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Association of 25-hydroxyvitamin D and physical activity with oral care needs among older U.S. adults

Jike Gao[1†], Lei Lu[1†], Jingxin Zhao[1], Yang Wang[1], Kun Xiang[1*] and Xiaoyu Sun[1*]

Abstract

Objectives This study aimed to investigate the independent and combined association of serum 25-hydroxyvitamin D [25(OH)D] levels and physical activity on oral care needs in older United States (US) adults.

Methods A cross-sectional study involving 6509 older adults aged 60 years and above data were included from the 2009–2018 National Health and Nutrition Examination Survey (NHANES). The main data for our study came from Questionnaires Data and Laboratory Data. Oral care needs refer to the different levels of overall care recommendations given by trained interviewers after oral examination of interviewees in the NHANES. The weighted multivariate logistic regression model and restricted cubic spline (RCS) were used to explore the associations between 25(OH)D levels, physical activity, and oral care needs. Additional propensity score matching (PSM) was performed to test the stability and reliability of the results.

Results The results showed that high serum 25(OH)D levels (OR = 0.99, 95% CI, 0.97–1.00, $P = 0.04$), and vigorous recreational activity (OR = 0.70, 95% CI, 0.53–0.93, $P = 0.01$) were independently associated significantly with lower risks of oral care needs. High levels of 25(OH)D combined with adequate physical activity might reduce oral care needs in older adults. The mediation effect analysis also showed a mediating effect of 25(OH)D in the association of vigorous recreational activity and oral care needs.

Conclusion High serum 25(OH)D levels and vigorous recreational activity have been linked to a reduced risk of oral care need among older adults. 25(OH)D is a potential mediator of the reduced need for oral health care associated with vigorous recreational activity when combined effects are considered. Vitamin D supplementation and increased physical activity may be a potential cost-effective oral public health strategy for older adults.

Keywords Vitamin D, Physical activity, Oral care needs, Oral disease, Aging

Introduction

Oral health is vital for essential functions such as chewing, speaking, and facial expression. Among oral diseases, untreated dental caries is the most prevalent condition globally, affecting nearly 2.4 billion people, with its incidence increasing after the age of 60 [1]. The second most common oral disease is severe periodontitis, which ranks as the sixth most prevalent disease worldwide, affecting approximately 734 million people. Its incidence also rises with age [1, 2]. Untreated caries and periodontitis can result in tooth defects and

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dentition problems, compromising the health of the jaw system, particularly in older adults [3]. Consequently, poor oral health can lead to imbalanced nutrient intake, chronic pain, reduced social functioning, and a significant burden on both physical and mental well-being [4–6]. Numerous risk factors for dental caries and periodontitis have been identified, and emerging evidence suggests that vitamin D levels play a significant role in both diseases [7, 8].

Vitamin D is a sterol hormone integral to bone physiology and the metabolism of phosphorus and calcium [9]. Beyond its well-established role in skeletal health, vitamin D has been extensively studied for its effects on the extraskeletal system, including autoimmune diseases, diabetes, cardiovascular and respiratory conditions, etc. [10]. The active form of vitamin D such as 25-hydroxyvitamin D [25(OH)D], can be produced by various cell types [11], and plays a key role in oral immune defense, involving oral epithelial cells, periodontal ligament cells, and gingival fibroblasts [12, 13]. In vitro studies have shown that vitamin D enhances the innate immune response of gingival epithelial cells by inducing the production of the antimicrobial peptide LL-37 and boosting the immune response to bacterial infections [14]. In vivo studies have also demonstrated that vitamin D deficiency is associated with periodontal disease features in experimental mice, including increased gingival inflammation and alveolar bone loss [15]. In clinical research, a study of the adult population in Norway, found that 25(OH)D concentration was negatively correlated with the number of caries and the severity of periodontitis [16]. Nevertheless, despite these findings, evidence on the relationship between vitamin D and oral health in older adults remains underexplored and warrants further investigation.

Regular physical activity, a healthy diet, and moderate sun exposure are recommended to prevent and treat vitamin D insufficiency [17]. Although endogenous synthesis through solar UV irradiation is the primary source of vitamin D, physical activity has also been shown to increase plasma vitamin D concentrations [18]. Interestingly, animal experiments have reported that exercise can reduce alveolar bone loss caused by periodontitis [19]. A cross-sectional study reported that individuals with low sedentary behavior and higher levels of physical activity had a lower prevalence of periodontitis activity [20]. Futhermore,in clinical research, a study of the adult population in Brazil, found that leisure physical activity was the only domain with the potential of reflecting the benefits of physical activity on oral health.

