Vitamin D status in active duty Navy military personnel: a systematic review

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ABSTRACT

Objectives Active duty Navy military personnel are prone to vitamin D deficiency due to an occupational environment detrimental to sunlight exposure. The main objective of this systematic review is to provide a worldwide overview of vitamin D status in this population.

Methods The Condition, Context, Population (CoCoPop) mnemonic was used to define the inclusion criteria (vitamin D status; all contexts; active duty Navy military personnel). Studies with recruits or veterans were excluded. Scopus, Web of Science and PubMed/Medline databases were searched from inception to 30 June 2022. Joanna Briggs Institute and Downs & Black checklists were used for quality assessment and data were synthesised in narrative and tabular formats.

Results Thirteen studies published between 1975 and 2022 and conducted in northern hemisphere Navies, including mainly young and male service members, were included. The prevalence of vitamin D deficiency was globally reported as significant. Nine studies included a total of 305 male submariners who performed 30–92 days submarine patrol and reported the effect of sunlight deprivation in the decrease of vitamin D levels.

Conclusions This new systematic review underlines the high prevalence of vitamin D deficiency in the Navy, especially in submariners, and the need to implement measures to prevent vitamin D deficiency. Serum 25(OH)D data available and the heterogeneity of the studies limited a pooled analysis. Most studies included only submariners, which may limit generalisability to all active duty Navy military personnel. Further research on this topic should be promoted.

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WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Vitamin D deficiency is a major public health problem worldwide.
⇒ Despite the adverse occupational context, knowledge about active duty Navy military personnel's vitamin D status is lacking.

WHAT THIS STUDY ADDS

⇒ The prevalence of vitamin D deficiency is significant in the Navy, especially in submariners.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ Measures to reduce the prevalence of vitamin D deficiency such as periodic vitamin D assessment should be implemented.
⇒ Future research may use the available military blood banks.

INTRODUCTION

Active duty Navy military personnel are particularly at risk of vitamin D deficiency, essentially due to an occupational environment that limits sunlight exposure (eg, protective military clothing, indoor and/or shift work, high latitude field duty).[1] Submariners are even more prone to vitamin D deficiency due to the total absence of sunlight exposure and reduced access to perishable food.[2–4]

Mainly because of the increasing attention to vitamin D in the popular and medical literature and better availability of assay procedures, a large increase in the incidence of vitamin D deficiency was observed in US Navy active duty military personnel serving between 1997 (1 case in 393 307 service members (SM)) and 2015 (543 cases in 322 784 SM), with a total of 2968 new diagnoses in this time frame.[5] In a previous study including Portuguese Navy active duty military personnel (n=555; 2014–20), the prevalence of vitamin D deficiency was 37.1%.[6]

In line with this trend, the number of US military active duty SM prescribed oral supplements solely of vitamin D increased 55-fold (from 0.3 to 18.3 SM/1000 SM) between 2005 and 2013; over this 9-year period 14 283 Navy active duty SM were prescribed oral supplements solely of vitamin D.[7 8] This fact draws attention to the value of vitamin D food fortification that should also be considered in the context of the Navy.[9 10]

Vitamin D plays an essential role in the skeletal and non-skeletal health of active duty Navy military personnel. This is apparent even in something as simple as acute pharyngitis in otherwise healthy SM, but also in autoimmune disorders in general.[11 12] Vitamin D has significant biological activity on the innate and adaptive immune systems, and is linked to the incidence and severity of multiple immune-related diseases including autoimmune disorders (eg, psoriasis, multiple sclerosis, rheumatoid arthritis, type 1 diabetes) and infectious diseases.[13] Preventing vitamin D deficiency is important to assure the readiness of active duty Navy military personnel, which is determined by physical fitness, nutritional status and the ability to remain free of injury and illness.[14]

Recognising the known adverse occupational environment for vitamin D status, on the one hand, and the importance of vitamin D for health, on the other, the objective of the present systematic review

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is to provide a worldwide overview of the prevalence of vitamin D deficiency, insufficiency and sufficiency in active duty Navy military personnel.

METHODS

This systematic review was registered on PROSPERO (CRD42022287057) and follows the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 statement.[15]

The Condition, Context, Population (CoCoPop) mnemonic (Condition: vitamin D status (serum 25-hydroxyvitamin D (25(OH)D); vitamin D deficiency defined as 25(OH)D <20 ng/mL or <50 nmol/L, insufficiency as 25(OH)D ≥20 ng/mL and <30 ng/mL or ≥50 nmol/L and <75 nmol/L, and sufficiency as 25(OH)D ≥30 ng/mL or ≥75 nmol/L, according to the Endocrine Society); Context: not delimited; Population: active duty Navy military personnel) was used to define the inclusion criteria.[16 17] Studies with recruits or veterans were excluded. Full articles unavailable or written in languages other than English, Portuguese, Spanish or French were also excluded.

