ISSN (electrónico): 1699-5198 - ISSN (papel): 0212-1611 - CODEN NUHOEQ S.V.R. 318

ARÁN

Nutrición Hospitalaria

Trabajo Original

Epidemiología y dietética

Effect of sunlight on vitamin D and hemoglobin levels among the residents of Ningbo, China

Efecto de la luz solar sobre los niveles de vitamina D y hemoglobina entre los residentes de Ningbo, China

Dongzhi Xu[1], Xuyue Hu[2], Ruijie Zhang[1,3], Ji Yang[1], Yi Yuan[1]

[1]Orthopedic Department. Ningbo No. 2 Hospital; [2]Orthopedic Department. The Third People's Hospital Health Care Group of Cixi; [3]Center for Cardiovascular and Cerebrovascular Epidemiology and Translational Medicine. Ningbo Institute of Life and Health Industry. University of Chinese Academy of Sciences. Ningbo, Zhejiang. People's Republic of China

Abstract

Objective: this study investigated the effect of sunlight on vitamin D and hemoglobin levels among the residents of Ningbo, China. The impact of gender, age, and season on vitamin D and hemoglobin levels was also explored.

Methods: a total of 8,481 research subjects, including 5,146 men and 3,335 women, who were permanent residents of Ningbo and received health checkups at Ningbo Second Hospital, were included in the study. Ningbo City climate bulletin data from 2019 to 2022 was also included.

Results: the study subjects received an average of 132.20 ± 40.05 h of sunlight exposure per month and had average vitamin D levels of 19.63 ± 6.61 ng/ml. Hemoglobin levels were adequate in 85.4 % of the participants and deficient in 14.6 %. Sunlight exposure correlated positively with vitamin D and negatively with hemoglobin levels. Regression analysis indicated that gender, age, and season affected vitamin D and hemoglobin levels to different degrees.

Conclusion: in Ningbo, vitamin D deficiency was common in adults while hemoglobin levels were mostly normal. The amount of sunlight exposure had a significant effect on vitamin D and hemoglobin levels and this relationship was impacted by gender, age, and season.

Keywords:

Vitamin D. Hemoglobin. Sunlight exposure. Gender. Age. Season.

Resumen

Objetivo: este estudio investigó el efecto de la luz solar sobre los niveles de vitamina D y hemoglobina entre los residentes de Ningbo, China. También se exploró el impacto del género, la edad y la estación del año en los niveles de vitamina D y hemoglobina.

Métodos: se incluyeron en el estudio un total de 8481 sujetos de investigación, incluidos 5146 hombres y 3335 mujeres, que eran residentes permanentes de Ningbo y recibieron controles médicos en el Segundo Hospital de Ningbo. También se incluyeron datos del boletín climático de la ciudad de Ningbo de 2019 a 2022.

Resultados: los sujetos del estudio recibieron un promedio de 132,20 ± 40,05 h de exposición solar al mes y tuvieron niveles promedio de vitamina D de 19,63 ± 6,61 ng/ml. Los niveles de hemoglobina fueron adecuados en el 85,4 % de los participantes y deficientes en el 14,6 %. La exposición a la luz solar se correlacionó positivamente con la vitamina D y negativamente con los niveles de hemoglobina. El análisis de regresión indicó que el género, la edad y la estación del año afectaron los niveles de vitamina D y hemoglobina en diferentes grados.

Conclusión: en Ningbo, la deficiencia de vitamina D era común en los adultos, mientras que los niveles de hemoglobina eran en su mayoría normales. La cantidad de exposición a la luz solar tuvo un efecto significativo sobre los niveles de vitamina D y hemoglobina y esta relación se vio afectada por el género, la edad y la estación del año.

Palabras clave:

Vitamina D. Hemoglobina. Exposición a la luz solar. Género. Edad. Estación del año.

Received: 26/09/2023 • Accepted: 31/03/2024

Conflicts of interest: the authors declare that they have no conflicts of interest.

Artificial intelligence: the authors declare not to have used artificial intelligence (AI) or any AI-assisted technologies in the elaboration of the article.