Older adults globally face a burden of age-related oral health deterioration. Despite the growing aging demographic [21], oral health in older adults has received less attention and fewer related public health and intervention measures [22]. Oral health not only influences oral conditions but also impacts systemic health. Improving oral health has been linked to better outcomes in several systemic diseases, including cognitive function, hypertension, diabetes, and pneumonia [23]. For older people especially, there is a direct link between oral and general health, with oral health being both a predictor and marker of frailty [24]. Therefore, the oral health needs of older adults need to be paid extra attention. Concurrently, the paucity of robust observational studies investigating the association between serum 25(OH)D levels, physical activity patterns, and oral care needs in aging populations has driven this investigation [4, 25]. We aimed to study whether vitamin D and physical activity are associated with oral health outcomes in older adults. Thus, this study aims to investigate the independent and combined association of serum 25(OH)D levels and physical activity on oral care needs among older adults in the United States, utilizing a nationally representative sample. This study also aims to examine the potential mediating effects of 25(OH)D on the relationship between physical activity and oral health outcomes. We hypothesized that high serum 25(OH)D levels and physical activity would be linked to a reduced risk of oral care need among older adults in the United States. The results from this study provide valuable insights for oral public health policy.

Method

Study design and data source

This cross-sectional study obtained data from the five cycles of the National Health and Nutrition Examination Survey (NHANES) from 2009 to 2018. NHANES has been a continuous multiphase nationally representative survey managed by the National Center for Health Statistics (NCHS) and provides a comprehensive assessment of the health and nutritional status of the US population living in all 50 states and the District of Columbia. NHANES' data aims to enhance US population health by promoting patient treatment and public policy support for health changes. The NCHS Institutional Review Board (IRB) approved the NHANES study protocol, and each participant provided written informed consent. The current study did not require informed consent or IRB approval because it used secondary data.

Study participants

A total of 6509 participants aged 60 years and older were included from the five cycles from 2009–2010, 2011–2012, 2013–2014, 2015–2016, and 2017–2018. All participants were divided into yes (n = 3174) and no (n = 3335). The yes group consisted of those who recommended oral

care needs. Participants in the no group were not recommended for oral care needs. Pregnant women, those under the age of 60, those who did not undergo a complete oral examination, and those with missing covariate information were excluded.

Study measures

Oral care needs

Oral care needs were assessed using the Overall Recommendation for Care, which was provided after an oral examination. Similar assessment and classification were performed in a previous study [26].The oral examinations on individuals aged over 30 were performed by certified dentists (health technologists who were assigned to conduct the oral health examinations), who reported the clinical information on oral health topics, including teeth number, root caries, crown caries, dental sealants, and recommendations for dental care. Dental care recommendations include those of continue your routine care, see a dentist at your earliest convenience, see a dentist within the next two weeks, and see a dentist immediately.

Serum 25(OH) levels

The serum concentrations of 25-hydroxyvitamin D2 and 25-hydroxyvitamin D3 were quantitatively measured (nmol/L) using high-performance liquid chromatography coupled with tandem mass spectrometry. Similar assessment was performed in a previous study [27]. Blood was collected from participants aged 1 year and older by a phlebotomist, most assays were completed in 35 laboratories across the United States. The NCHS Ethics Review Board (ERB) ensures that research involving human participants protects the rights and welfare of study participants and conforms to U.S. federal regulations.

Physical activity

Physical activity and health-related variables were collected from Questionnaire Data of NHANES, these questions in the Questionnaire were asked, in the home, by trained interviewers using the Computer-Assisted Personal Interview (CAPI) system.

The Global Physical Activity Questionnaire (GPAQ) was used to assess the levels of physical activity, it has been proven that GPAQ has a higher level of validity and reliability [28]. Key variables included vigorous and moderate recreational activities. Vigorous activity was defined as participating in sports, fitness, or recreational activities that significantly increase breathing or heart rate, such as running or playing basketball, for at least 10 min in a typical week. Moderate activity refers to activities like brisk walking, bicycling, swimming, or volleyball that slightly increase breathing or heart rate, also performed for a minimum of 10 min in a typical week.

Clinical measures

Elaborate in more detail in the assessment of hypertension using Blood Pressure & Cholesterol Questionnaire (BPQ) and diabetes using Diabetes Questionnaire (DIQ). Data on oral hygiene habits were collected from Oral Health Questionnaires (OHQ). Participants who used floss or other oral hygiene tools in addition to brushing were categorized as having good oral hygiene habits, while those who did not were defined as having poor oral hygiene habits. Similar assessment was performed in a previous study or previous studies [29, 30].

Covariates

The self-reported covariates includes age, sex, race/ethnicity, education level, body mass index (BMI), and household income-to-poverty ratio (PIR). Race/ethnicity was categorized into four categories, namely Hispanic, Non-Hispanic White, Non-Hispanic Black, and Other. Education level was defined as 12th grade, high school grade or equivalent, some college, and college graduate or above. BMI was calculated as weight (kg) divided by height squared (m^2), and categorized into the following groups: less than 18.5, 18.5–24.9, −25.0–29.9, −30.0–34.9, −35.0–39.9 and greater than 40.0. PIR was divided into three categories, less than 1, 1–3, and greater than 3. Similar assessment and classification were performed in a previous study or previous studies [31].

