061, FSQ071, FSQ081, FSQ092, and FSQ102) or, for those under 18, responses to eight food security questions (FSQ32d-f, FSQ111, FSQ121, FSQ132, FSQ141, and FSQ146). For adults 18 and older, the coding for the categorical variable FSDAD was as follows: no affirmative answers in any of the items = full food security, 1-2 affirmative answers = marginal food security, 3-5 affirmative answers = low food security, and 6-10 affirmative answers = very low food security. For

those who were under 18, the coding for the categorical FSDCH variable was as follows: no affirmative answers in any of the items = full food security, one affirmative answer = marginal food security, 2-4 affirmative answers = low food security, and 5-8 affirmative answers = very low food security. The NHANES coded food security categories were used as the food security index in this study.

The final independent variable was duration of sunlight exposure as measured by variables DEQ034: “When {you go/SP goes} outside on a very sunny day, for more than one hour, how often {do you/does SP}; a. Stay in the shade?; c. Wear a long sleeved shirt?; d. Use sunscreen?,” DED120: “The next questions ask about the time you spent outdoors during the past 30 days. By outdoors, I mean outside and not under any shade. How much time did you usually spend outdoors between 9 in the morning and 5 in the afternoon on the days that you worked or went to school?,” and DED125: “During the past 30 days, how much time did you usually spend outdoors between 9 in the morning and 5 in the afternoon on the days when you were not working or going to school?” DED120 and DED125 were combined and divided by 30 as a new continuous variable (UVD) to give an average for daily sunlight exposure. The continuous UVD variable was then categorized into below recommended (less than 10 minutes daily), achieving recommended (10 – 19 minutes daily), and above recommended (greater than 19 minutes).

Dependent Variables

The first categorical binary dependent variable was the presence of asthma. For participants who responded “yes” to the question MCQ010: “Has a doctor or other health

professional ever told {you/SP} that {you have/s/he/SP has} asthma (az-ma)?,” the variable MCQ035= “{Do you/Does SP} still have asthma (az-ma)?” was used to evaluate the participant’s current asthma status. However, if participants indicated “yes” to MCQ010 but “no” or “don’t know” for MCQ035, they were recoded as a new binary variable (ASTH) as “no current asthma.”

The second categorical binary dependent variable was asthma exacerbation severity, which was categorized by the variable MCQ050: “[During the past 12 months], {have you/has SP} had to visit an emergency room or urgent care center because of asthma (az-ma)?” which would suggest a more severe presentation of asthma exacerbation. Participants who indicated “don’t know” for MCQ050 were recoded as “no” in the new HOSP binary variable.

The final categorical binary dependent variable was having an RTI. The variable HSQ500: "The next questions are about {your/SP's} recent health during the 30 days outlined on the calendar. Did {you/SP} have a head cold or chest cold that started during those 30 days?" and HSQ520: “Did {you/SP} have flu, pneumonia, or ear infections that started during those 30 days?” were used to evaluate the final dependent variable. Participants who answered yes to either HSQ500 and/or HSQ520 were recoded as “yes” were combined into a new binary variable, RTI.

Covariates

The first covariate was the categorical variable of race. The variable RIDRETH3: “{Do you/Does SP} consider {yourself/himself/herself} to be Hispanic, Latino, or of Spanish origin?” and “Please give me the number of the group that represents

{your/SP's} Hispanic/Latino or Spanish origin or ancestry. Please select 1 or more of these categories." NHANES recoded the responses for both questions to separate participants who identified as "Mexican American" from "Other Hispanic."

The second covariate was the categorical variable of household crowding index. The continuous variable DMDHHSIZ was calculated based on a series of screening questions. The DMDHHSIZ variable data was divided by the variable HOD050: "How many rooms are in this home? Count the kitchen but not the bathroom," to acquire the household crowding index, which was recoded as a new continuous variable (HHCI).

The last covariate considered for the study was the categorical variable smoking status, which includes exposure to second-hand smoke (SHS). Several variables were used to assess smoking status and exposure to SHS. To determine if individuals are current smokers, former smokers, or never smokers the variable SMQ621: "The following questions are about cigarette smoking and other tobacco use. Do not include cigars or marijuana. About how many cigarettes have you smoked in your entire life?" and SMQ681: "The following questions ask about use of tobacco products in the past 5 days. During the past 5 days, including today, did you smoke cigarettes, pipes, cigars, little cigars or cigarillos, water pipes, hookahs, or e-cigarettes?" were used to categorize participants into a new categorical variable (SMK). Individuals who have smoked 100 or more cigarettes in their lifetime and answered "yes" to SMQ681 were recoded as current smokers. Individuals who have smoked 100 or more cigarettes in their lifetime and answered "no" to SMQ681 were recoded as former smokers. Those who have not smoked 100 cigarettes in their lifetime and answered "no" to SMQ681 were recoded as

never smokers. Additionally, those who answered “don’t know” to SMQ621 but “yes” to SMQ681 were coded as current smokers. As SHS affects the respiratory tract similarly to smoking, SHS exposure was also included in the new categorical variable SMK. The variables SMQ470: “Now I would like to ask you a few questions about smoking in this home. Not counting decks, porches, or detached garages, how many people who live here smoke cigarettes, cigars, little cigars, pipes, water pipes, hookah, or any other tobacco product inside this home?” will help determine if individuals are exposed to SHS at home. Additionally, variables SMQ858: “I will now ask you about tobacco smoke in other places. While {you were/SP was} working at a job or business outside of the home, did someone else smoke cigarettes or other tobacco products indoors?,” SMQ862: “While {you were/SP was} in a restaurant, did someone else smoke cigarettes or other tobacco products indoors?,” SMQ868: “While {you were/SP was} in a bar, did someone else smoke cigarettes or other tobacco products indoors?,” SMQ872: “While {you were/SP was} riding in a car or motor vehicle, did someone else smoke cigarettes or other tobacco products?,” SMQ876: “While {you were/SP was} in a home other than {your/his/her} own, did someone else smoke cigarettes or other tobacco products indoors?,” and SMQ880: “While {you were/SP was} in the other indoor area, did someone else smoke cigarettes or other tobacco products?” helped to determine if individuals were exposed to SHS in places other than the home. If participants indicated a number other than 0 for variable SMQ470 and affirmative responses to SMQ858, SMQ862, SMQ868, SMQ872, SMQ876, or SMQ880, they were coded as having exposure to SHS. If participants

indicated 0 for SMQ470 and negative responses to the other variables listed, they were coded as not having exposure to SHS.

Data Analysis Plan

I used the NHANES public-use data sets for analysis and evaluated responses and subsequent follow-ups to determine whether missing responses were true missing data points. Records that contained true missing data for the independent and dependent variables, as well as covariates, were discarded. I used IBM SPSS Version 29 to run descriptive statistics, with the mean as the measure of central tendency. I then conducted a complex sample binary logistic regression analysis.

Research Questions

RQ1: Is there a relationship between vitamin D supplementation, food security index, duration of sunlight exposure, and the presence of asthma in participants 16-30 during the winter months in the U.S. after controlling for race, household crowding index, and smoking?

H₀1: There is no relationship between vitamin D supplementation, food security index, duration of sunlight exposure, and the presence of asthma in participants 16-30 during the fall and winter months in the U.S. after controlling for race, household crowding index, and smoking.

H_a1: There is a relationship between vitamin D supplementation, food security index, duration of sunlight exposure, and the presence of asthma in participants 16-30 during the fall and winter months in the U.S. after controlling for race, household crowding index, and smoking.