The literature search was performed according to Peer Review of Electronic Search Strategies guidelines in the Scopus, Web of Science and PubMed/Medline databases from inception to 30 June 2022 using the following search strategy: ("Vitamin D" OR "Vitamin D Deficiency" OR "25-Hydroxyvitamin D 2" OR "Cholecalciferol" OR "Ergocalciferol" OR "Calcifediol" OR "25-hydroxyvitamin D" OR "25-hydroxy vitamin D" OR "25(OH)D" OR "25OHD") AND ("military personnel" OR "military" OR "Navy personnel" OR "sailor*" OR "marine*" OR "submariner*" OR "coast guard") for Scopus and Web of Science databases and ("Vitamin D"(MeSH) OR "Vitamin D Deficiency"(MeSH) OR "25-Hydroxyvitamin D 2"(MeSH) OR "Cholecalciferol"(MeSH) OR "Ergocalciferols"(MeSH) OR "Calcifediol"(MeSH) OR "25-hydroxyvitamin D" OR "25-hydroxy vitamin D" OR "25(OH)D" OR "25OHD") AND ("Military Personnel"(MeSH) OR "military" OR "Navy personnel" OR "sailor*" OR "marine*" OR "submariner*" OR "coast guard") for the PubMed/Medline database.[18 19]

Two authors (MH and DR) independently screened all records reading first the title and abstract, then the full text. Data extraction was then performed using a standard extraction form including general information (authors; year of publication), study characteristics (research design; study setting – latitude, season and country), population characteristics (sample size; distribution by age, gender, rank or years of military service, ethnicity, and other relevant variables for vitamin D status available), Navy military occupational setting (warship or submarine type; ashore vs onboard; indoor vs outdoor), vitamin D data (method/assay used for measurement of 25(OH)D; mean (SD), median (IQR), and/or range of serum 25(OH)D concentrations; cut-off points for vitamin D deficiency, insufficiency and sufficiency; prevalence of vitamin D deficiency, insufficiency and sufficiency) and, if applicable, intervention characteristics (intervention, groups, outcome). They also conducted the critical appraisal of all studies using the Joanna Briggs Institute's critical appraisal checklist for studies reporting prevalence data (observational epidemiological studies reporting prevalence) and the Downs & Black checklist (randomised or non-randomised experimental studies).[20 21] Disagreements were resolved by consensus, with a third author (ES-L) acting as arbitrator when required.

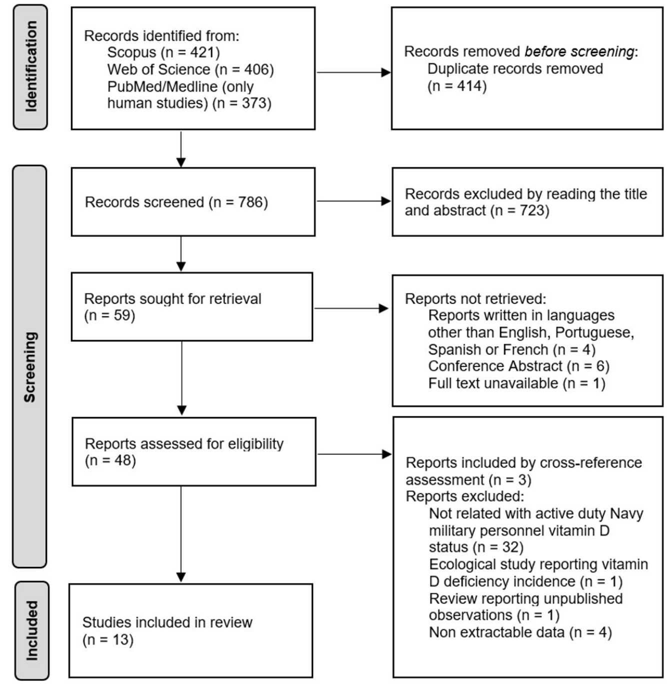

Figure 1 PRISMA 2020 flow diagram for systematic review which included searches of databases and registers only.

RESULTS

Thirteen studies reporting serum 25(OH)D data from active duty Navy (and Marines, as they are commonly included in the Navy setting) military personnel published between 1975 and 2022 were included in the systematic review.[2–4 6 11 12 22–28] Some studies with active duty Navy military personnel and serum 25(OH)D measurements were excluded from the analysis because serum 25(OH)D data were not extractable (n=4) or the full text was not available (n=1).[14 29–32] An ecological study reporting the incidence of vitamin D deficiency and a review reporting unpublished observations were also excluded.[5 33] Figure 1 shows the PRISMA 2020 flow diagram for this systematic review.[15]