Statistical analysis

Following the NHANES analysis guidelines, all analyses used sampling weights to account for the complex NHANES survey design to ensure the nationwide representativeness of the results. The Shapiro–Wilk test was used to assess the normality of continuous data, ensuring it was distributed normally. The significance difference between yes or no groups for recommendation of oral care needs was examined using the independent t-test and Mann–Whitney U-test for continuous variable, and Chi-square test for categorical variables. The weighted multivariate logistic regression model was used to examine the relationship between 25(OH)D levels, physical activity status, and oral care needs. Model 1 was unadjusted, while model 2 was adjusted for sex age, race, education level, PIR, BMI, diagnosis of hypertension, diabetes, and oral hygiene habits. The no group used as reference.. We employed RCS regression models to further explore the dose–response between 25(OH)D levels and oral care needs.

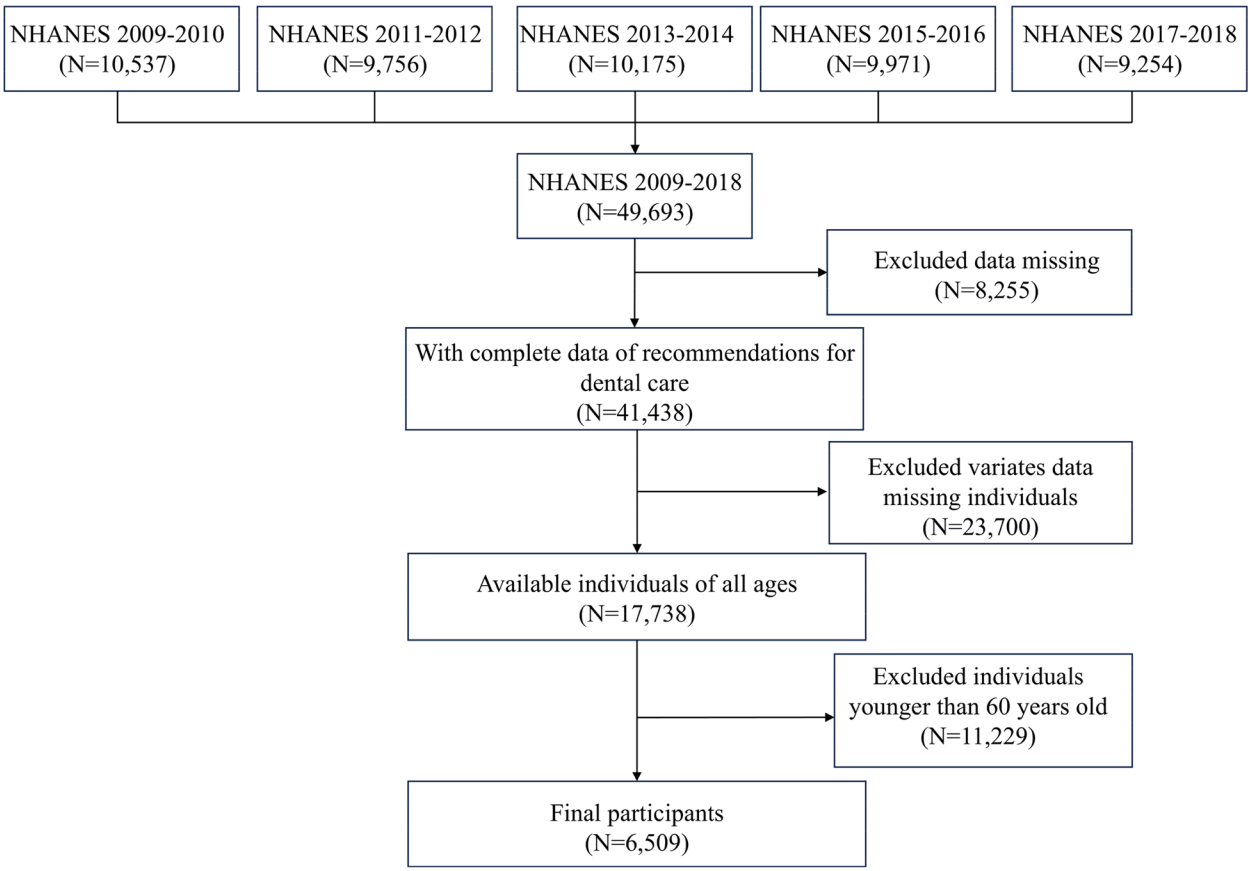

Fig. 1 Flow chart for screening subjects. Data from NHANES 2009 to 2018

To ascertain whether the combined effect of 25(OH) D and physical activity was greater than the cumulative effect of the two on the additive and multiplicative scales, this study added more interaction factors. The additive scale interaction was evaluated by calculating relative excess risk due to interaction (RERI), synergy index (SI), and attributable proportion (AP). Furthermore, by mediation analysis, this study preliminarily investigated the possible mechanism of 25(OH)D between oral health issues and physical activity. Propensity score matching (PSM) was employed to enhance the reliability and robustness of the results. We used the 1:1 nearest neighbor matching method to conduct PSM, with age, race, sex, education level, PIR, and oral hygiene habits selected as matching variables.