RQ2: Is there a relationship between vitamin D supplementation, food security index, duration of sunlight exposure, and the severity of asthma exacerbations in participants 16-30 during the fall and winter months in the U.S. after controlling for race, household crowding index, and smoking?

H₀2: There is no relationship between vitamin D supplementation, food security index, duration of sunlight exposure, and the severity of asthma exacerbations in participants 16-30 during the fall and winter months in the U.S. after controlling for race, household crowding index, and smoking.

H_a2: There is a relationship between vitamin D supplementation, food security index, duration of sunlight exposure, and the severity of asthma exacerbations in participants 16-30 during the fall and winter months in the U.S. after controlling for race, household crowding index, and smoking.

RQ3: Is there a relationship between vitamin D supplementation, food security index, duration of sunlight exposure, and having RTIs in participants 16-30 during the fall and winter months in the U.S. after controlling for race, household crowding index, and smoking?

H₀3: There is no relationship between vitamin D supplementation, food security index, duration of sunlight exposure, and having RTIs in participants 16-30 during the fall and winter months in the U.S. after controlling for race, household crowding index, and smoking.

H_a3: There is a relationship between vitamin D supplementation, food security index, duration of sunlight exposure, and having RTIs in participants 16-30 during the

fall and winter months in the U.S. after controlling for race, household crowding index, and smoking.

Statistical Tests

Binary Logistic Regression

I conducted a binary logistic regression analysis for all research questions to predict the probability of a dichotomous outcome based on multiple independent categorical variables. Assumptions that must be met in binary logistic regression include dichotomous dependent variables, categorical or continuous independent variables, mutually exclusive dependent variables, independent observations, absence of outliers in the continuous independent variables, linearity between continuous independent variables and the logit transformation of the dependent variables, and expected frequencies over five (Warner, 2021). Since the mutually exclusive dependent variables for the research questions were dichotomous and I was tested multiple categorical variables, the first, second, and third assumptions were met. To test for the independence of observations, I conducted a Pearson correlation to test the independent variables. Correlation coefficients of less than -0.7 or greater than 0.7 indicated that the independent variables were highly correlated (KnowHow, 2021). Before transforming the continuous independent variables into categorical variable, I tested for outliers by using the Mahalanobis distance to calculate the probability for all three dependent variables against the continuous independent variables and deselected cases with probability values less than 0.001 (KnowHow, 2021). No outliers were noted using this method. Additionally, to test for linear relationships between continuous variables before categorization, I used the logit

transformation of the dependent variable, and transformed the continuous variables into their natural log (LN) form and used a binary logistic regression analysis to test if the LN form had a statistically significant interaction with the continuous variable, which would violate the assumption. Finally, an evaluation of the contingency table for the binary logistic regression indicated that the final assumption has been met.

One important consideration was appropriately weighting results when a complex multistage sampling strategy was used on multiple NHANES cycles. Using the Complex Samples Package in SPSS, the data was evaluated using weighted values by applying the sum of the annual average weight for the 2013-2014 and 2017-2018 to variables in the combined dataset. In conducting a binary logistic regression analysis, a chi-square test for all research questions was established to determine if there is a relationship between the independent and dependent variables. Furthermore, Nagelkerke's R^2 was examined to explain the strength of the relationships between the independent and dependent variables. A p -value of 0.05 was used to determine the statistical significance, and a 95% confidence interval (CI) was implemented. Additionally, the variables in the equation table exemplify the contribution made by each independent variable to the model. The contingency table was used to calculate the odds ratio (OR) to determine the OR of an outcome based on the independent variables.

Threats to Validity

Threats to validity should be identified and mitigated to reduce their impact on the study findings.

Internal Validity

Internal validity refers to the accuracy of the study findings. Since NHANES datasets contain numerous variables, validity testing for the comprehensive survey instrument was not conducted. However, through various iterations of the NHANES questionnaire survey and comparison of the data collected in adjacent NHANES cycles, it is inferred that the NHANES instruments were valid and reliable.

Some other considerations in research studies that can threaten accuracy were sample selection bias, recall bias, and non-response bias. Through NHANES' complex, multistage, random sampling, sample selection bias was decreased. Using weighted responses further mitigated and corrected for non-response and recall biases. Records with missing data for the independent variables were evaluated to determine if the data were truly missing and were subsequently removed. Missing data for the dependent variables were similarly excluded from analysis. Appropriate weighting for complex samples corrects significance levels and any biases towards the alternative hypotheses by providing variance estimates that are closer to the true values (CDC, 2018).

External Validity

External validity refers to the generalizability of the findings. Similar to helping to mitigate threats to internal validity, weighting helped to mitigate threats to external validity by correcting for disproportionate sampling and improving representativeness of the findings (The DHS Program, 2015). A large, national, representative sample size further helped to improve the generalizability of the findings to the target population within the U.S.

Another threat to the external validity of the findings was the seasonality and geographic restrictions of biospecimen collection. Biospecimen collection depended on the expected weather during certain times of the year. Since inclement weather was expected in northern states, sample collection from November to April was planned for southern states. Sample collection during the winter months in parts of the U.S. and not in all selected PSUs threatened the generalizability of the study.

Furthermore, the findings only apply to the target population represented by the sample living in the U.S. With different food fortification and healthcare maintenance policies in various countries, the study would need to be carried out in target locations to determine the applicability of the findings.

Construct Validity

Construct validity refers to how accurately the operational definitions reflect what they are intended to measure. By using multiple variables to test for a construct, validity was improved by using multiple methods or variables.

Ethical Procedures

In a national survey, the main ethical issue of concern is confidentiality. Federal laws are in place to ensure the confidentiality of national survey data. Disclosure of confidential information would result in monetary penalties and possible jail time (CDC, 2024b). The ethical procedures in this study were upheld through the Walden University Institutional Review Board (IRB). IRB approval was requested and granted (11-11-25-1179453) before data analysis and interpretation. In a study analyzing secondary data, I complied with all the procedures for protecting human subjects. I downloaded the

publicly available NHANES datasets, which were then stored in a secure, password-protected OneDrive account, to which only I had access. All findings were reported ethically, including the evidence, data, findings, and conclusions.

Summary

This nonexperimental quantitative cross-sectional study involved evaluating 2013-2014 and 2017-2018 NHANES survey cycles using a complex sample binary logistic regression analysis. The study design was consistent with the overall study purpose to evaluate the relationships between the independent variables vitamin D supplementation, food security index, and sunlight exposure, and the dependent variables presence of asthma, asthma exacerbation severity, and RTIs in the research questions. Determining if there was a statistically significant relationship between risk factors and outcome variables provided evidence for population-scale policies under the five-tier PHIP. The findings of the statistical analysis from the study are presented in Chapter 4.

Chapter 4: Results

The purpose of this quantitative study was to determine whether there was a relationship between the independent variables vitamin D supplementation, duration of sunlight exposure, and food security index, with the dependent variables asthma, asthma exacerbation severity, and RTIs in individuals aged 16-30, while controlling for race, household crowding index, and smoking. Chapter 4 includes descriptive and inferential data analysis results on data collected from the 2013-2014 and 2017-2018 NHANES cycles. In this section, I discussed associations between the dependent and independent variables while controlling for factors that are known to affect respiratory health outcomes. These results helped provide evidence to either support or challenge the role vitamin D has in respiratory health.

Research Questions and Hypotheses

RQ1: Is there a relationship between vitamin D supplementation, food security index, duration of sunlight exposure, and the presence of asthma in participants 16-30 during the winter months in the U.S. after controlling for race, household crowding index, and smoking?