The general information and characteristics of the studies (country, latitude and season) are shown in table 1 in order of year of publication. The description of the Navy military occupational setting (table 2), population characteristics (table 3) and vitamin D data (table 4) are summarised below. The prevalence of vitamin D deficiency was globally reported as significant (between 29.1% and 37.1%), despite the country or calendar year.[6 11 22] Only two studies had an experimental design.[4 28] Duplessis *et al* investigated the efficacy of 400 IU daily vitamin D supplementation on vitamin D homeostasis in submariners during a 76-day patrol and concluded that 400 IU of daily vitamin D supplementation failed to arrest the observed vitamin D decrements sustained underway.[4] Gasier *et al* determined the efficacy of higher doses of supplemental vitamin D (1000 and 2000 IU/day) on maintaining serum 25(OH)D levels in submariners during a 3-month patrol and concluded that, although the greatest changes in mean serum 25(OH)D levels were observed in the group of submariners supplemented with 2000 IU/day, there was no significant advantage in those supplemented with 1000 or 2000 IU/day compared with those not given supplements.[28] Only one study reported the sample distribution by rank or years of military service (2 officers, 4 midshipmen and 24 enlisted men).[25]

Table 1 General information and characteristics (country, latitude and season) of the included studies

Ref	Title	Authors	Year of publication	Journal	Country	Latitude	Season
23	Studies of vitamin D deficiency in man	Preece *et al*	1975	Q J Med	UK	ND	ND
25	Effect of a 68-day submarine patrol on serum 25-hydroxyvitamin D levels in healthy men	Gilman *et al*	1982	Int J Vitam Nutr Res	USA	ND	ND
24	Effects of the submarine environment on renal-stone risk factors and vitamin D metabolism	Dlugos *et al*	1995	Undersea and Hyperbaric Medicine	USA	ND (Southeastern USA)	Summer and autumn
4	Vitamin D supplementation in underway submariners	Duplessis *et al*	2005	Aviat Space Environ Med	USA	47.7°N (home port in Kitsap Naval Base, Bangor, Washington) and 21.3°N (6-day port call in Pearl Harbour, Hawaiian Islands)	Winter and spring (January to April)
2	Effects of a prolonged submersion on bone strength and metabolism in young healthy submariners	Luria *et al*	2010	Calcif Tissue Int	Israel	ND	ND
26	Effects of seasonal vitamin D deficiency and respiratory acidosis on bone metabolism markers in submarine crewmembers during prolonged patrols	Holy *et al*	2012	J Appl Physiol	France	ND	Summer and autumn (September to November), and winter and spring (February to April)
12	Preclinical erum 25-hydroxyvitamin D levels and risk of type 1 diabetes in a cohort of US military personnel	Munger *et al*	2013	Am J Epidemiol	USA	North: states at latitudes higher than 41–42°; Middle: states at latitudes between 37° and 41–42°; South: states at latitudes below ~37°; Outside the continental USA, Alaska, Hawaii, and Puerto Rico	Winter, spring, summer and autumn
27	Changes in vitamin D and matrix metalloproteinase-9 in submariners during a submerged patrol	Baker *et al*	2014	Occup Environ Med	UK	56.0°N (Clyde Naval Base, Faslane, Scotland)	Winter and spring (January to April)
28	The efficacy of vitamin D supplementation during a prolonged submarine patrol	Gasier *et al*	2014	Calcif Tissue Int	USA	47.7°N (Kitsap Naval Base, Bangor, Washington)	Autumn and winter (October to February)
11	Vitamin D levels and monospot tests in military personnel with acute pharyngitis: a retrospective chart review	Maloney *et al*	2014	PLoS One	USA	34.5°N (Camp Lejeune, North Carolina)	Winter, spring, summer and autumn (7September 2010 to 6 July 2011)
3	Energy expenditure and changes in body composition during submarine deployment: a observational study "DasBoost 2–2017"	Rietjens *et al*	2020	Nutrients	Netherlands	ND	ND
22	Low vitamin D states observed in U.S. marines and Navy sailors with early multi-symptom illness	Maloney and Goolkasian	2020	Biomolecules	USA	ND	ND
6	Vitamin D levels in Portuguese military personnel	Henriques *et al*	2022	BMJ Mil Health	Portugal	ND	Winter, spring, summer and autumn

ND, not defined.

Table 2 Description of the Navy military occupational setting in each study

Ref	Warship or submarine type	Ashore vs onboard	Indoor vs outdoor
23	Nuclear submarine, 2-month patrol	Onboard	Indoor
25	Ballistic missile submarine, 68-day patrol	Onboard	Indoor
24	Ballistic missile submarine, 68-day patrol	Onboard	Indoor
4	Ballistic missile submarine, 76-day patrol (49-day submerged underway + 6-day port call + 21-day submerged underway)	Onboard	Indoor
2	Dolphin class submarine (non-nuclear submarine, diesel-electric propulsion, dimensions 57×6.8 x 6.2 m), 30-day patrol	Onboard	Indoor
26	Ballistic missile submarine, 60-day patrol	Onboard	Indoor
12	ND	ND	ND
27	Nuclear-powered ballistic submarine (HMS Vigilant), 85-day patrol	Both	Both
28	Nuclear-powered ballistic submarine, 92-day patrol	Onboard	Indoor
11	ND	ND	ND
3	Submarine, 3-month patrol	Onboard	Indoor
22	ND	ND	ND
6	ND	ND	ND

ND, not defined.