All statistical analyses were conducted using R 4.3.3, and a *P* value of less than 0.05 was considered statistically significant.

Results

Flow of study participants

The flow of the study sample is presented in Fig. 1. Of 49,693 participants, 6509 were included in the present study. After excluding 8,255 participants with missing data, 41,438 had complete data for dental care recommendations. Then, 23,700 were excluded due to missing variates data, leaving 17,738 individuals of all ages. Finally, 11,229 individuals younger than 60 years old were excluded, resulting in 6509 final participants for the study.

Out of 6509 participants, 3174 were recommended for oral care needs and 3335 not recommended for it.

Baseline characteristics

Basic characteristics of the study participants are presented in Table 1. The need for oral care was lower among females, non-Hispanic whites, those with higher education, higher PIR, non-diabetics, and individuals with better oral hygiene habits. The specific key differences data are described as follows:

Sociodemographics: The average age of participants was 69.4 years, and most were females (53.9%), and belongs to the no group (58.1%). Educational attainment differed significantly ($P < 0.001$): 31.6% had some college/AA degrees (vs. 27.8% in a no group), while only 22.42% held college degrees (vs. 35.9%). Income disparity was pronounced: 42.3% of the yes group had PIR > 3 (vs. 59.1%; $P < 0.001$).

Table 1 Basic characteristics of study participants

Characteristics	Total population *N* = 6509	Recommendation for oral care needs		*P*
		Yes *N* = 3174 (%?)	No *N* = 3335 (%?)	
Sex, %				
Male	46.1	52.2	41.9	< 0.001
Female	53.9	47.8	58.1	
Age in years, mean ± SD	69.4 ± 0.1	69.3 ± 0.2	69.5 ± 0.2	0.31
Race, %				
Hispanic	7.4	7.5	7.3	0.40
Non-Hispanic white	78.7	78.2	79.1	
Non-Hispanic black	8.1	7.9	8.2	
Other	5.9	6.4	5.4	
Education level, %				
Less than 12th grade	15.8	20.0	13.0	< 0.001
High school grade/equivalent	24.4	26.0	23.3	
Some college/AA degree	29.4	31.6	27.8	
College graduate/above	30.4	22.4	35.9	
PIR, %				
< 1	9.9	13.7	7.2	< 0.001
1–3	37.9	44.0	33.7	
> 3	52.2	42.3	59.1	
BMI in kg/m^2, %				
< 18.5	1.1	1.3	0.9	< 0.001
18.5–24.9	23.5	28.7	18.6	
25–29.9	36.0	37.7	34.3	
30–34.9	23.6	20.1	26.9	
35–39.9	10.0	7.7	12.2	
≥ 40	5.9	4.5	7.2	
Hypertension, %				
No	42.4	39.6	44.3	< 0.01
Yes	57.6	60.4	55.7	
Diabetes, %				
No	78.3	75.4	80.4	< 0.005
Yes	21.7	24.6	19.6	
Good oral hygiene, %				
No	33.3	37.2	30.6	< 0.005
Yes	66.7	62.8	69.4	
Vigorous recreational activity, %				
No	88.3	91.2	86.4	< 0.001
Yes	11.7	8.8	13.6	
Moderate recreational activity, %				
No	57.3	63.1	53.4	< 0.001
Yes	42.7	36.9	46.6	
25(OH)D in nmol/L, mean ± SD	82.2 ± 0.8	77.1 ± 0.9	85.8 ± 0.9	< 0.001

Abbreviations: *25(OH)D* 25-hydroxyvitamin D, *PIR* poverty-income ratio, *BMI* body mass index

Race: Hispanic including Mexican Americanand other Hispanic; others including Multi-Racial

Clinical Data: BMI distribution diverged ($P < 0.001$): 37.7% were overweight (25–29.9 kg/m^2; vs. 34.3%), but fewer had class II/III obesity (BMI ≥ 35; 12.2% vs. 19.4%). Comorbid hypertension (60.4% vs. 55.7%; $P < 0.01$) and diabetes (24.7% vs. 19.6%; $P < 0.01$) were elevated in the yes group. Physical inactivity correlated strongly: 91.2%

Table 2 Association of 25(OH)D and physical activity with oral care needs

Characteristics	Model 1		Model 2	
	OR (95% CI)	*P*	OR (95% CI)	*P*
25(OH)D	0.99 (0.99—0.99)	< 0.001	0.99 (0.99—1.00)	0.04
Vigorous recreational activity				
No	Reference		Reference	
Yes	0.62 (0.49—0.77)	< 0.001	0.70 (0.53—0.93)	0.01
Moderate recreational activity				
No	Reference		Reference	
Yes	0.67 (0.56—0.80)	< 0.001	0.95 (0.81—1.10)	0.49

Abbreviations: *25(OH)D* 25-hydroxyvitamin D, *OR* odd ratio, *CI* confidence interval, *PIR* poverty-income ratio, *BMI* body mass index

Model 1: unadjusted

Model 2: adjusted for sex, age, race, education level, PIR, BMI, diagnosis of hypertension, diabetes and oral hygiene habits. All estimates accounted for complex survey designs

reported no vigorous activity (vs. 86.4%; $P<0.001$), and 63.1% lacked moderate activity (vs. 53.4%; $P<0.001$).