H₀1: There is no relationship between vitamin D supplementation, food security index, duration of sunlight exposure, and the presence of asthma in participants 16-30 during the fall and winter months in the U.S. after controlling for race, household crowding index, and smoking.

H_a1: There is a relationship between vitamin D supplementation, food security index, duration of sunlight exposure, and the presence of asthma in participants 16-30

during the fall and winter months in the U.S. after controlling for race, household crowding index, and smoking.

RQ2: Is there a relationship between vitamin D supplementation, food security index, duration of sunlight exposure, and the severity of asthma exacerbations in participants 16-30 during the fall and winter months in the U.S. after controlling for race, household crowding index, and smoking?

H₀2: There is no relationship between vitamin D supplementation, food security index, duration of sunlight exposure, and the severity of asthma exacerbations in participants 16-30 during the fall and winter months in the U.S. after controlling for race, household crowding index, and smoking.

H_a2: There is a relationship between vitamin D supplementation, food security index, duration of sunlight exposure, and the severity of asthma exacerbations in participants 16-30 during the fall and winter months in the U.S. after controlling for race, household crowding index, and smoking.

RQ3: Is there a relationship between vitamin D supplementation, food security index, duration of sunlight exposure, and having RTIs in participants 16-30 during the fall and winter months in the U.S. after controlling for race, household crowding index, and smoking?

H₀3: There is no relationship between vitamin D supplementation, food security index, duration of sunlight exposure, and having RTIs in participants 16-30 during the fall and winter months in the U.S. after controlling for race, household crowding index, and smoking.

H_{a3}: There is a relationship between vitamin D supplementation, food security index, duration of sunlight exposure, and having RTIs in participants 16-30 during the fall and winter months in the U.S. after controlling for race, household crowding index, and smoking.

Data Collection

2013-2014 and 2017-2018 NHANES datasets were collected and analyzed after IRB approval. Datasets were then exported from sources as XPT files. After importing files into SPSS, variables in the data set that did not apply to the study were deleted from files. All participants were between 16 and 30, completed the initial NHANES screening, completed the follow up MEC examination and interview between November 1 and April 30, and had not been told by a medical professional they had weak or failing kidneys. I excluded individuals under 16 and over 30, individuals who had their screening and MEC interviews between May 1 and October 31, and individuals who had been told they had weak or failing kidneys by healthcare professionals. A total of 1,456 survey participants met inclusion criteria for the current study.

Factors that were previously associated with asthma, asthma exacerbation, and RTIs include race, HCI, smoking, and SHS exposure. These variables were included in the complex sample logistic regression analysis as covariates. To justify inclusion of controlling variables, a complex sample logistic regression was assessed for current asthma (see Table 1), asthma exacerbation (see Table 2), and RTI (see Table 3).

Table 1*Tests of Model Effects of Current Asthma*

Variables	
Race	
Wald χ^2 , df	15.344, 5
p value	0.009
Nagelkerke's pseudo R^2	0.024
HCI	
Wald χ^2 , df	0.001, 7
p value	1.000
Nagelkerke's pseudo R^2	0.082
SMK	
Wald χ^2 , df	1.242, 3
p value	0.743
Nagelkerke's pseudo R^2	0.001

Table 2*Tests of Model Effects of Asthma Exacerbation*

Variables	
Race	
Wald χ^2 , df	23,698.887, 5
p value	<0.001
Nagelkerke's pseudo R^2	0.071
HCI	
Wald χ^2 , df	0.000, 3
p value	1.000
Nagelkerke's pseudo R^2	0.144
SMK	
Wald χ^2 , df	0.000, 2
p value	1.000
Nagelkerke's pseudo R^2	0.002

Table 3*Tests of Model Effects of RTI*

Variables	
Race	
Wald χ^2 , df	13.100, 5
p value	0.022
Nagelkerke's pseudo R ²	0.012
HCI	
Wald χ^2 , df	4.502E+14, 18
p value	<0.001
Nagelkerke's pseudo R ²	0.101
SMK	
Wald χ^2 , df	29,022.872, 2
p value	<0.001
Nagelkerke's pseudo R ²	0.005

Race was significantly associated with all three dependent variables. However, HCI and smoking demonstrated significant relationships with RTIs. Therefore, all three variables were included as covariates in the final study.

Results

Descriptive Analysis

NHANES sample selection uses a complex multi-stage sampling process. The guidelines for using the datasets recommend that analysis should be completed using a complex sampling package in SPSS. After applying interview and medical examination center (MEC) weights, an estimate of population frequency was obtained and included in the descriptive analysis (see Table 4). Through oversampling of underrepresented populations and application of sample weighting, the population estimates of racial and ethnic groups demonstrated a representative sample of the U.S. population.

Table 4*Descriptive Statistics of Characteristics of Study Population (N = 1,456)*

	Frequency (<i>weighted estimate</i>)	Percent (<i>weighted estimate</i>)
Current asthma status		
Yes	122 (2,354,920)	8.4 (8.3)
No	1,334 (26,136,009)	91.6 (91.7)
Severe asthma exacerbation		
Yes	15 (295,097)	1.0 (1.0)
No	1,441 (28,195,832)	99.0 (99.0)
RTIs		
Yes	310 (6,855,032)	21.3 (24.1)
No	1,146 (21,635,897)	78.7 (75.9)
VDDS		
Below RDA	116 (2,318,994)	41.7 (38.8)
Achieving RDA	81 (1,787,194)	31.3 (29.9)
Above RDA	70 (1,873,930)	27.0 (31.3)
Missing	1,189	81.7
FSI		
Full food security	892 (18,549,948)	63.3 (66.8)
Marginal food security	196 (3,142,257)	13.9 (11.3)
Low food security	184 (3,095,688)	13.0 (11.2)
Very low food security	138 (2,975,717)	9.8 (10.7)
Missing	46	3.2
UVD		
Below recommended daily exposure	560 (13,446,459)	64.7 (64.8)
Meeting recommended daily exposure	207 (4,961,650)	23.9 (23.9)
Above recommended daily exposure	98 (2,335,817)	11.3 (11.3)
Missing	591	40.6
Race		
Non-Hispanic White	383 (14,074,486)	26.3 (49.4)
Non-Hispanic Black	372 (4,748,577)	25.5 (16.7)
Non-Hispanic Asian	173 (1,627,999)	11.9 (5.7)
Mexican American	312 (4,686,696)	21.4 (16.4)
Other Hispanic	120 (1,952,475)	8.2 (6.9)
Other race and multiracial	96 (1,400,697)	6.6 (4.9)
HCI		
Less than 1 PPR	915 (19,760,637)	62.8 (71.0)
1 to 1.5 PPR	409 (7,009,202)	28.1 (25.2)
Greater than 1.5 PPR	93 (1,043,205)	6.4 (3.8)
Missing	39	2.7
SMK		
Current smoker	306 (6,753,071)	21.0 (23.7)
Non-smoker without SHS	804 (15,157,003)	55.2 (53.2)
Non-smoker with SHS	344 (6,569,642)	23.6 (23.1)

Missing

2

0.1

Note. Weighted values established by complex sampling analysis plan using the analysis weight for MEC4YR, SDMVSTRA, and SDMVPSU from the publicly available 2013-2014 and 2017-2018 NHANES dataset. FSI= food security index; HCI= household crowding index; PPR= persons per room; RDA= recommended dietary allowance; RTIs= respiratory tract infections; SHS= second-hand smoke; SMK= smoking status; UVD= average sunlight exposure; VDDS= average vitamin D supplementation intake.