Critical appraisal of observational and experimental studies, respectively, is shown in the online supplemental material.[20 21] Overall, the quality of the studies was good. In the observational studies, the main weaknesses were sample representativeness and size, and the absence of identification of confounding factors while, in the experimental studies, the lack of reporting of intervention adverse events and inaccurate probability values were noted.

Nine studies focused on submariners, including a total of 305 male SM who performed a submarine patrol from 30 to 92 days.[2–4 23–28] All but one study reported the effect of submersion (sunlight deprivation) in the decrease of 25(OH)D levels, even when they were taking any vitamin D supplementation.[28] One study also presented a comparison of summer versus winter patrols, reporting that winter crew members had lower 25(OH)D levels before the beginning of the submarine patrol and

Table 3 Demographic characteristics of the population considered in each study

Ref	Sample size (sample collection period)	Distribution by age (years)	Distribution by gender	Distribution by ethnicity	Distribution by other relevant variables for vitamin D status
23	7	ND	100% men	100% Caucasian	ND
25	30	Mean (range) 25.2 (19–36)	100% men	ND	Daily average vitamin D2 intake: ND
24	30	Range 21–37	100% men	ND	100% no history of renal stones or diseases known to influence calcium metabolism; no sunlight exposure, nor ultraviolet light exposure in 290–320 nm range; no medications, vitamin supplements or alcohol during deployment; standard US Navy diet including milk and breakfast cereals fortified with vitamin D
4	51 (26 experimental group and 25 control group)	Mean (range) 28 (20–46)	100% men	3.9% African American, 96.1% Caucasian	ND
2	32	Mean (SD) 22.8 (3.8)	100% men	ND	100% healthy and no medications or dietary supplements
26	40 (20 winter patrol and 20 summer patrol)	Winter patrol: mean (SD) 31 (2); summer patrol: mean (SD) 29 (1)	100% men	100% Caucasian	100% excellent health, no major diseases nor any injury, no vitamin D supplementation during the last 4 months before submersion and during the experiment. Body weight: ND
12	923 (310 cases and 613 controls)(1997–2009)	Mean (SD) age at first serum sample: cases 20.6 (4.1); controls 20.6 (4.0)	95% men, 5% women	60.5% non-Hispanic white, 21.4% non-Hispanic black, 12.7% Hispanic, 5.4% Other	Latitude of residence at entry into the military: 19.6% North, 31.6% Middle, 42.1% South, 1.1% Outside, 5.6% Missing data
27	90 (49 submariners, 33 controls, 8 support)	Mean (SD) age Submariners 33.4 (6.1); Controls 32.4 (7.6); Support 34.8 (7.3)	ND	ND	32,2% daily vitamin supplements containing 5 mg vitamin D (11 controls, 1 support, 17 submariners). BMI: ND
28	53 (16 placebo group, 20 1000 IU/day group, 17 2000 IU/day group	Mean (SD) age Placebo 28.3 (4.7); 1000 IU/day 29.4 (5.0); 2000 IU/day: 28.1 (5.4)	100% men	86.8% non-Hispanic white; 13.2% Other	Pill compliance, time spent topside during patrol, BMI, fat mass and fat-free mass: ND
11	25 (19 Marines and 6 Sailors) (8 October 2010 to 30 June 2011)	Mean (SD) 30.3 (6.9)	72% men and 28% women	ND	Season: 40% winter, 20% spring, 8% summer, 32% autumn
3	13	Mean (SD) 27.8 (5.8)	100% men	ND	Habitual physical activity, smoking, intake of dietary supplements, alcohol consumption, body weight and body composition: ND
22	117 (105 Marines and 12 Sailors)(21 September 2010 to 21 July 2011)	Marines: 20–31 years (44.8%); 32–56 years (55.2%)	85,5% men and 14,5% women	ND	100% no vitamin D supplementation or medication that interfered with vitamin D3 metabolism. Deployment status (Sailors: yes (50%), no (50%); Marines: war zone (71.4%), non-war zone (28.6%))
6	555 (2 May 2014 to 17 November 2020)	18–29 years (3.6%); 30–39 years (17.7%); 40–49 years (21.3%); 50–59 years (39.1%); 60–65 years (18.4%)	85,2% men and 14,8% women	ND	Season: 24.3% winter, 23.1% spring, 21.8% summer, 30.8% autumn

BMI, body mass index; ND, not defined.