Biomarker Levels: Mean serum 25(OH)D was significantly lower in the yes group (77.1 nmol/L vs. 85.8; $P<0.001$).

Association of 25(OH)D levels and physical activity with oral care needs

Table 2 presents the associations between high serum 25(OH)D, physical activity, and oral care needs. The unadjusted model showed that high serum 25(OH)D levels showed a significant inverse correlation with oral care needs (OR = 0.99, 95% CI = 0.99—1.00, $P<0.001$). Both vigorous (OR = 0.62, 95% CI = 0.49—0.77, $P<0.001$) and moderate activities (OR = 0.67, 95% CI = 0.56—0.80, $P<0.001$) were linked to reduced requirements (per 39% and 33%). The adjusted model demonstrated that each unit increase in serum 25(OH)D levels was associated with 1% lower odds of requiring oral care needs (OR = 0.99, 95% CI = 0.99—0.99, $P=0.04$) after adjusting for race, age, education level, sex, PIR, BMI, diabetes, hypertension, and oral hygiene habits. Participation in vigorous recreational activity reduced oral care needs by 30% (OR = 0.70, 95% CI = 0.53—0.93, $P=0.01$). Furthermore, RCS analysis revealed a dose–response relationship between 25(OH)D levels and oral care needs ($P<0.001$) (Fig. 2).

Joint association of 25(OH)D levels and physical activity with oral care needs

In joint analyses, individuals with low 25(OH)D levels and inadequate physical activity served as controls. The weighted multivariate logistic regression analysis model indicated the following (Table 3), in vigorous recreational

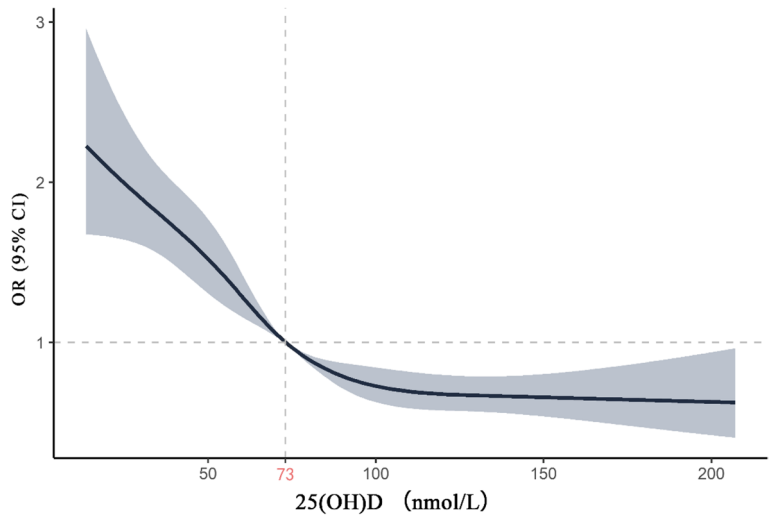

Fig. 2 Dose–response relationship between 25(OH)D and oral care needs

Table 3 Joint association of 25(OH)D and physical activity and oral care needs

Characteristics			OR (95% CI)[a]	*P*
25(OH)D	Low level	No vigorous recreational activity	Reference	
		vigorous recreational activity	0.77 (0.53—1.12)	0.18
	High level	No vigorous recreational activity	0.76 (0.58—1.00)	0.05
		vigorous recreational activity	0.49 (0.32—0.74)	< 0.01
25(OH)D	Low level	No moderate recreational activity	Reference	
		moderate recreational activity	0.90 (0.73—1.11)	0.30
	High level	No moderate recreational activity	0.71 (0.53—0.96)	0.02
		moderate recreational activity	0.71 (0.52—0.98)	0.04

Abbreviations: *25(OH)D* 25-hydroxyvitamin D, *OR* odd ratio, *CI* confidence interval, *PIR* poverty-income ratio, *BMI* body mass index

[a] The results were adjusted for sex, age, race, education level, PIR, BMI, diagnosis of hypertension, diabetes and oral hygiene habits. All estimates accounted for complex survey designs