The majority of those surveyed did not have asthma, severe asthma exacerbation, or respiratory tract infections (RTIs) during the survey period (91.6%, 99.0%, and 78.7%, respectively). When the sample weights were applied, the sample frequencies did not vary from the population estimates. Furthermore, 81.7% of the surveyed sample did not provide information regarding vitamin supplementation and therefore, were missing vitamin D supplementation data. Of those who did provide vitamin supplementation information, 41.7% ingested below the daily vitamin D RDA dosage (10 µg/day). Additionally, 40.6% of the surveyed population did not provide information about time spent outdoors during the surveyed period, thereby missing information about vitamin D acquisition through UV exposure. Out of those who provided answers to the question about the amount of time spent outdoors, 64.7% were outside for an average of less than 10 minutes a day, which was below the daily recommended UV exposure to produce sufficient cutaneous vitamin D.

Logistic Regression Assumptions Testing

In using a binary logistic regression analysis, assumptions that must be met include dichotomous dependent variables, categorical or continuous independent variables, the dependent variables were mutually exclusive, observations were independent, there were no outliers in the continuous independent variables that can affect the analysis, there was a linear relationship between continuous independent variables and the logit transformation of the dependent variables, and expected frequencies over five in each cell (Warner, 2021). The first, second, and third assumptions were met by the mutually exclusive dichotomous dependent variables for the research questions. To test for the independence of observations, I conducted a Pearson correlation to test the independent variables (see Table 5). The correlation coefficients demonstrated in Table 3 indicated that the independent variables were not highly correlated (greater than -7 and less than 7), thereby meeting the fourth assumption.

Table 5

Pearson Correlation for Independent Variables

Variables	Pearson correlation		
	Vitamin D supplementation	FSI	Sunlight exposure
VDDS	1	-0.074	0.002
FSI	-0.074	1	0.045
UVD	0.002	0.045	1

Using the Mahalanobis distance to test for outliers in the continuous independent variables vitamin D supplementation dosage and duration of sunlight exposure, before recategorization into categorical variables, 180 values were calculated and found to be

between 0.023 and 39.044. As no values were below 0.001, the fifth assumption that there were no outliers was met.

To test the sixth assumption for linear relationships between the continuous variables in the study, before recategorization into categorical variables, I conducted a logit transformation of the dependent dichotomous variables and transformed the continuous variables into their natural log (LN) form. Using a binary logistic regression analysis, I evaluated the LN form against the corresponding continuous variables to determine if a linear relationship was present (see Table 6). There was no significant relationship between the LN of the continuous variables and their corresponding continuous variable, indicating the absence of linear relationships, thereby meeting the sixth assumption.

Finally, the contingency tables for the binary logistic regression indicated the expected frequencies were 5 or greater in each cell, fulfilling the final assumption.

Table 6

Testing for Linear Relationship Between Continuous Variables

Variables	B	S.E.	Wald	df	Sig.	Exp(B)
LN_VDDS by VDDS	-0.005	0.016	0.109	1	0.741	0.995
LN_UVD by UVD	0.061	0.054	1.303	1	0.254	1.063
HCI by LN HCI	0.097	0.195	0.247	1	0.619	1.102

Note. LN_VDDS = natural log of vitamin D supplementation. LN_UVD = natural log of average daily sunlight exposure. LN_HCI = natural log of household crowding index.

Complex Sampling Binary Logistic Regression

RQ1

Analysis of the complex sample binary logistic regression (see Table 7) revealed that the logistic regression results for RQ1 demonstrated a weak yet significant relationship between the variables in the model ($\chi^2(10, N = 171) = 20.663$, Nagelkerke's pseudo $R^2 = 0.085$, $p = 0.024$) indicating that the model could distinguish between respondents who did and did not have current asthma. The model explained that 8.5% of the variation in the respondents' asthma status was explained by the variation of the independent variables while controlling for race, HCI, and smoking exposure. The sensitivity and specificity of the model were 0.0% and 100.0%, respectively (see Table 8), suggesting that the model cannot be used to predict individuals with asthma but can be used to predict those who did not have asthma. Additionally, the independent variables were not significant predictors of current asthma in participants (see Table 7). Therefore, the effect of the model on the outcomes and odds ratios of predictors (see Table 9 and Table 10) were not evaluated.

Table 7

Tests of Model Effects

Variables	Current asthma	Asthma exacerbation	RTIs
Corrected model			
Wald χ^2 , df	20.663, 10	11,887.967, 8	169.897, 10
<i>p</i> value	0.024	< 0.001	< 0.001
VDD			
Wald χ^2 , df	3.383, 2	8,496.124, 2	2.372, 2

VDDS									
Below RDA	1.031	0.724	1.424	13	0.178	2.803	0.587	13.398	
Achieving RDA	0.133	0.706	0.189	13	0.853	1.142	0.249	5.246	
Above RDA	0.000 ^a	.	.	.	.	1.000	.	.	
FSI									
Full food security	-0.687	0.546	-1.258	13	0.230	0.503	0.155	1.636	
Marginal food security	-0.834	0.755	-1.106	13	0.289	0.434	0.085	2.216	
Low food security	-1.180	0.829	-1.422	13	0.178	0.307	0.051	1.844	
Very low food security	0.000 ^a	.	.	.	.	1.000	.	.	
UVD									
Below recommended	-0.001	0.425	-0.003	13	0.997	0.999	0.398	2.502	
Achieving recommended	-0.693	0.897	-0.772	13	0.454	0.500	0.072	3.471	
Above recommended	0.000 ^a	.	.	.	.	1.000	.	.	
Race	-0.011	0.089	-0.128	13	0.900	0.989	0.816	1.197	
HCI	0.535	0.561	0.954	13	0.358	1.707	0.508	5.734	
SMK	-0.252	0.365	-0.691	13	0.502	0.777	0.353	1.709	

Note. RDA = recommended daily allowance. a. Set to zero because this parameter is redundant.

Table 10

Independent Variable and OR of Current Asthma for RQI

Current asthma	OR	95% CI	
		Lower	Upper
VDDS			
Below RDA (reference)	.	.	.
Achieving RDA	0.407	0.125	1.324
Above RDA	0.357	0.075	1.705
FSI			
Full food security (reference)	.	.	.
Marginal food security	0.863	0.187	3.978
Low food security	0.611	0.074	5.019
Very low food security	1.987	0.611	6.463
UVD			
Below recommended (reference)	.	.	.
Achieving recommended	0.501	0.099	2.544
Above recommended	1.001	0.400	2.510
Race	0.989	0.816	1.197
HCI	1.707	0.508	5.734
SMK	0.777	0.353	1.709

RQ2

The complex sample binary logistic regression analysis for RQ2 demonstrated a moderate yet significant relationship between the variables in the model ($\chi^2(8, N = 171) = 11,887.967$, Nagelkerke's pseudo $R^2 = 0.292$, $p < 0.001$) (see Table 7) indicating that the model could distinguish between respondents who did and did not have experience asthma exacerbation. The model explained that 29.2% of the variation in the respondents' asthma exacerbation status was explained by the variation of the independent variables while controlling for race, HCI, and smoking exposure.

The sensitivity and specificity of the model were 0.0% and 100.0%, respectively (see Table 11), suggesting that the model cannot be used to predict individuals with asthma exacerbation but can be used to predict those who did not have asthma exacerbation.

Table 11*Classification Table for RQ2*

Observed outcome Asthma exacerbation	Predicted		Percent correct
	Yes	No	
Yes	0.000	143,204.690	0.0%
No	0.000	4,395,901.206	100.0%
Overall percent	0.0%	100.0%	96.8%

Additionally, vitamin D supplementation was the only significant predictor of asthma exacerbation ($p < 0.001$) after controlling for race, HCI, and smoking exposure (see Table 7 and Table 12).