Table 4 Vitamin D dataset obtained from each study

Ref	Method/assay used for measurement of 25(OH)D	Mean (SD), median (IQR) and/or range of 25(OH) D concentrations (1 ng/mL=2.5 nmol/L)	Cut-off points for vitamin D deficiency, insufficiency and sufficiency	Prevalence of vitamin D deficiency, insufficiency and sufficiency
23	ND	Mean (SD) ng/mL. Pre-patrol 13.7 (1.1) and post-patrol 7.9 (1.2)	ND	ND
25	Competitive binding technique without preparative chromatography (specifically and selectively assesses in range 0.5–100 ng/mL)	Mean (SD) (range) ng/mL. 2-day pre-patrol: 42.7 (4.6) (13.2–110.0); late-patrol 30.0 (3.9)(0–96)	Sufficiency (15–80 ng/mL)	Insufficiency: pre-patrol (6.7%) and late-patrol (30%)
24	Radio-receptor assay using calf thymus protein by method of Reinhardt *et al*. Inter- and intra-assay coefficient of variation: 8% and 5%	Mean (SD) ng/mL. Pre-patrol: 31 (1.7); day 68: 19 (2.5) (n=20)	Normal range (8–42 ng/mL)	Post-patrol 25(OH)D levels <10 ng/mL (20%)
4	Radioimmunoassay	Mean (SD) ng/mL. Experimental group: pre-patrol 28.3 (15); day 49: 24.1 (10); day 55: 27.5 (11); day 76: 22.8 (10). Placebo group: pre-patrol 26.3 (10); day 49: 20.7 (9); day 55: 23.5 (8); day 76: 21.4 (10)	Sufficiency (10–68 ng/mL)	Sufficiency (100%)
2	Radioimmunoassay (DiaSorin, Stillwater, Minnesota, USA). Interassay coefficient of variation: 98.6%	Mean (SD) ng/mL. Pre-patrol: 25.54 (7.30); post-patrol 21.66 (5.38)	Reference values for healthy men (8.9–46.7 ng/mL)	ND
26	Radioimmunoassay 25(OH)D 125I RIA kits (DiaSorin). Within- and between-run coefficients of variation: 8.6% and 9.1%	Mean ng/mL. Summer patrol: baseline 36; day 20: 25 (decreased 31%); day 58: 21(decreased 16%) Winter patrol: baseline 17 (decreased 15% until patrol day 58)	Severe deficiency (<15 ng/mL), deficiency (<20 ng/mL), insufficiency (<30 ng/mL)	Deficiency (winter patrol): 100% deficiency at pre-patrol, day 20, day 41 and day 58 (mean (SD) always <20 ng/mL)
12	Direct, competitive chemiluminescence immunoassay (CLIA) using the LIAISON 25(OH) Vitamin D Total assay (DiaSorin). Inter- and intra-assay coefficient of variation: 5.3% and 3.1%	Mean (range) nmol/L. Non-Hispanic white: cases 93.2 (42.1–172); controls 97.0 (31–211) Non-Hispanic black: cases 49.1(19.2–92); controls 49.8 (12.7–113) Hispanic: cases 84.4 (35.4–142); controls 82.2 (47.0–152). Season: winter (January–April) 66.0; summer (July–October) 85.5; spring and Fall (May, June, November, December) 72.3	Categories: <25, 25–<50, 50–<75, 75–<100 and ≥100 nmol/L	Non-Hispanic white: <75 nmol/L (18.3%), 75–<100 nmol/L (42,3%), ≥100 nmol/L (39.4%). Non-Hispanic black: <50 nmol/L (57,6%), 50–<75 nmol/L (35.8%), ≥75 nmol/L (6,6%)
27	IDS OCTEIA 25(OH)D assay (ELISA-Immuno Diagnostic Systems, Bolton, UK). Assay sensitivity 5 nmol/L; intra- and inter-batch variability: 5.3% and 4.6%	Mean (range) nmol/L. Controls: pre-patrol 57.9 (25.8–141), post-patrol 70.5 (35.9–203.0) (mean change +0.19 (0.01–0.38)) Support: pre-patrol 44.0 (26.7–71.5), post-patrol 54.1 (35.0–86.4) mean change +0.23 (−0.14–0.60)) Submariners: pre-patrol 49.2 (23.8–106.6), post-patrol 47.6 (25.6;114.4) mean change=−0.04 (−0.19–0.11))	Normal range (48–144 nmol/L)	Insufficiency (post-patrol): 100% submariners (25(OH)D 24–40 nmol/L)
28	Radioimmunoassay (DiaSorin). Clinical chemistry laboratory accredited by the College of American Pathologists and regularly participates in inter-lab assay validation for 25(OH)D	Mean (SD) nmol/L. All: pre-patrol 52 (16) Pre-patrol: placebo 49.92 (17.56), 1000 IU/day 52.39 (14.01), 2000 IU/day 53.44 (16.86). Post-patrol change: placebo 3.3 (13.1), 1000 IU/day 4.6 (11.3), 2000 IU/day 13.0 (14.0)	Deficiency (<30 nmol/L) and insufficiency (<50 nmol/L)	Pre-patrol: Deficiency: all (5.7%); placebo (6.3%); 1000 IU/day (5%); 2000 IU/day (5.9%). Insufficiency: all (49.1%); placebo (62.5%), 1000 IU/day (35%); 2000 IU/day (35.3%) Post-patrol: Deficiency: placebo (6.3%); 1000 IU/day (0%); 2000 IU/day (5.9%). Insufficiency: placebo (25%), 1000 IU/day (35%); 2000 IU/day (5.9%)
11	Immunochemiluminometric assay (DiaSorin LIASON at Lab Corp of America) and liquid chromatography/tandem mass spectroscopy (LC/MS/MS) (Quest Diagnostic Nichols Institute Lab)	Median (IQR) ng/mL. Positive monospot test (n=9): 20.80 (10.15). Negative monospot test (n=16): 30.35 (17.05)	Deficiency (<20 ng/mL), insufficiency (20–<30 ng/mL), normal (30–100 ng/mL)	Deficiency (32%), insufficiency (28%), sufficiency (40%)
3	ND	Mean (SD) nmol/L, n=12. Pre-patrol 200 (41); post-patrol 173 (35) (change −25 (39) (−14%))	Deficiency (<80 nmol/L)	Deficiency: pre-patrol (17%) and post-patrol (67%)
22	Immunochemiluminometric assay (DiaSorin LIASON instrument) or liquid chromatography/tandem mass spectroscopy (LC/MS/MS)	Mean (SD) ng/mL. Marines: group 20–31 years (n=47) 24.81 (9.94); group 32–56 years (n=58) 28.08 (9.15). Median (IQR) ng/mL. Sailors: group deployed (n=6) 18 (5.75); group not deployed (n=6) 31.5 (22)	Deficiency (<20 ng/mL), insufficiency (20–<30 ng/mL), normal (30–100 ng/mL)	Deficiency (29.1%), insufficiency (34.2%), sufficiency (36.7%)
6	Chemiluminescence (Alinity, Abbott, Lisbon and ADVIA Centaur XP, Siemens, Oporto). Equipment certified by the Centres for Disease Control and Prevention Vitamin D Standardization-Certification Programme	Mean (SD) ng/mL. 24.3 (10.9)	Deficiency (<20 ng/mL), insufficiency (≥20 and <30 ng/mL), sufficiency (≥30 ng/mL)	Deficiency (37.1%), insufficiency (37.7%), sufficiency (25.2%)