Xu D, Hu X, Zhang R, Yang J, Yuan Y. Effect of sunlight on vitamin D and hemoglobin levels among the residents of Ningbo, China. Nutr Hosp 2024;41(4):850-857
DOI: http://dx.doi.org/10.20960/nh.04969

Correspondence:
Yi Yuan. Orthopedic Department. Ningbo No. 2 Hospital. 41 Xibei Street. 315010 Ningbo, Zhejiang. People's Republic of China
e-mail: nbjoint@163.com

INTRODUCTION

Vitamin D, categorized as an indispensable fat-soluble vitamin (1), orchestrates pivotal roles in modulating calcium and phosphorus metabolism, along with facilitating bone morphogenesis (2). It governs bone accrual and physical maturation, interlinked profoundly with the cardiovascular, endocrine, and immune systems within the human anatomy (3). A staggering statistic reflects that over a billion children and adults globally grapple with vitamin D deficiency or insufficiency (4). Predominantly, the skin autonomously synthesizes this vitamin via exposure to ultraviolet light (UV) (5). This synthesis transpires when UV rays convert 7-dehydrocholesterol into vitamin D3, subsequently metabolized by the liver into 25-hydroxyvitamin D. Eventually, the kidneys convert this intermediary form to the biologically active variant of vitamin D, termed calcitriol. Sunlight exposure results in an augmentation of vitamin D levels in the integument (6). A diminution in levels of this vital vitamin can instigate conditions like osteochondrosis, osteoporosis, fractures, and rickets, besides escalating the risk of specific cancers.

Hemoglobin (Hb), a complex heterotetramer, primarily functions to ferry oxygen (O_2) from the respiratory organs to the peripheral tissues and reciprocally transports carbon dioxide (CO_2) from tissues to the lungs. The kinetics underlying Hb-O_2 interaction are meticulously calibrated to optimize this transfer, adapting to individual physiological growth, development, and metabolic fluctuations (7). Anemia's prevalence escalates with aging, afflicting approximately 6 % of individuals within the 50-64 years bracket and around 11 % of those aged 65 years and above (8). Both elevated and diminished hemoglobin concentrations correlate with augmented risks of cardiovascular diseases (CVD) (9,10). Concomitantly, anemia is related to escalated risks of cognitive impairment and instances of dementia in the elderly demographic (≥ 65 years) (11-13) and demonstrates a connection to increased occurrences of fractures (14), heart failure, and various other medical conditions.

The multifariousness in geographic locales, sunlight exposure durations, dietary habits, and attire preferences have manifested divergent prevalence rates of vitamin D deficiency across various regions in China (15). Consequently, a nuanced comprehension of the levels of vitamin D and hemoglobin across distinct regions can act as a linchpin for devising preventive strategies and therapeutic interventions for the contingent diseases. Ningbo, situated along the southern coast of China, typified by its subtropical monsoon climate, harbors a confluence of hills and plains, thereby providing a unique context for this study. The region, positioned at east longitude 120° 55'-122° 16' and north latitude 28° 51'-30° 33', witnesses an annual average temperature of 16.3 °C and amasses an annual sunlight exposure approximating 2,070 hours (16).

Embarking on a meticulous cross-sectional analysis, this study harnesses sunshine exposure and temperature data gleaned from the Ningbo region spanning a recent three-year trajectory, amalgamated with clinical data procured from its healthy denizens. The research endeavors to unravel the nexus between sunshine exposure and serum concentrations of vitamin D and hemoglobin, delving deeper to elucidate the influences of gender, age, and seasonal variations on these biochemical indices. The ensuing discussion seeks to proffer a holistic and nuanced perspective, intertwining multifarious elements to contribute a comprehensive understanding of the subject matter and advocate plausible preventative and remedial approaches.

MATERIAL AND METHODS

GENERAL INFORMATION

The foundational data for this intricate study originated from a meticulous cross-sectional population survey, operational from October 2019 to October 2022 in Ningbo, Zhejiang, China. The assembled cohort comprised 8,481 subjects, stratified into 5,146 men and 3,335 women, all enduring residents of Ningbo. The participative subjects underwent comprehensive physical examinations at the Health Examination Center located within the Second Hospital of Ningbo. Concurrently, climatic bulletins encapsulating the corresponding time frame were procured to enrich the dataset. The inclusion criteria meticulously omitted individuals afflicted with pathological states potentially skewing vitamin D or hemoglobin levels, such as hyperthyroidism, profound hepatic and renal maladies, malignant neoplasms, intensive infections, and leukemia.

METHODOLOGICAL FRAMEWORK

The acquisition process encompassed collection of indispensable parameters including the subjects' name, gender, age, month of examination, prevalent disease information, combined vitamin D (D2 + D3) concentrations (ng/mL) and hemoglobin levels (g/L) from the repositories of the Second Hospital of Ningbo. Corresponding average monthly temperature (°C) and sunlight exposure (h) metrics were extricated from Ningbo climatic bulletins. Chemiluminescence served as the predominant modality for quantifying total vitamin D (D2 + D3). Benchmarks established vitamin D sufficiency, insufficiency, and deficiency as 30-100 ng/mL, < 20 ng/mL, and 20-30 ng/mL, respectively. Hemoglobin quantification predominantly deployed the hemocytometer colorimetric method, with deficiency and sufficiency demarcated as < 130 g/L and ≥ 130 g/L, respectively. Stratification of subjects ensued according to age brackets and seasons, categorized according to the Gregorian calendar.