Table 12*Complex Sample Binary Logistic Regression for RQ2*

Severe asthma exacerbation	B	Std. error	<i>t</i>	df	Sig.	Exp(B)	95% CI Exp(B)	
							Lower	Upper
VDDS								
Below RDA	1.042	1.107	0.941	13	0.364	2.836	0.259	31.027
Achieving RDA	-25.604	1.087	-23.556	13	<0.001	<0.001	7.253E-13	7.942E-11
Above RDA	0.000 ^b	.	.	.	.	1.000	.	.
FSI								
Full food security	26.856	14041.197	0.002	13	0.999	4.606E+11	0.000	. ^a
Marginal food security	1.418	12659.870	0.000	13	1.000	4.129	0.000	. ^a
Low food security	0.843	12659.158	0.000	13	1.000	2.324		
Very low food security	0.000 ^b	.	.	.	.	1.000	.	.
UVD								
Below recommended	25.091	9774.010	0.003	13	0.998	7.886E+10	0.000	. ^a
Achieving recommended	-0.710	0.000	.	13	.	0.492	0.492	0.492
Above recommended	0.000 ^b	.	.	.	.	1.000	.	.
Race	-0.153	0.093	-1.651	13	0.123	0.858	0.702	1.049
HCI	-0.678	1.178	-0.576	13	0.575	0.507	0.040	6.465
SMK	-0.097	0.251	-0.385	13	0.706	0.908	0.528	1.561

Note. The maximum likelihood estimates do not exist. Results are shown based on the last iteration. Validity of the model fit is uncertain. a. Set to system missing because floating point overflow occurred while computing this value. b. Set to zero because this parameter is redundant.

Further analysis of the complex sample binary logistic regression results indicated that the odds ratio (OR) associated with achieving vitamin D RDA was 2.676E-12 (95% CI = 1.416E-12 and 5.057E-12) (see Table 13), suggesting that compared with the reference group (individuals who ingest on average < 10 µg/day vitamin D supplementation), individuals who ingest an average of 10 – 19 µg/day of vitamin D are at a significantly lower (<0.001) risk of experiencing asthma exacerbations.

Table 13

Independent Variable and OR of Severe Asthma Exacerbation for RQ2

Severe asthma exacerbation	OR	95% CI	
		Lower	Upper
VDDS			
Below RDA (reference)	.	.	.
Achieving RDA	2.676E-12	1.416E-12	5.057E-12
Above RDA	0.353	0.032	3.858
FSI			
Full food security (reference)	.	.	.
Marginal food security	8.964E-12	0.000	.
Low food security	5.045E-12	0.000	.
Very low food security	2.171E-12	0.000	.
UVD			
Below recommended (reference)	.	.	.
Achieving recommended	6.2351E-12	0.000	.
Above recommended	1.268E-11	0.000	.
Race	0.858	0.702	1.049
HCI	0.507	0.040	6.465
SMK	0.908	0.528	1.561

Note. The maximum likelihood estimates do not exist. Results are shown based on the last iteration. Validity of the model fit is uncertain.

RQ3

The complex sample binary logistic regression analysis for RQ3 demonstrated a weak yet significant ($\chi^2(10, N = 171) = 169.897$, Nagelkerke's pseudo $R^2 = 0.050$, $p < 0.001$) (see Table 7) indicating that the model could distinguish between respondents who

did and did not have RTIs. The model explained that 5.0% of the variation in the respondents' RTI status was explained by the variation of the independent variables while controlling for race, HCI, and smoking exposure.

The sensitivity and specificity of the model were 5.5% and 99.6%, respectively (see Table 14), suggesting that the model cannot be used to predict individuals with RTIs but can be used to predict those who did not have RTIs. Additionally, based on the findings in Table 5, FSI was the only significant predictor of RTIs ($p < 0.001$) after controlling for race, HCI, and smoking exposure.

Table 14

Classification Table for RQ3

Observed outcome RTIs	Predicted		Percent correct
	Yes	No	
Yes	69,024.176	1,192,757.875	5.5%
No	12,392.299	3,264,931.546	99.6%
Overall percent	1.8%	98.2%	73.4%

However, looking at the analysis of each food security index category, there is no statistical significance between FSI categories and RTIs (see Table 15). Therefore, the OR of RTIs attributed to FSI (see Table 16) was not evaluated.

Table 15

Complex Sample Binary Logistic Regression for RQ3

RTIs	B	Std. error	<i>t</i>	df	Sig.	Exp(B)	95% CI Exp (B)	
							Lower	Upper
VDDS								
Below RDA	-0.326	0.382	-0.853	13	0.409	0.722	0.317	1.647
Achieving RDA	0.080	0.336	0.239	13	0.815	1.084	0.524	2.242
Above RDA	0.000 ^a	.	.	.	.	1.000	.	.

FSI									
Full food security	0.643	0.401	1.602	13	0.133	1.902	0.799	4.526	
Marginal food security	0.262	0.718	0.364	13	0.721	1.299	0.276	6.123	
Low food security	0.536	0.530	1.012	13	0.330	1.709	0.544	5.372	
Very low food security	0.000 ^a	.	.	.	.	1.000	.	.	
UVD									
Below recommended	-0.700	0.492	-1.421	13	0.179	0.497	0.171	1.439	
Achieving recommended	-1.428	0.652	-2.188	13	0.048	0.240	0.059	0.982	
Above recommended	0.000 ^a	.	.	.	.	1.000	.	.	
Race	-0.059	0.080	-0.737	13	0.474	0.943	0.794	1.120	
HCI	0.108	0.372	0.291	13	0.776	1.114	0.499	2.491	
SMK	-0.110	0.340	-0.323	13	0.752	0.896	0.430	1.868	

Note. a. Set to zero because this parameter is redundant.

Table 16

Independent Variable and OR of RTI for RQ3

	RTIs	OR	95% CI	
			Lower	Upper
VDDS				
Below RDA (reference)		.	.	.
Achieving RDA		1.501	0.848	2.655
Above RDA		1.385	0.607	3.159
FSI				
Full food security (reference)		.	.	.
Marginal food security		0.683	0.321	1.451
Low food security		0.899	0.415	1.948
Very low food security		0.526	0.221	1.251
UVD				
Below recommended (reference)		.	.	.
Achieving recommended		0.483	0.132	1.768
Above recommended		2.013	0.695	5.832
Race		0.943	0.794	1.120
HCI		1.114	0.499	2.491
SMK		0.896	0.430	1.868

Summary

Results of the study indicated achieving daily vitamin D RDA through supplementation was associated with decreased asthma exacerbation. Additionally, FSI was associated with RTIs. However, the relationship between individual FSI categories and RTIs could not be established based on the complex sample binary logistic regression analysis. Based on these findings, there was evidence to suggest that achieving daily vitamin D RDA through supplementation may decrease cases of asthma exacerbation that require emergency medical services or urgent health visits. In Chapter 5, I explored the interpretation of these findings, limitations, recommendations, and implications for social change.