ND, not defined.

therefore they were at higher risk of severe vitamin D deprivation.[26] The mean (SD) serum 25(OH)D level before deployment ranged between 13.7 (1.1) ng/mL and 42.7 (4.6) ng/mL with an assumed outlier of 80 (16.4) ng/mL; after submarine patrol, a lower mean (SD) serum 25(OH)D level was observed ranging between 7.9 (1.2) ng/mL and 30 (3.9) ng/mL with the same outlier of 69.2 (14.0) ng/mL (table 4). Differences in serum 25(OH)D data reported and different cut-offs did not allow for aggregation of information on vitamin D status. Only one study presented a table with the individual 25(OH)D levels (pre- and late-patrol), which enabled translation to vitamin D status characterisation according to the Endocrine Society cut-offs: deficiency (increased from 13.3% to 30%), insufficiency (increased from 26.7% to 40%), and sufficiency (decreased from 60% to 30%).[17 25]

DISCUSSION

This systematic review included 13 studies carried out between 1975 and 2022 in Northern hemisphere Navies, mostly including submariners in an onboard and indoor occupational setting, which show serum 25(OH)D data in active duty military personnel, most of whom were young and male. This indicates concerns related to the vitamin D status, particularly in submariners, and strengthens the value of this new systematic review.

Several review papers have highlighted the worldwide spread of vitamin D deficiency that led to the development and implementation of a variety of interventions to reduce the prevalence of vitamin D deficiency and related diseases (eg, food fortification and/or supplementation policies).[34] The Finnish vitamin D food fortification policy is an example of success.[35] The vitamin D status data (according to the Endocrine Society) from the two studies included in this systematic review with larger samples of active duty Navy military personnel are in line with a high prevalence of vitamin D deficiency (37.1% in 555 Portuguese Navy SM) and with the influence of personal factors such as skin colour in vitamin D levels (57.6% in 198 non-Hispanic black US Navy SM).[6 12 17] Other important determinants of serum 25(OH)D levels are season and latitude. Seasonal variation in serum 25(OH)D concentration has been confirmed previously, but not all studies included this type of information.[36] Included studies were developed at latitudes above ~30°N, which may impact negatively on the SM serum 25(OH)D levels because sunlight is not strong enough to trigger synthesis of vitamin D in the skin at latitudes above ~40°N from October to March.[37] In fact, Fallowfield *et al* reported a threefold increase between pre-eployment (home base, UK; 51°N) and mid-deployment (Helmand Province, Afghanistan; 31°N) serum 25(OH)D concentrations in a group of 98 volunteers including Marines deployed from March to June.[14]