STATISTICAL ANALYSIS

Analytical processing was executed utilizing SPSS 26 software, with R and GraphPad deployed for graphical representations. Quantitative datasets were articulated as "$x \pm s$", and the interrelation, or lack thereof, between categorical variables was deciphered through Chi-square analysis, with count data delineated as the number and percentage of cases. Multiple logistic regression analyses were leveraged to scrutinize the influence of light duration on vitamin D and hemoglobin concentrations across diverse strata of gender, age, and seasonality. A p-value threshold of < 0.05 constituted the criterion for statistical significance, reinforcing the credibility and rigor of the analytical results.

RESULTS

DEMOGRAPHIC DISTRIBUTION

The evaluated cohort comprised a comprehensive total of 8,481 subjects, differentiated into 5,146 males (60.7 %) and 3,335 females (39.3 %). The seasonal distribution of subjects was strategically allocated, encompassing 1,197 subjects (14.1 %) in spring, 1,878 (22.1 %) in summer, 2,868 subjects (33.8 %) in autumn, and 2,720 subjects (32.1 %) in winter. The gender proportions remained steadfast across each seasonal phase.

AGE AND HEMOGLOBIN STRATIFICATION

Subjects were distributed across various age brackets, with most (7,245; 85.4 %) exhibiting a hemoglobin concentration of ≥ 130 g/L, contrasting with the remaining 1,236 (14.6 %) residing within the < 130 g/L hemoglobin concentration bracket. The mean vitamin D concentration was documented as 19.63 ± 6.61 ng/ml, juxtaposed with the mean monthly sunlight exposure of 132.20 ± 40.05 h, and a mean temperature of 19.01 ± 6.71 °C.

COMPARATIVE ANALYSIS OF VITAMIN D AND HEMOGLOBIN LEVELS

The analysis unveiled significant disparities in vitamin D concentrations, contingent on gender, age, and seasonal variation ($p < 0.001$). Women exhibited diminished serum vitamin D concentrations compared to men, and markedly elevated concentrations were discerned in individuals surpassing 55 years of age. Elevated vitamin D levels corresponded to summer and autumnal assessments compared to winter and spring, depicting the seasonal dependency (Table I).

Concurrently, hemoglobin concentrations revealed analogous variations, accentuated by gender, age, and seasonal progression ($p < 0.001$), with men exhibiting superior concentrations relative to women and subjects aged ≥ 65 years manifesting substantially reduced levels compared to their younger counterparts (Table II).

SUNLIGHT EXPOSURE AND CORRELATIONAL ANALYSIS

Sunlight exposure exhibited profound differences among subjects with diverse vitamin D statuses across gender, age, and seasons, save for spring. A pronounced positive correlation emerged between sunlight exposure and vitamin D concentrations ($r = 0.453$, $p < 0.001$) (Fig. 1).

Conversely, sunlight exposure depicted discernable variations between hemoglobin sufficient and deficient individuals, particularly among different genders ($p < 0.05$), but remained consistent across different ages and seasons, except within the 35-44 or ≥ 65 years age brackets. A noteworthy negative correlation materialized between sunlight exposure and hemoglobin concentrations ($r = 0.233$, $p < 0.001$) (Fig. 2).

Table I. Distribution of vitamin D level in groups

	Sufficiency		Deficiency		Insufficiency		χ^2	*p*-value
	Case	Percent	Case	Percent	Case	Percent		
Gender								
Male	394	7.66	2679	52.06	2073	40.28	186.755	< 0.001
Female	168	5.04	2236	67.05	931	27.92		
Age								
< 35	31	3.19	705	72.46	237	24.36	233.205	< 0.001
35-44	75	3.84	1247	63.85	631	32.31		
45-54	180	6.60	1575	57.71	974	35.69		
55-64	182	10.03	882	48.62	750	41.35		
≥ 65	94	9.29	506	50.00	412	40.71		
Season								
Spring	51	4.26	838	70.01	308	25.73	394.082	< 0.001
Summer	193	10.28	852	45.37	833	44.36		
Autumn	226	8.41	1366	50.86	1094	40.73		
Winter	92	3.38	1859	68.35	769	28.27		

Table II. Distribution of haemoglobin (Hb) level in groups

	< 130		≥ 130		χ^2	*p*-value
	Case	Percent	Case	Percent		
Gender						< 0.001
Male	127	2.47 %	5019	97.53 %	1540.446	
Female	1109	33.25 %	2226	66.75 %		
Age						< 0.001
< 35	155	15.93 %	818	84.07 %		
35-44	331	16.95 %	1622	83.05 %		
45-54	387	14.18 %	2342	85.82 %	50.850	
55-64	181	9.98 %	1633	90.02 %		
≥ 65	182	17.98 %	830	82.02 %		
Season						< 0.001
Spring	201	16.79 %	996	83.21 %		
Summer	336	17.89 %	1542	82.11 %	35.515	
Autumn	327	12.17 %	2359	87.83 %		
Winter	372	13.68 %	2348	86.32 %		