Chapter 5: Discussion, Conclusions, and Recommendations

There is a gap in terms of finding cost-effective and accessible approaches for maintaining asthma and respiratory health to improve QALY of populations at risk. The purpose of this nonexperimental quantitative cross-sectional study was to determine whether there was a relationship between vitamin D supplementation, FSI, duration of sunlight exposure, asthma, asthma exacerbation severity, and RTIs in individuals between 16 and 30 while controlling for race, HCl, and smoking. Although the literature review suggested there are relationships between vitamin D, immune system development, asthma, and RTIs, Endocrine Society guidelines do not recommend routine vitamin D testing or higher dose supplementation to individuals under the age of 74 who do not have signs of hypocalcemia or skeletal dysfunction. Previous research has suggested the need to examine the relationship between vitamin D status, vitamin D supplementation, sunlight exposure, and respiratory outcomes, while controlling for known confounding factors.

I conducted complex sample binary logistic regression analyses to determine whether an association existed between dependent and independent variables while controlling for covariates. Results of these analyses which were presented in Chapter 4 indicated vitamin D supplementation was significantly associated with asthma exacerbations. In addition, FSI was significantly associated with RTIs. However, the nature of the relationship between FSI and RTIs could not be established based on findings. Furthermore, there were no significant associations between independent predictors and current asthma status of participants.

In this chapter, I discuss my interpretations of findings, study limitations, recommendations for further research, and implications for professional practice in terms of promoting positive social change.

Interpretation of the Findings

Analyses of 2013-2014 and 2017-2018 NHANES data revealed significant associations between independent variables and respiratory outcomes. Findings from analyses confirmed and disconfirmed peer-reviewed literature that was described in Chapter 2.

Factors Associated with Current Asthma

In the current study, there was no relationship between vitamin D supplementation, FSI, duration of sunlight exposure, and the presence of asthma in participants during fall and winter months in the United States after controlling for race, HCI, and smoking.

Findings of the complex sample binary logistic regression contradicted previous findings that suggested an inverse relationship between vitamin D levels and asthma. In the current study, I assumed serum vitamin D levels were maintained with sufficient daily vitamin D supplementation intake, as individuals who take vitamin D supplements have a three times higher total vitamin D intake compared with diet alone. Additionally, Kong et al. (2025) stated FSI is significantly associated with having asthma and wheezing. Furthermore, FSI was not associated with the incidence of asthma (Clemens et al., 2021; Tarazona-Mez et al., 2020). Moreover, Munkhbayarlakh et al. (2019) suggested

incidence of asthma was significantly different between high sun exposure and low sun exposure groups.

Factors Associated with Asthma Exacerbation Severity

Based on the complex sampling logistic regression analysis, there was no relationship between FSI, duration of sunlight exposure, and severity of asthma exacerbations in participants after controlling for race, HCI, and smoking. I rejected the null hypothesis that there was no relationship between vitamin D supplementation and severity of asthma exacerbations in these participants.

Herrera et al. (2023) stated those with lower sunlight exposure were at a significantly higher risk of asthma exacerbation necessitating hospitalization. Food insecurity was significantly associated with poor asthma control, an indication of increased incidence of asthma exacerbation episodes (Tarazona-Meza et al., 2020). Findings contradicted these conclusions. Daily vitamin D supplementation is not significantly associated with a decrease in asthma exacerbation episodes (Jat et al., 2021). However, complex sample binary logistic regression results confirmed that consistent long-term vitamin D supplementation above the Endocrine Society's recommended 15 µg per day is significantly associated with a reduction in asthma exacerbations.

Factors Associated with RTIs

Based on findings of the current study, there was no relationship between vitamin D supplementation, duration of sunlight exposure, and having RTIs in participants. I rejected the null hypothesis that there is no relationship between food security index and having RTIs.

Urashima et al. (2010) indicated that there was no significant relationship between vitamin D supplementation and a decreased risk of RTIs. Findings of the complex binary logistic regression analysis contradicted this. However, subsequent studies have shown no significant relationship between vitamin D supplementation and incidence of RTIs. Furthermore, sunlight exposure did not significantly reduce incidence of RTIs (Harrison et al., 2021). Tse et al. (2016) stated FSI is not significantly associated with increased risk of RTIs.

Findings in the Context of the Five-Tier PHIP

Using the five-tier PHIP to explain relationships between independent and dependent variables was necessary to provide a more in-depth evaluation of modifiable risk factors that contribute to asthma, asthma exacerbation severity, and RTIs. In this study, I found significant relationships between vitamin D supplementation, FSI, and adverse respiratory outcomes.

Supplementation at or just above the RDA for vitamin D (10-19 $\mu\text{g}/\text{day}$) was significantly associated with decreased asthma exacerbations. Results also indicated FSI was significantly associated with RTIs, although the nature of the relationship could not be established.

Focusing on the bottom two tiers of the five-tier PHIP, which have the most significant population effect, evidence regarding FSI as a socioeconomic factor and vitamin supplementation as an explanation for changing the environmental context of vitamin D dietary intake can provide information on barriers that contribute to adverse respiratory outcomes in transitional adults between 16 and 30.

Limitations of the Study

The NHANES are cross-sectional self-reported population-based surveys that are prone to recall bias, which threatened internal validity of the study. Furthermore, dietary intake of vitamin D in food were collected for some individuals, but missing for many. Excluding these variables from data improved internal validity by alleviating quantities of missing information while excluding information that could provide a more accurate representation of individual vitamin D status.

Moreover, NHANES collects data on a subset of the population, which increases the risk of ecological fallacy when inferences are made about an individual based on a group of participants.

Finally, decreasing the measurement level for vitamin D supplementation dose and duration of sunlight exposure from continuous variables to categorical variables was necessary to consolidate findings for interpretation. However, in doing so, decreasing the measurements from a higher level to a lower level of measurement decreased the precision and variation of the study's findings.

Recommendations

Additional research using primary data collection is warranted to explore the relationships between the independent and dependent variables, ensuring comprehensive data collection that includes dietary recall and serum vitamin D evaluation. This study was limited to the secondary data available through NHANES, which had missing values. Missing values did not include questions for which participants refused to answer, but only included questions that were skipped altogether. Future studies with a more

comprehensive data collection process, including dietary sources of vitamin D and serum evaluation, can further elucidate the relationship between vitamin D supplementation, FSI, sunlight exposure, current asthma status, asthma exacerbation severity, and RTIs.

As vitamin D may demonstrate seasonal variations depending on geographic location, future studies that evaluate locations with low and high sunlight availability during November to April can provide more information to confirm or disconfirm the relationship between sunlight exposure and respiratory outcomes.

Based on the findings of this study, I recommend that interventions be developed and tailored to reach young adults who are making nutritional decisions. The findings in this study suggested that achieving the vitamin D RDA can decrease asthma exacerbations, thereby improving long-term respiratory outcomes. Furthermore, people with food insecurity, poor nutritional quality, and variation are at a higher risk of developing RTIs. Therefore, interventions that target improved food quality, such as fortifying staple food items, can significantly improve health outcomes by altering the environmental context, ensuring that healthier decisions become the default.

Implications

In this study, I examined the relationship between vitamin D supplementation, FSI, sunlight exposure, current asthma status, asthma exacerbation severity, and RTIs in participants ages 16-30 during the fall and winter months in the U.S., while controlling for race, household crowding index, and smoking. Understanding the contributing factors to adverse respiratory outcomes can provide evidence at the societal and policy level for the practical development of interventions to decrease modifiable risk factors.

Having a better understanding of the relationships between modifiable risk factors and adverse respiratory outcomes in vulnerable populations can lead to positive social change by improving nutrition, education, and food access policies in young adults. Improving access to diverse, higher-nutrition, lower-calorie local and seasonal food items can aid public health programs in achieving the Healthy People 2030 goals of significantly reducing asthma-related emergency department visits among individuals over five and increasing total vitamin D intake across all populations. Meeting these goals will improve long-term respiratory and overall health outcomes in young adults as they age.