Active duty Navy military personnel should also benefit from the abovementioned policies, at least at Navy facilities, and periodic measurement of serum 25(OH)D should be implemented. There is some evidence that deployment of SM may be associated with lower serum 25(OH)D levels, suggesting that serum 25(OH)D levels should be checked before and after deployment.[22] Serum total 25(OH)D concentration—a very difficult analytical parameter to assess—remains the best biomarker to define vitamin D status and standardised 25(OH)D measurements are essential in clinical and research settings.[38] Despite the measurement method (eg, assays based on liquid chromatography–tandem mass spectrometry measurement systems or automated immunoassays), currently it must meet the minimal performance criteria set by the Vitamin D Standardization Program founded in 2010 by the US National Institutes of Health, Office of Dietary Supplements: precision (mean total percent coefficient of variation ≤10%) and accuracy (mean bias ≤±5%).[38] Three out of the nine reports published after 2010 did not mention the measurement method or reported standardised measurements.[3 11 22]

Submariners, as SM particularly exposed to occupational factors that may adversely affect bone health (eg, relatively high carbon dioxide content in breathed air, lack of sunlight exposure, confined environment that limits physical activity, restricted diet with reduced access to perishable food), deserve the attention of the Navy Occupational Health Department.[2–4] Beyond individual and cultural risk factors, merging the occupational risk factors (serum 25(OH)D level decreased in crew members during patrols) and the environmental risk factors (serum 25(OH)D levels lower in winter than in summer) for vitamin D deficiency means that submariners assigned to winter patrols are particularly prone to vitamin D deficiency and should take vitamin D supplementation before boarding.[26]

Despite two exceptions,[27 28] previous publications reported a significant reduction in serum 25(OH)D level of 15–47% during submarine patrols that lasted about approximately 1–2 months due to lack of sunlight exposure (ie, ultraviolet B light radiation).[2 4 23 24 26] Gunner *et al* reported a decrease in serum 25(OH)D levels in two cohorts of male submariners deploying in winter (n=32) and summer (n=64) for 12 weeks, with a pre-deployment serum 25(OH)D concentration lower for winter than for summer (38±16 vs 53±20 nmol/L, p<0001) and the decrease notably below 25 nmol/L in winter for those without vitamin D supplementation.[39] Even in a cohort of 34 male submariners who remained alongside for a similar duration in summer without vitamin D supplementation, the serum 25(OH)D decreased substantially between July and October.[39]

The need for food fortification and supplementation policies also results from the low vitamin D dietary intake. The Endocrine Society suggests that adults aged 19–50 years require at least 600 IU/day vitamin D to maximise bone health and muscle function and highlights that at least 1500–2000 IU/day vitamin D may be required to raise the blood 25(OH)D level consistently above 30 ng/mL.[17] Gilman *et al* reported that the mean dietary intake of vitamin D by submariners was 88±44 IU/day during a patrol (vs 159±65 IU/day before a patrol) due to the limited storage capacity for fresh dairy products onboard the submarine.[25] Even so, subjects who showed an increase in serum 25(OH)D level during the late-patrol period had a higher average intake of vitamin D2 than those showing a decrease (172 IU/day vs 56 IU/day); the eight men with higher serum 25(OH)D levels at the end of the patrol increased their daily vitamin D2 intake during the patrol from 68 IU/day to 211 IU/day.[25] Gasier *et al* also reported a low dietary vitamin D intake before (land-dwelling; 256±157 IU/day; 44±28% of the recommended dietary allowance for vitamin D) and during (sea-dwelling; 53±37% of the recommended dietary allowance for vitamin D) a 3-month submarine patrol using a validated food frequency questionnaire.[28] A recent systematic review and meta-analysis of interventional studies evaluated the efficacy of vitamin D fortified foods on serum bone biomarkers and found a significant effect on serum 25(OH)D (MD: 16.94 nmol/L; 95% CI 13.38 to 20.50; p<0.001, I^2=99.0%) based on the random effect model.[40] Offering dried vitamin D-enhanced mushrooms could substantially contribute to alleviating vitamin D deficiency.[41] Another recent systematic review of dietary intake assessment methods in maritime settings concluded that subjective dietary assessment methods (eg, dietary records or multiple recalls) combining menu analysis with new technologies (eg, mobile applications) might be an applicable method on board, but a valid and reproducible Food Frequency Questionnaire for the assessment of vitamin D dietary intake is also a simple and fast research method available.[42 43]