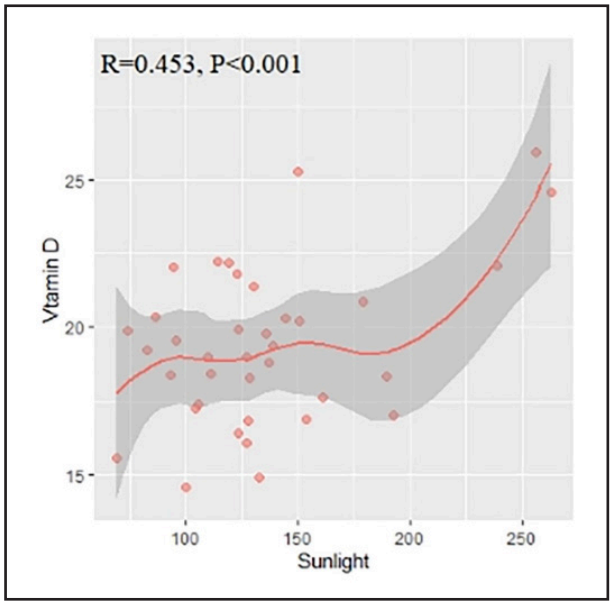

Figure 1.
The relationship between vitamin D level and sunlight (linear regression).

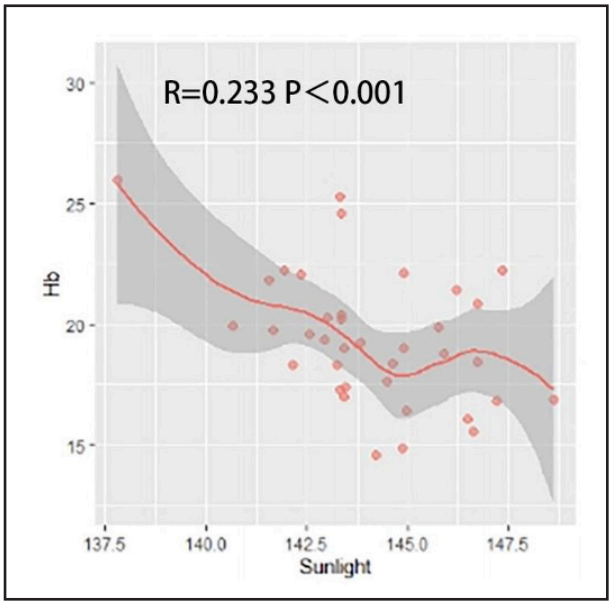

Figure 2.
The relationship between Hb level and sunlight (linear regression).

MULTIPLE LOGISTIC REGRESSION ANALYSIS

This multivariate analysis delineated the heightened susceptibility of women to vitamin D deficiency under constrained sunlight exposure relative to men (OR (female): OR (male) = 1.513). The proclivity for vitamin D deficiency attenuated with advancing age, reaching its zenith during winter. Surprisingly, temperature did not manifest as a decisive contributor to vitamin D synthesis ($p < 0.05$) (Table III). Similarly, women demonstrated elevated predisposition to hemoglobin deficiency at equivalent sunlight exposures (OR (female): OR (male) = 0.050). The impact of age and seasonal transition on hemoglobin concentrations was substantial, underscoring their influence (Table IV).

Table III. The impact of sunlight exposure on vitamin D

Variables	OR	Coefficient	SE	Wald χ^2	*p*-value	OR 95 % CI	
						Lower	Upper
Gender							
Male	Reference						
Female	1.513	0.414	0.097	18.217	< 0.001	1.251	1.830
Age group				77.933	< 0.001		
< 35	Reference						
35-44	0.865	-0.145	0.219	0.436	0.509	0.563	1.329
45-54	0.466	-0.764	0.200	14.622	< 0.001	0.315	0.689
55-64	0.305	-1.186	0.200	35.021	< 0.001	0.206	0.452
≥ 65	0.347	-1.057	0.215	24.106	< 0.001	0.228	0.530
Seasons				15.809	< 0.001		
Spring	Reference						
Summer	0.517	-0.660	0.248	7.066	0.008	0.318	0.841
Autumn	0.540	-0.617	0.178	12.048	0.001	0.381	0.765
Winter	1.091	0.087	0.207	0.177	0.674	0.727	1.638
Temperate	0.991	-0.009	0.019	0.212	0.645	0.954	1.029
Sunlight	0.994	-0.007	0.001	30.377	< 0.001	0.991	0.996
Constant	73.930	4.303	0.389	122.509	< 0.001	-	-