Food fortification policies for staple foods will ensure that individuals have access to readily available sources of vitamin D, in place of additional, often cost-prohibitive, supplementation, to meet the RDA as established by the Endocrine Society. Furthermore, these policies can alter the environmental context, as recommended by the five-tier PHIP, with the most significant population impact.

One potential method of improving access would be for public organizations and colleges to host food fairs, with local farms coordinating with the host organizations to sell seasonal food items at lower prices. During food fairs, local professional or amateur chefs can put on demonstrations where attendees can learn how to use available ingredients to prepare nutritious dishes, using items from the fair or found at a lower cost from their local market. As Hafiz et al. (2023) and Klobodu and Goto (2024) reported, young adults not only consider access to healthy foods a challenge, but also perceive a lack of self-efficacy in utilizing what is available as an additional barrier to healthy

dietary choices. Addressing both challenges through community collaborative partnerships can significantly improve nutritional health, food access, and, by extension, respiratory health outcomes.

Conclusion

The purpose of this cross-sectional, quantitative study was to examine the relationship between vitamin D supplementation, food security index (FSI), sunlight exposure, current asthma status, asthma exacerbation severity, and respiratory tract infections (RTIs) in participants 16-30 during the fall and winter months in the U.S. after controlling for race, household crowding index, and smoking. Complex sample binary logistic regression analysis results of the 2013-2014 and 2017-2018 NHANES showed that there were significant associations between vitamin D supplementation and asthma exacerbation severity. Results also showed a significant relationship between FSI and RTIs. Future studies should investigate variables such as total daily dietary intake of vitamin D from food sources and serum vitamin D levels to understand better the relationship between vitamin D intake and respiratory outcomes.

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Appendix A: Copyright Permission Letter for Figure 3



450 Fame Avenue
Hanover, PA 17331

May 23, 2025

Yun (Melody) O'Donnell
Program Manager, Associate Teaching Professor
College of Nursing & Health Sciences
Department of Medical Laboratory Science
University of Massachusetts Dartmouth
285 Old Westport Road
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Thomas R. Frieden, MD, MPH
American Journal of Public Health
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Appendix B: RQ1 Data Variables

Dataset	Variable	Question/Description	Response	Type
2013-2014 & 2017-2018 NHANES	RIDAGEYR	What is {your/{NAME}'s} birthdate?	0 to 79 Range of values 80 Age older than 80	Defines study population
2013-2014 & 2017-2018 NHANES	RIDEXMON	Six-month time period when the examination was performed	1 November 1 through April 30 2 May 1 through October 31	Defines study population
2013-2014 & 2017-2018 NHANES	HSQ500	“Did {you/SP} have a head cold or chest cold that started during those 30 days?”	1 Yes 2 No 7 Refused 9 Don't know	Defines study population
2013-2014 & 2017-2018 NHANES	KIQ022	“{Have you/Has SP} ever been told by a doctor or other health professional that {you/s/he} had weak or failing kidneys? Do not include kidney stones, bladder (bladd-er) infections, or incontinence (in-kon-ti-nens)”	1 Yes 2 No	Defines study population
Create new	VDDS Created from DSD103 and DSQTVD	Average daily vitamin D supplementation intake	0 to 1260 Range of values (µg)	Independent variable
2013-2014 & 2017-2018 NHANES	FSDAD Created from FSQ032a-c, FSQ041, FSQ052, FSQ061, FSQ071, FSQ081, FSQ092, FSQ102	Adult food security index	1 Full food security 2 Marginal food security 3 Low food security 4 Very low food security	Independent variable
	FSDCH Created from FSQ32d-f, FSQ111, FSQ121, FSQ132, FSQ141, FSQ146	Child food security index		

Create new	UVD Created from DED120 and DED125	The next questions asks about the time you spent outdoors during the past 30 days. By outdoors, I mean outside and not under any shade. How much time did you usually spend outdoors between 9 in the morning and 5 in the afternoon on the days that you worked or went to school? During the past 30 days, how much time did you usually spend outdoors between 9 in the morning and 5 in the afternoon on the days when you were not working or going to school?	15 to 480 Range of values (minutes) 0 No time spent outdoors 14 1-14 minutes 7777 Refused 9999 Don't know	Independent variable
Create new	ASTH Created from MCQ010 and MCQ035	Has a doctor or other health professional ever told {you/SP} that {you have/s/he/SP has} asthma (az-ma)? {Do you/Does SP} still have asthma (az-ma)?	1 Yes 2 No	Dependent variable
2013-2014 & 2017-2018 NHANES	RIDRETH3	“{Do you/Does SP} consider {yourself/himself/herself} to be Hispanic, Latino, or of Spanish origin? Please give me the number of the group that represents {your/SP's} Hispanic/Latino or Spanish origin or ancestry. Please select 1 or more of these categories.	1 Mexican American 2 Other Hispanic 3 Non-Hispanic White 4 Non-Hispanic Black 6 Non-Hispanic Asian 7 Other Race-Including Multi-Racial	Covariate
Create new	HHCI Created from DMDHHSIZ and HOD050	Total number of people in the Household How many rooms are in this home? Count the kitchen but not the bathroom.	0 to 6 Range of values (PPR) 7 ≥ 7 PPR	Covariate

Create new	<p>SMK Created from SMQ621, SMQ681, SMQ470, SMQ858, SMQ862, SMQ868, SMQ872, SMQ876, SMQ880</p>	<p>The following questions are about cigarette smoking and other tobacco use. Do not include cigars or marijuana. About how many cigarettes have you smoked in your entire life?</p> <p>The following questions ask about use of tobacco products in the past 5 days. During the past 5 days, including today, did you smoke cigarettes, pipes, cigars, little cigars or cigarillos, water pipes, hookahs, or e-cigarettes?</p> <p>Now I would like to ask you a few questions about smoking in this home. Not counting decks, porches, or detached garages, how many people who live here smoke cigarettes, cigars, little cigars, pipes, water pipes, hookah, or any other tobacco product inside this home?</p> <p>I will now ask you about tobacco smoke in other places. While {you were/SP was} working at a job or business outside of the home/in a restaurant/bar/motor vehicle/in a home other than yours/ or in another indoor area, did someone else smoke cigarettes or other tobacco products (indoors)?</p>	<p>1 Current smoker 2 Non-smoker, no SHS exposure 3 Non-smoker, SHS exposure 4 Refused</p>	Covariate
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Appendix C: RQ2 Data Variables

Dataset	Variable	Question/Description	Response	Type
2013-2014 & 2017-2018 NHANES	RIDAGEYR	What is {your/{NAME}'s} birthdate?	0 to 79 Range of values 80 (80+)	Defines study population
2013-2014 & 2017-2018 NHANES	RIDEXMON	Six-month time period when the examination was performed	1 November 1 through April 30 2 May 1 through October 31	Defines study population
2013-2014 & 2017-2018 NHANES	HSQ500	“Did {you/SP} have a head cold or chest cold that started during those 30 days?”	1 Yes 2 No 7 Refused 9 Don't know	Defines study population
2013-2014 & 2017-2018 NHANES	KIQ022	“{Have you/Has SP} ever been told by a doctor or other health professional that {you/s/he} had weak or failing kidneys? Do not include kidney stones, bladder (bladd-er) infections, or incontinence (in-kon-ti-nens)	1 Yes 2 No 7 Refused 9 Don't know	Defines study population
Create new	VDDS Created from DSD103 and DSQTVD	Average daily vitamin D supplementation intake	0 to 1260 Range of values (µg)	Independent variable
2013-2014 & 2017-2018 NHANES	FSDAD Created from FSQ032a-c, FSQ041, FSQ052, FSQ061, FSQ071, FSQ081, FSQ092, FSQ102	Adult food security index	1 Full food security 2 Marginal food security 3 Low food security 4 Very low food security	Independent variable
	FSDCH Created from FSQ32d-f, FSQ111, FSQ121, FSQ132, FSQ141, FSQ146	Child food security index		