Table 4 Interactive effects of 25(OH)D and physical activity on oral care needs

Characteristics		Interactive effects (95% CI)			
Vigorous recreational activity	Additive effects	Model 1		Model 2	
		Estimate/OR (95% CI)	*P*	Estimate/OR (95% CI)	*P*
	RERI	%1.%2 (−0.98—0.99)	/	0.05 (−14.3—14.38)	/
	AP	%1.%2 (−0.21—0.21)	/	%1.%2 (−0.22—0.231)	/
	SI	−0.06 (−3.19—3.07)	/	0.59 (−3.07—4.251)	/
	Multiplicative effect	1.0 (0.99—1.01)	1.00	1.00 (0.99—1.006)	0.61
Moderate recreational activity	Additive effects				
	RERI	1.0 (−0.71—0.72)	/	0.06 (−1.01—1.13)	/
	AP	1.0 (−0.25—0.26)	/	1.0 (−0.26—0.26)	/
	SI	0.21 (−0.42—0.85)	/	0.58 (−0.15—1.32)	/
	Multiplicative effect	1.0 (1.00—1.00)	0.86	1.00 (0.99—1.00)	0.57

Abbreviations: *25(OH)D* 25-hydroxyvitamin D, *OR* odd ratio, *CI* confidence interval, *PIR* poverty-income ratio, *BMI* body mass index, *RERI* relative excess risk due to interaction, *SI* synergy index, *AP* attributable proportion

Model 2: adjusted for sex, age, race, education level, PIR, BMI, diagnosis of hypertension, diabetes, and oral hygiene habits. All estimates accounted for complex survey designs

activity group, individuals with high 25(OH)D levels and inadequate vigorous recreational activity showed 24% lower odds of oral care needs (OR = 0.76, 95% CI = 0.58—0.97, $P < 0.05$) and those with high 25(OH)D levels and vigorous recreational activity had stronger 51% risk reduction (OR = 0.49, 95% CI = 0.32—0.74, $P < 0.01$) compared with the control group. However, there was no relationship between low 25(OH)D levels and vigorous recreational activity, and less need for oral care (OR = 0.77, 95% CI = 0.53—1.12, $P = 0.18$). In moderate recreational activity group, when compared to the combination of low 25(OH)D levels and inadequate physical activity, participants with high 25(OH)D levels and inadequate vigorous recreational activity (OR = 0.71, 95% CI = 0.53—0.96, $P = 0.02$), and high 25(OH)D levels and vigorous recreational activity (OR = 0.71, 95% CI = 0.52—0.98, $P = 0.04$) both had 29% reduction of oral care needs. These findings suggested the significant roles of 25(OH)D and recreational activities in the prevention and treatment of oral diseases.

In addition, this study conducted an interaction test to analyze the interaction between 25(OH)D and physical activity and oral care needs. No significant multiplicative or additive interaction was found between 25(OH)D and physical activity on oral care needs (Table 4). Considering the potential impact of physical activity on levels of 25(OH)D, additional mediation analysis was conducted to infer whether 25(OH)D mediates the association between physical activity and oral health issues, the results indicated that (Table 5), in the correlation between vigorous recreational activity and oral care needs, the mediating proportions of 25(OH)D was 19%, while this ratio reached 28% when the variable was moderate recreational activity.

Table 5 The mediation analysis of 25(OH)D on the association between physical activity and oral problems

Mediators	Indirect effect		Direct effect		Total effect		Proportion of mediation
	$\beta_{indirect}$ (95% CI)	*P*	β_{direct} (95% CI)	*P*	β_{total} (95% CI)	*P*	
	Vigorous recreational activity						
25(OH)D	−0.02 (−0.03—0.01)	< 0.001	−0.08 (−0.11—0.03)	< 0.001	−0.10 (−0.13—0.05)	< 0.001	18.8%
	Moderate recreational activity						
25(OH)D	−0.02 (−0.02—0.01)	< 0.001	−0.04 (−0.07—0.02)	< 0.001	−0.06 (−0.09—0.04)	< 0.001	28.9%

Sensitivity analyse

Following propensity score matching (PSM), 6348 individuals with 1:1 matches were included in the analysis (Table 6. Table 6 is placed at the end of the text.). The results of weighted logistics regression indicated that higher levels of 25(OH)D might reduce oral care needs (OR = 0.99 per nmol/L, 95% CI = 0.99–0.99, $P < 0.001$) (Table 7). In addition, the results showed that gdults engaging in moderate recreation exhibited 30% lower odds of requiring oral care (OR = 0.70, 95% CI, 0.59–0.83, $P < 0.001$). Individuals who engaged in adequate vigorous recreational activity correlated with 35% risk reduction (OR = 0.65, 95% CI = 0.52–0.82, $P < 0.001$), and this association persisted after adjusting for confounding factors OR = 0.71, 95% CI = 0.53–0.95, $P = 0.02$). RCS analysis revealed a dose–response relationship between 25(OH)D and oral care needs (Fig. 3).

Discussion

This study investigated the independent and combined effects of 25(OH)D and physical activity on oral care needs in the older population Our findings suggest that higher levels of 25(OH)D and regular physical activity were both associated with a reduced risk of oral care needs after controlling for conventional risk factors such as diabetes, hypertension, and oral hygiene practices. Specifically, higher levels of 25(OH)D concentration (> 73 nmol/L) and vigorous recreational activity were associated with a reduced risk of oral care needs. This suggests the possible roles of 25(OH)D and physical activity in the treatment and prevention of oral diseases.