Table IV. The impact of sunlight exposure on Hb

Variables	OR	Coefficient	SE	Wald χ^2	*p*-value	OR 95 % CI	
						Lower	Upper
Gender							0.060
Male	Reference						
Female	0.050	-3.005	0.098	942.368	< 0.001	0.041	
Age group				62.361	< 0.001		
< 35	Reference						
35-44	1.725	0.545	0.136	16.029	< 0.001	1.321	2.252
45-54	1.393	0.332	0.118	7.864	0.005	1.105	1.756
55-64	1.76	0.565	0.114	24.489	< 0.001	1.407	2.201
≥ 65	2.584	0.949	0.129	54.495	< 0.001	2.008	3.324
Seasons				12.706	0.005		
Spring	Reference						
Summer	0.905	-0.1	0.106	0.879	0.348	0.735	1.115
Autumn	0.762	-0.272	0.099	7.625	0.006	0.628	0.924
Winter	1.061	0.059	0.092	0.419	0.517	0.887	1.270
Sunlight	0.998	-0.002	0.001	5.579	0.018	0.996	1.000
Constant	686.333	6.531	0.235	775.296	< 0.001	-	-

SYNTHESIS OF FINDINGS

The detailed analysis of results elucidates pivotal insights into the interdependence between vitamin D and hemoglobin concentrations, sunlight exposure, and various demographic and temporal parameters. These intricate interrelations and distinct patterns amplify the comprehensive understanding of the multifaceted interactions and their subsequent implications on physiological well-being and disease predisposition.

DISCUSSION

This study reveals that Ningbo receives less sunlight exposure compared to other regions of the country (17). However, the latitude of this region is influenced by the convergence of cold and warm air masses, and it is characterized by a notable presence of large mountains and oceans. Ningbo's geographical location and natural environment significantly affect the local weather patterns, leading to frequent catastrophic events and prevalent cloudy and rainy weather. The vitamin D levels are notably low among Ningbo residents, with merely 7.66 % and 5.04 % of men and women, respectively, having adequate levels. The current study shows that vitamin D deficiency was marginally more prevalent in women than in men. The Korean National Health and Nutrition Examination Survey (KNHANES), spanning from 2008 to 2014, revealed that 76.7 % of the female population had vitamin D deficiency (< 50 nmol/L) (18), contrasted with 54.6 % in Japan (19). Furthermore, the prevalence of vitamin D insufficiency and deficiency in Ningbo considerably surpasses the national average of 66.3 % (20). Ningbo's latitude, ranging between 28.51-30.33°, results in prolonged sunlight paths and diminished UV rays due to its oblique angle. Lifestyle-affected exposure to air pollution further restricts solar irradiation and impairs vitamin D synthesis in the skin. Although 85.4 % of the Ningbo population has sufficient hemoglobin levels, they are comparatively lower than those observed at different altitudes in China (21). A correlation exists between the variances in environmental oxygen levels at different altitudes and the dietary habits of the population.

This study identified a positive correlation between vitamin D and sunlight exposure. Although this vitamin can be partially obtained through diet, the majority is absorbed by the skin through ultraviolet B (UVB) radiation from the sun. Adequate UVB radiation triggers the conversion of 7-dehydrocholesterol (7-DHC) to pre-vitamin D3 (22), thereby enhancing vitamin D production. Given the same geographical conditions, climate, air quality, working environment, and health conditions, young Chinese women, who typically prioritize fair complexion, often use sunscreen and sunshade umbrellas to avoid direct sunlight. Consequently, a lack of sunlight exposure might be one of the reasons for diminished vitamin D synthesis in this demographic (23). Meanwhile, women of reproductive age (18-44 years) have high vitamin D consumption, but the intake levels of vitamin D remain relatively constant. Estrogen intensifies the function of vitamin D by promoting its accumulation and by amplifying the expression of vitamin D receptors. As middle-aged women in perimenopause and menopause exhibit lower levels of estrogen (24,25), it may elucidate why the overall serum vitamin D levels were lower in women than in men in this study. This observation aligns with previous studies (26-28).

Individuals > 55 years of age displayed significantly elevated levels of vitamin D compared to their middle-aged counterparts. This could be attributed to the fact that younger individuals, burdened with academic and professional pressures, predominantly stay indoors, while older, retired individuals tend to partake more in outdoor activities and thereby, receive increased sunlight exposure. This pattern correlates with the retirement ages of 60 for men and 55 for women. Vitamin D levels were significantly higher in summer and autumn compared to winter and spring, peaking in summer and reaching a nadir in winter — consistent with earlier studies (29-31). The summer months offer extended exposure to sunlight and high UV radiation, and the milder weather in autumn encourages outdoor activities. In contrast, winter, characterized by lower temperatures, necessitates wearing multiple layers of clothing and results in minimal skin exposure, and spring sees a greater number of rainy days, which together with reduced UV radiation exposure, constrain the synthesis of vitamin D (32).