Create new	UVD Created from DED120 and DED125	The next questions ask about the time you spent outdoors during the past 30 days. By outdoors, I mean outside and not under any shade. How much time did you usually spend outdoors between 9 in the morning and 5 in the afternoon on the days that you worked or went to school? During the past 30 days, how much time did you usually spend outdoors between 9 in the morning and 5 in the afternoon on the days when you were not working or going to school?	15 to 480 Range of values (minutes) 0 No time spent outdoors 14 1-14 minutes 7777 Refused 9999 Don't know	Independent variable
Create new	HOSP Created from MCQ050	[During the past 12 months], {have you/has SP} had to visit an emergency room or urgent care center because of asthma (az-ma)?	1 Yes 2 No	Dependent variable
2013-2014 & 2017-2018 NHANES	RIDRETH3	“{Do you/Does SP} consider {yourself/himself/herself} to be Hispanic, Latino, or of Spanish origin? Please give me the number of the group that represents {your/SP's} Hispanic/Latino or Spanish origin or ancestry. Please select 1 or more of these categories.	1 Mexican American 2 Other Hispanic 3 Non-Hispanic White 4 Non-Hispanic Black 6 Non-Hispanic Asian 7 Other Race-Including Multi-Racial	Covariate
Create new	HHCI Created from DMDHHSIZ and HOD050	Total number of people in the Household How many rooms are in this home? Count the kitchen but not the bathroom.	0 to 6 Range of values (PPR) 7 ≥ 7 PPR	Covariate
Create new	SMK Created from SMQ621,	The following questions are about cigarette smoking and other tobacco use. Do	1 Current smoker	Covariate

	<p>SMQ681, SMQ470, SMQ858, SMQ862, SMQ868, SMQ872, SMQ876, SMQ880</p>	<p>not include cigars or marijuana. About how many cigarettes have you smoked in your entire life?</p> <p>The following questions ask about use of tobacco products in the past 5 days. During the past 5 days, including today, did you smoke cigarettes, pipes, cigars, little cigars or cigarillos, water pipes, hookahs, or e-cigarettes?</p> <p>Now I would like to ask you a few questions about smoking in this home. Not counting decks, porches, or detached garages, how many people who live here smoke cigarettes, cigars, little cigars, pipes, water pipes, hookah, or any other tobacco product inside this home?</p> <p>I will now ask you about tobacco smoke in other places. While {you were/SP was} working at a job or business outside of the home/in a restaurant/bar/motor vehicle/in a home other than yours/ or in another indoor area, did someone else smoke cigarettes or other tobacco products (indoors)?</p>	<p>2 Non-smoker, no SHS exposure 3 Non-smoker, SHS exposure 4 Refused</p>	
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Appendix D: RQ3 Data Variables

Dataset	Variable	Question/Description	Response	Type
2013-2014 & 2017-2018 NHANES	RIDAGEYR	What is {your/{NAME}'s} birthdate?	0 to 79 Range of values 80 (80+)	Defines study population
2013-2014 & 2017-2018 NHANES	RIDEXMON	Six-month time period when the examination was performed	1 November 1 through April 30 2 May 1 through October 31	Defines study population
2013-2014 & 2017-2018 NHANES	HSQ500	“Did {you/SP} have a head cold or chest cold that started during those 30 days?”	1 Yes 2 No 7 Refused 9 Don't know	Defines study population
2013-2014 & 2017-2018 NHANES	KIQ022	“{Have you/Has SP} ever been told by a doctor or other health professional that {you/s/he} had weak or failing kidneys? Do not include kidney stones, bladder (bladd-er) infections, or incontinence (in-kon-ti-nens)	1 Yes 2 No 7 Refused 9 Don't know	Defines study population
Create new	VDDS Created from DSD103 and DSQTVD	Average daily vitamin D supplementation intake	0 to 1260 Range of values (µg)	Independent variable
2013-2014 & 2017-2018 NHANES	FSDAD Created from FSQ032a-c, FSQ041, FSQ052, FSQ061, FSQ071, FSQ081, FSQ092, FSQ102	Adult food security index	1 Full food security 2 Marginal food security 3 Low food security 4 Very low food security	Independent variable
	FSDCH Created from FSQ32d-f, FSQ111, FSQ121, FSQ132, FSQ141, FSQ146	Child food security index		

Create new	UVD Created from DED120 and DED125	The next questions ask about the time you spent outdoors during the past 30 days. By outdoors, I mean outside and not under any shade. How much time did you usually spend outdoors between 9 in the morning and 5 in the afternoon on the days that you worked or went to school? During the past 30 days, how much time did you usually spend outdoors between 9 in the morning and 5 in the afternoon on the days when you were not working or going to school?	15 to 480 Range of values (minutes) 0 No time spent outdoors 14 1-14 minutes 7777 Refused 9999 Don't know	Independent variable
Create new	RTI Created from HSQ500 and HSQ520	The next questions are about {your/SP's} recent health during the 30 days outlined on the calendar. Did {you/SP} have a head cold or chest cold that started during those 30 days? Did {you/SP} have flu, pneumonia, or ear infections that started during those 30 days?	1 Yes 2 No	Dependent variable
2013-2014 & 2017-2018 NHANES	RIDRETH3	“{Do you/Does SP} consider {yourself/himself/herself} to be Hispanic, Latino, or of Spanish origin? Please give me the number of the group that represents {your/SP's} Hispanic/Latino or Spanish origin or ancestry. Please select 1 or more of these categories.	1 Mexican American 2 Other Hispanic 3 Non-Hispanic White 4 Non-Hispanic Black 6 Non-Hispanic Asian 7 Other Race-Including Multi-Racial	Covariate
Create new	HHCI	Total number of people in the Household	0 to 6 Range of values (PPR) 7 ≥ 7 PPR	Covariate

	Created from DMDHHSIZ and HOD050	How many rooms are in this home? Count the kitchen but not the bathroom.		
Create new	SMK Created from SMQ621, SMQ681, SMQ470, SMQ858, SMQ862, SMQ868, SMQ872, SMQ876, SMQ880	<p>The following questions are about cigarette smoking and other tobacco use. Do not include cigars or marijuana. About how many cigarettes have you smoked in your entire life?</p> <p>The following questions ask about use of tobacco products in the past 5 days. During the past 5 days, including today, did you smoke cigarettes, pipes, cigars, little cigars or cigarillos, water pipes, hookahs, or e-cigarettes?</p> <p>Now I would like to ask you a few questions about smoking in this home. Not counting decks, porches, or detached garages, how many people who live here smoke cigarettes, cigars, little cigars, pipes, water pipes, hookah, or any other tobacco product inside this home?</p> <p>I will now ask you about tobacco smoke in other places. While {you were/SP was} working at a job or business outside of the home/in a restaurant/bar/motor vehicle/in a home other than yours/ or in another indoor area, did someone else smoke cigarettes or other tobacco products (indoors)?</p>	<p>1 Current smoker</p> <p>2 Non-smoker, no SHS exposure</p> <p>3 Non-smoker, SHS exposure</p> <p>4 Refused</p>	Covariate