Vitamin D, measured through serum 25(OH)D levels, is a well-established marker of vitamin D status in the body [32, 33]. Epidemiological studies have demonstrated that low 25(OH)D levels are linked to a higher risk of major chronic and acute conditions, including cancer, autoimmune diseases, cardiovascular disease, infections, and all-cause mortality [17]. In the previously mentioned study on 25(OH)D and periodontitis in the Norwegian population [16]. the age grouping did not reflect the correlation with the severity of periodontitis, these results may be because most of their samples are under 60 years old, and patients over 60 years old are lost to follow-up because of weakness or the participation rate of examination is low. Considering the screening cost of 25(OH)D, it is more economical to identify people at high risk of vitamin D deficiency, making targeted 25(OH)D measurement more cost-effective [10]. We found that when the concentration of 25(OH)D was 73 nmol/l, the benefit efficiency of this preventive effect began to plateau after fully adjusting for confounders in this study. Therefore, measuring 25(OH)D levels in individuals at risk of deficiency may prove to be both an economically efficient and effective public health strategy.

Physical activity is another well-known determinant of health, with a wide range of benefits for various conditions, including cancer, diabetes, stroke, and cognitive impairment. It is estimated that if the global population were more active, 4–5 million deaths could be prevented annually [34]. In our study, we found that participants with high levels of 25(OH)D with vigorous recreational activities had the lowest risk of oral care needs. After PSM analysis and adjusting for confounding factors, vigorous recreational activity was linked to lower oral care needs, the decline of correlation degree indicates that there may be effect-mediated dilution, for example, physical activity may indirectly lead to the deterioration of oral hygiene habits of older adults, thus directly affecting the oral hygiene outcome. Mediation analysis indicated that 25(OH)D partially mediates the relationship between physical activity and oral health. This suggests that regular physical activity may contribute to better oral health by increasing 25(OH)D levels, which in turn helps reduce the risk of oral diseases. However, we did not observe a multiplicative or additive effect between 25(OH)D and physical activity, suggesting that these factors independently contribute to oral health, rather than having a combined or enhanced effect. However, the related reports on the impact of recreational physical activity and work physical activity on the incidence of

Table 6 Weighted characteristics of study participants

Characteristics	Total population N = 6348	Recommendation for oral care needs		*P*
		Yes N = 3174 (%?)	No N = 3174 (%?)	
SEX, %				
Male	48.3	52.2	45.4	< 0.001
Female	51.7	47.8	54.6	
Age in years, mean ± SD	69.3 ± 0.2	69.3 ± 0.2	69.3 ± 0.2	0.80
Race, %				
Hispanic	7.3	7.5	7.1	0.17
Non-Hispanic white	78.5	78.2	78.8	
Non-Hispanic black	8.2	7.9	8.5	
Other	6.0	6.4	5.7	
Education level, %				
Less than 12th grade	16.6	20.0	14.1	< 0.001
High school grade/equivalent	25.2	26.0	24.6	
Some college/AA degree	30.0	31.6	28.8	
College graduate/above	28.2	22.4	32.5	
PIR, %				
< 1	10.3	13.7	7.8	< 0.001
1–3	39.6	44.0	36.4	
> 3	50.1	42.3	55.8	
BMI in kg/m^2, %				
< 18.5	24.0	30.8	19.3	< 0.001
18.5–24.9	1.1	1.4	0.9	
25–29.9	35.6	40.5	33.5	
30–34.9	23.7	21.6	27.3	
35–39.9	9.9	0.8	12.1	
≥ 40	5.7	4.8	6.8	
Hypertension, %				
No	42.1	39.6	43.9	0.01
Yes	57.9	60.4	56.1	
Diabetes, %				
No	77.8	75.4	79.6	0.01
Yes	22.2	24.7	20.4	
Good oral hygiene, %				
No	34.0	37.2	31.5	0.01
Yes	66.0	62.8	68.5	
Vigorous recreational activity, %				
No	88.8	91.2	87.1	< 0.001
Yes	11.2	8.8	13.0	
Moderate recreational activity, %				
No	58.1	63.1	54.5	< 0.001
Yes	41.9	37.0	45.6	
25(OH)D in nmol/L, mean ± SD	81.7 ± 0.8	77.1 ± 0.9	85.1 ± 0.9	< 0.001

The data are provided as mean ± SD for continuous variables and as percentages for categorical variables. *25(OH)D* 25-hydroxyvitamin D, *OR* Odd Ratio, *CI* Confidence interval, *PIR* Poverty-Income Ratio, *BMI* Body Mass Index

Race: Hispanic including Mexican American and other Hispanic; others including Multi-Racial