Increased exposure to sunlight is associated with lower hemoglobin levels, potentially due to the damaging effect of UV irradiation on the red blood cell membrane (33). Additionally, irradiating red blood cells with light wavelengths that can induce skin diseases causes oxygen-dependent colloid-permeable hemolysis through the formation of peroxides (34).

Hemoglobin levels are significantly higher in men than in women, primarily because women have higher levels of estrogen and lower levels of androgens, hormones necessary for stimulating bone marrow and blood production. The decline in hemoglobin levels with age may be associated with decreased secretion and erythropoietic capability of the liver, kidneys, and other organs. A diminished hematopoietic capacity of bone marrow lowers the body's ability to absorb iron, and chronic blood loss can result from gastrointestinal diseases (35). Erythrocytosis is also more prevalent in men, possibly due to the higher smoking rate in this population (36). Hemoglobin levels were higher in autumn, a phenomenon potentially related to the local dietary habits of Ningbo residents.

The strength of this study lies in the data allowing for stratification by gender, age, and season. However, the study has several limitations. Firstly, its cross-sectional design prohibits the deduction of causality. Secondly, it does not offer extensive insights into the nutritional dietary intake and sunlight exposure in the population.

To address the findings of this study, health education should be extensively disseminated to encourage people to optimize natural conditions, advocate for the reasonable enhancement of outdoor activities, increase sunlight exposure, modify dietary structure, and augment the intake of vitamin D-rich foods. Women should be cautioned

against excessive sunscreen use. For those at high risk of vitamin D deficiency, or during the seasons when vitamin D levels are likely to be low, oral vitamin D supplements and fortified foods should be reasonably and timely promoted, based on individual's current vitamin levels. Utilizing lamps that produce UVB radiation is another alternative for promoting vitamin D production in some individuals (37). Vitamin D supplementation is crucial to avoid prolonged exposure to intense sunlight, capable of causing cellular damage. The effect of sunlight exposure on hemoglobin necessitates further exploration and analysis. Clinicians should monitor vitamin D status and hemoglobin levels to mitigate the adverse health impacts of their deficiencies.

CONCLUSION

This study underscores the significant vitamin D deficiency among residents of Ningbo, attributed to specific geographical, environmental, and lifestyle factors, with a pronounced prevalence in women. The constrained sunlight exposure in Ningbo, due to its unique geographical and atmospheric conditions, results in diminished vitamin D synthesis and variations in hemoglobin levels, reflecting the role of environmental elements in health outcomes. The conspicuous deficiency of vitamin D in Ningbo necessitates targeted health interventions and awareness campaigns. These interventions should encourage outdoor activities, balanced diets rich in vitamin D, and adequate sunlight exposure, considering its potential adverse effects.

In conclusion, the research sheds light on the distinct health challenges in Ningbo, highlighting the influence of localized factors on health indicators and urging for region-specific health strategies to ameliorate the overall well-being of the population in such unique environmental settings.

CONSENT FOR PUBLICATION

Not applicable. The study received an exemption from the Human Research Ethics Committee of Ningbo Second Hospital and did not require informed consent. Verify that all methods are implemented in accordance with relevant guidelines and regulations.

AUTHORS' CONTRIBUTIONS

Yi Yuan: formulation of overarching research goals and aims; Dongzhi Xu: data collection; Xuyue Hu: data curation and writing, original draft; Ruijie Zhang: data analysis and statistics; Ji Yang: English translation and polishing.

FUNDING

This study was supported by the Medical and Health Science and Technology Project of Zhejiang Province (No. 2020KY264), Ningbo public welfare science and technology planning project (No.2021S169).

ACKNOWLEDGMENTS

I would first like to thank my supervisor, Yi Yuan, whose expertise was invaluable in formulating the research questions and methodology. And I would particularly like to acknowledge my team mates, Dongzhi Xua, Xuyue Hu, Ruijie Zhang, Ji Yang, for their wonderful collaboration and patient support.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

This study was approved by the Ethics Committee of HwaMei Hospital, University of Chinese Academy of Sciences (Ningbo, China; approval code: SL-NBEY-KY-2023- 17-01).