Concerning supplementation during submarine patrols, Holick reported a study conducted in 22 submariners who were not exposed to any sunlight for 3 months, half of whom received a vitamin D pill (600 IU/day) and the other half received a placebo pill.[33] In the placebo group, from the baseline before the submariners entered the submarine, a 37.8% and 38.6% decrease in serum 25(OH)D concentration was observed after 1.5 and 3 months, respectively. In the vitamin D group, the same decrease was less obvious (17.6% and 0.3%).[33] Interestingly, both groups showed a marked increase in serum 25(OH)D concentration 1 month after leaving the submarine (44% and 20.9% in the placebo and vitamin D groups, respectively) compared with baseline values, but there was no reference to the pre- and post-patrol season.[33] Similar observations were made by Schlichting and Styer in a report from the Naval Submarine Medical Research Laboratory based on a study with 22 submariners aged 18–35 years from a crew of an American fleet ballistic nuclear-powered submarine about to go on a 2-month deployment.[44] Eleven received a daily multivitamin-mineral supplement (with 10.0 mg ergocalciferol) and 11 received a non-nutritional placebo.[44] Serum 25(OH)D levels fell between pre-patrol (November) and mid-patrol (1 month; 38% in the placebo group and 17% in the supplemented group) and end-patrol (2 months; 40% in the placebo group and 3% in the supplemented group) and increased after the crew had returned to the base (in both groups, serum 25(OH)D levels 30 days post-patrol were above all patrol values and also above pre-patrol values).[44] Gasier *et al* used a higher dose of 2000 IU/day but, although the group receiving 2000 IU/day showed the greatest change in serum 25(OH)D levels following the patrol (+13 nmol/L), this was not statistically significant (mean changes in serum 25(OH)D per 100 IU supplemented vitamin D of 0.5 ± 1.3 and 0.7 ± 0.7 nmol/L for the 1000 and 2000 IU/day groups, respectively).[28] This probably means that submariners may need more than 2000 IU/day vitamin D to maintain vitamin D sufficiency. In athletes, in the five randomised controlled trials included in a recent systematic review and meta-analysis about the effects of vitamin D3 supplementation on serum 25(OH)D concentration and strength, the daily dosage ranged between 2857 IU (12 weeks) and 18 750 IU (8 days; bolus of 150 000 IU).[45] Note also that the Endocrine Society suggests that all adults who are vitamin D-deficient should be treated with 6000 IU vitamin D2 or vitamin D3 daily for 8 weeks (or 50 000 IU once a week) to achieve a blood level of 25(OH)D above 30 ng/mL, followed by maintenance therapy of 1500–2000 IU/day.[17]

Overall, low baseline serum 25(OH)D levels are a matter of concern for submariners preparing to submerge for a prolonged period of time.[28] It seems appropriate to implement a vitamin D food fortification policy in the Navy, assess vitamin D levels periodically, implement a vitamin D supplementation policy for vitamin D-deficient cases to ensure adequate levels before deployment, and provide a vitamin D-rich diet while on board. Future research may address shorter submarine patrols (less than 30 days), long-term effects of repeated submersions on bone health (eg, bone mass density) with objective data, and the use of ultraviolet B lamps on board submarines, as there is evidence that short-term medium and high doses of ultraviolet B irradiation increase serum 25(OH)D levels.[46 47] To include a broader sample of active duty Navy military personnel, the value of blood banks should be acknowledged. Currently, the United States Department of Defence Serum Repository houses more than 62 million serial blood-derived serum specimens from all military SM admitted since 1985. It is undoubtedly the largest bank of human serum in the world and a precious source to conduct a militarily relevant epidemiological study about vitamin D status.[48]

The present systematic review is the first to address the vitamin D status in active duty Navy military personnel and was performed with strict adherence to globally accepted systematic review methods for evidence screening, quality assessment and data analysis, which ensures the transparency and reproducibility of the results. Other known relevant studies were not neglected and were brought to the discussion. The results reported for the submariners may also be observed in other workforces where the working environment precludes sunlight exposure (eg, permanent night shift workers and those who work underground).[27] For example, Daugaard *et al* observed lower serum 25(OH)D concentrations among permanent, not rotating, night workers compared with indoor workers and Peng *et al* reported a tendency for lower serum 25(OH)D levels in underground coal mine workers (70.2% of 2532 underground workers vs 58.2% of 1256 surface workers with serum 25(OH)D<25 nmol/L).[49 50]

However, this systematic review has some limitations. First, the serum 25(OH)D data from the studies were not available in a way that allowed presentation of the prevalence of vitamin D deficiency, insufficiency and sufficiency according to the Endocrine Society for all studies. Second, most studies included only submariners, which may limit generalisability to all active duty Navy military personnel. Third, the heterogeneity of the studies concerning variables relevant to vitamin D levels such as latitude, season, skin colour and vitamin D dietary intake (among others) limited a pooled analysis. Finally, all studies showed some weaknesses in their critical appraisal.

CONCLUSIONS

This is the first worldwide overview of vitamin D status in active duty Navy military personnel to be published. The prevalence of vitamin D deficiency is significant in the Navy, especially in submariners, and countermeasures should be triggered by the Navy Occupational Health Department, starting by including periodic vitamin D assessment. More studies on this topic are needed to overcome the identified limitations and to produce new knowledge that can support suitable interventions to prevent vitamin D deficiency.

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