Table 7 Association of 25(OH)D and physical activity and oral care needs

Characteristics	Model 1		Model 2	
	OR (95% CI)	*P*	OR (95% CI)	*P*
25(OH)D	0.99 (0.99—0.99)	< 0.001	0.99 (0.99—1.00)	0.48
Vigorous recreational activity				
No	Reference		Reference	
Yes	0.65 (0.52—0.82)	< 0.001	0.71 (0.53—0.95)	0.02
Moderate recreational activity				
No	Reference		Reference	
Yes	0.70 (0.59—0.83)	< 0.001	0.95 (0.81—1.11)	0.50

Abbreviations: *25(OH)D* 25-hydroxyvitamin D, *OR* odd ratio, *CI* confidence interval, *PIR* poverty-income ratio, *BMI* body mass index

Model 1: unadjusted

Model 2: adjusted for sex, age, race, education level, PIR, BMI, diagnosis of hypertension, diabetes and oral hygiene habits. All estimates accounted for complex survey designs

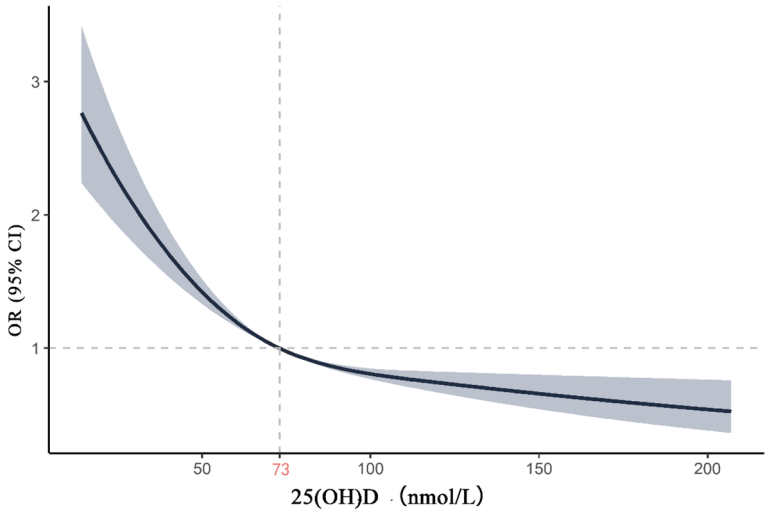

Fig. 3 Dose–response relationship between 25(OH)D and oral care needs

periodontitis in the general population and athletes are not completely consistent [35, 36]. In this study, we specifically focused on recreational activities, but the impact of work-related physical activity on oral health was not assessed. Given that older adults tend to have less work-related physical activity, further research is needed to determine whether including this type of activity would alter the relationship between physical activity and oral care needs.

Our study has several limitations. First, although we excluded type 2 diabetes, we could not exclude the factors of smoking and drinking status due to the high level of missing information. Second, we are unable to ascertain the causative relationship between these factors because the cross-sectional design of this study is limited to assessing the link at a particular time point. Finally, the proportion of healthy individuals in the database is high, which overlooks the oral care needs of disabled people. Considering that a considerable number of disabled people have limited physical activity and impaired abilities in sports, oral health maintenance, and medical communication, it can be suggested based on our conclusions that providing them with additional vitamin D is necessary. More research should be conducted to promote the development of health care and prevention for special populations.

Conclusion

This study investigated the independent and combined associations of serum 25-hydroxyvitamin D [25(OH)D] levels physical activity and with oral care needs among older US adults. Our results demonstrated three principal findings: Adequate vigorous recreational activity was associated with a 35% reduction in oral care needs.

There is a dose–effect relationship between the increase of serum 25(OH)D level and the decrease of oral care demand risk. Participants combining high 25(OH)D (≥ 50 nmol/L) and regular vigorous activity exhibited the strongest protection, with 51% lower odds versus those with low 25(OH)D and inactivity. These findings suggest that improving 25(OH)D levels and encouraging physical activity, such as increased sun exposure and outdoor exercise, may play significant roles in the prevention and management of oral diseases in older adults.

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Authors' contributions
JK-G: data analysis-project analysis-result proofreading&writing-original draft. L-L: data analysis-writing-&review. JX-Z and Y-W: review&editing. X-K: code operation-data analysis-&data management. XY-S: conceptualization and funding acquisition. All authors read and approved the final manuscript.

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Data availability
Ethics approval and consent to participate National Health and Nutrition Examination Survey (NHANES) is a publicly available data set and all participants in NHANES provide written informed consent, consistent with approval from the National Center for Health Statistics Research Ethics Review Board (NCHS ERB) (protocol#2005–06 for NHANES cycle 2009–2010,protocol #2011–17 for NHANES cycles 2011–2012,2013–2014,2015–2016,protocol #2011–17 and protocol #2018–01 for NHANES cycle 2017–2018). Nutrition Examination Survey (NHANES). For information on accessing the data, see https://wwwn.cdc.gov/nchs/nhanes/.

Declarations

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Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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Publisher's Note

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