REFERENCES

1. Stevens SL. Fat-Soluble Vitamins. Nurs Clin North Am 2021;56(1):33-45. DOI: 10.1016/j.cnur.2020.10.003
2. Kim D. The Role of Vitamin D in Thyroid Diseases. Int J Mol Sci 2017;18(9):1949. DOI: 10.3390/ijms18091949
3. Zmijewski MA. Vitamin D and Human Health. Int J Mol Sci 2019;20(1):145. DOI: 10.3390/ijms20010145
4. Holick MF. The vitamin D deficiency pandemic: Approaches for diagnosis, treatment and prevention. Rev Endocr Metab Disord 2017;18(2):153-65. DOI: 10.1007/s11154-017-9424-1
5. Saraff V, Shaw N. Sunshine and vitamin D. Arch Dis Child 2016;101(2):190-2. DOI: 10.1136/archdischild-2014-307214
6. Saliba W, Barnett O, Rennert HS, Rennert G. The risk of all-cause mortality is inversely related to serum 25(OH)D levels. J Clin Endocrinol Metab 2012;97(8):2792-8. DOI: 10.1210/jc.2012-1747
7. Thom CS, Dickson CF, Gell DA, Weiss MJ. Hemoglobin variants: biochemical properties and clinical correlates. Cold Spring Harb Perspect Med 2013;3(3):a011858. DOI: 10.1101/cshperspect.a011858
8. Guralnik JM, Eisenstaedt RS, Ferrucci L, Klein HG, Woodman RC. Prevalence of anemia in persons 65 years and older in the United States: evidence for a high rate of unexplained anemia. Blood 2004;104(8):2263-8. DOI: 10.1182/blood-2004-05-1812
9. Lee G, Choi S, Kim K, Yun JM, Son JS, Jeong SM, et al. Association of Hemoglobin Concentration and Its Change With Cardiovascular and All-Cause Mortality. J Am Heart Assoc 2018;7(3):e007723. DOI: 10.1161/JAHA.117.007723
10. Kim MY, Jee SH, Yun JE, Baek SJ, Lee DC. Hemoglobin concentration and risk of cardiovascular disease in Korean men and women - the Korean heart study. J Korean Med Sci 2013;28(9):1316-22. DOI: 10.3346/jkms.2013.28.9.1316
11. Andro M, Le Squere P, Estivin S, Gentric A. Anaemia and cognitive performances in the elderly: a systematic review. Eur J Neurol 2013;20(9):1234-40. DOI: 10.1111/ene.12175
12. Peters R, Burch L, Warner J, Beckett N, Poulter R, Bulpitt C. Haemoglobin, anaemia, dementia and cognitive decline in the elderly, a systematic review. BMC Geriatr 2008;8:18. DOI: 10.1186/1471-2318-8-18
13. Shah RC, Wilson RS, Tang Y, Dong X, Murray A, Bennett DA. Relation of hemoglobin to level of cognitive function in older persons. Neuroepidemiology 2009;32(1):40-6. DOI: 10.1159/000170905
14. Valderrábano RJ, Lee J, Lui LY, Hoffman AR, Cummings SR, Orwoll ES, et al; Osteoporotic Fractures in Men (MrOS) Study Research Group. Older Men With Anemia Have Increased Fracture Risk Independent of Bone Mineral Density. J Clin Endocrinol Metab 2017;102(7):2199-206. DOI: 10.1210/jc.2017-00266

15. Fan P, Wang Q, Li J, Lu C, Xu Y, Cao H, et al. Poor Status of Vitamin D: A Survey of Area With Lowest Sunlight Radiation in Sichuan, China. Front Endocrinol (Lausanne) 2021;12:626983. DOI: 10.3389/fendo.2021.626983
16. Li G, Huang J, Xu G, Pan X, Qian X, Xu J, et al. Temporal variation in associations between temperature and years of life lost in a southern China city with typical subtropical climate. Sci Rep 2017;7(1):4650. DOI: 10.1038/s41598-017-04945-6
17. Lian Xingye, Meng Zengdong. Relationship between quantity of illumination and human vitamin D concentration and bone mineral density in different region. Chinese Journal of Osteoporosis 2012;18(2):183-7. DOI: 10.3969/j.issn1006-7108.2012.02.022
18. Park JH, Hong IY, Chung JW, Choi HS. Vitamin D status in South Korean population: Seven-year trend from the KNHANES. Medicine (Baltimore) 2018;97(26):e11032. DOI: 10.1097/MD.0000000000011032
19. Nakamura K, Kitamura K, Takachi R, Saito T, Kobayashi R, Oshiki R, et al. Impact of demographic, environmental, and lifestyle factors on vitamin D sufficiency in 9084 Japanese adults. Bone 2015;74:10-7. DOI: 10.1016/j.bone.2014.12.064
20. Yu S, Fang H, Han J, Cheng X, Xia L, Li S, et al. The high prevalence of hypovitaminosis D in China: a multicenter vitamin D status survey. Medicine (Baltimore) 2015;94(8):e585. DOI: 10.1097/MD.0000000000000585. Erratum in: Medicine (Baltimore) 2015;94(11):1.
21. Cao Rui, Zheng Hui, Ge Miao. Curvilinear Model Analysis between Reference Values of Chinese Middlescent Men's Hemoglobin and Altitude. Journal of Modern Laboratory Medicine 2010,25(1):10-3. DOI: 10.3969/j.issn.1671-7414.2010.01.004
22. Holick MF. Sunlight and vitamin D for bone health and prevention of autoimmune diseases, cancers, and cardiovascular disease. Am J Clin Nutr 2004;80(6 Suppl):1678S-88S. DOI: 10.1093/ajcn/80.6.1678S
23. Engelsen O. The relationship between ultraviolet radiation exposure and vitamin D status. Nutrients 2010;2(5):482-95. DOI: 10.3390/nu2050482
24. Dupuis ML, Pagano MT, Pierdominici M, Ortona E. The role of vitamin D in autoimmune diseases: could sex make the difference? Biol Sex Differ 2021;12(1):12. DOI: 10.1186/s13293-021-00358-3
25. Neale RE, Khan SR, Lucas RM, Waterhouse M, Whiteman DC, Olsen CM. The effect of sunscreen on vitamin D: a review. Br J Dermatol 2019;181(5):907-15. DOI: 10.1111/bjd.17980
26. Niculescu DA, Capatina CAM, Dusceac R, Caragheorgheopol A, Ghemigian A, Poiana C. Seasonal variation of serum vitamin D levels in Romania. Arch Osteoporos 2017;12(1):113. DOI: 10.1007/s11657-017-0407-3
27. Semba RD, Houston DK, Bandinelli S, Sun K, Cherubini A, Cappola AR, et al. Relationship of 25-hydroxyvitamin D with all-cause and cardiovascular disease mortality in older community-dwelling adults. Eur J Clin Nutr 2010;64(2):203-9. DOI: 10.1038/ejcn.2009.140
28. Tolppanen AM, Fraser A, Fraser WD, Lawlor DA. Risk factors for variation in 25-hydroxyvitamin D_3 and D_2 concentrations and vitamin D deficiency in children. J Clin Endocrinol Metab 2012;97(4):1202-10. DOI: 10.1210/jc.2011-2516
29. Wierzejska R, Jarosz M, Sawicki W, Bachanek M, Siuba-Strzelińska M. Vitamin D Concentration in Maternal and Umbilical Cord Blood by Season. Int J Environ Res Public Health 2017;14(10):1121. DOI: 10.3390/ijerph14101121
30. Niculescu DA, Capatina CAM, Dusceac R, Caragheorgheopol A, Ghemigian A, Poiana C. Seasonal variation of serum vitamin D levels in Romania. Arch Osteoporos 2017;12(1):113. DOI: 10.1007/s11657-017-0407-3
31. Lee J, Won Woo H, Kim J, Shin MH, Koh I, Youl Choi B, et al. Independent and interactive associations of season, dietary vitamin D, and vitamin D-related genetic variants with serum 25(OH)D in Korean adults aged 40 years or older. Endocr J 2021;68(6):701-11. DOI: 10.1507/endocrj.EJ20-0519
32. Gao G, Chen X. Serum vitamin D levels in Shanghai adults:effects of gender, age and season. Chinese Journal of Osteoporosis 2002;28(2):280-4 DOI: 10.3969/j.issn.1006-7108.2022.02.022
33. Zhu Yuzhen, Dai Yue, Liu Xuguo, Gai Yuhui, Wang Peng, Gao Feng. Effects of ultraviolet radiation on erythrocyte storage. Chinese Journal of Blood Transfusion 2000,03:179-80.
34. Goldstein BD, Harber LC. Erythropoietic protoporphyria: lipid peroxidation and red cell membrane damage associated with photohemolysis. J Clin Invest 1972;51(4):892-902. DOI: 10.1172/JCI106884
35. Liang Wenjin, Zong Yongxue, Mei Guijie. Effects of age factors on hemoglobin content in human body.Chinese Convalescent Medicine 2012;05:471.
36. Shaheen NA, Rehan H, Moghairi A, Gmati G, Damlaj M, Salama H, et al. Hematological indices in the adult saudi population: Reference intervals by gender, age, and region. Front Med (Lausanne) 2022;9:901937. DOI: 10.3389/fmed.2022.901937
37. Holick MF, Chen TC, Lu Z, Sauter E. Vitamin D and skin physiology: a D-lightful story. J Bone Miner Res 2007;22 Suppl 2:V28-33. DOI: 10.1359/jbmr.07s211