Factors Associated with Vitamin D Deficiency in a Norwegian Population: the HUNT Study

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ABSTRACT

Vitamin D deficiency occurs worldwide. Winter season and high body mass index (BMI) are associated with low levels of serum 25-hydroxyvitamin D [25(OH)D]. Our aim was to estimate the prevalence of vitamin D deficiency in a Norwegian adult population and to examine factors associated with vitamin D deficiency. A cohort of 25, 616 adults (19-55 years) who participated in both the second and third Nord-Trøndelag Health Study [HUNT 2 (1995-1997) & HUNT 3 (2006-2008)] was established in a previous study. A 10% random sample of the cohort population was recruited for serum 25(OH)D measurements (n=2584), which was used for the current cross-sectional study. Vitamin D deficiency was defined as serum 25(OH)D level <50 nmol/L. The overall prevalence of vitamin D deficiency was 40% but varied by season (winter: 64%; summer: 20%). Winter season [adjusted prevalence ratio (PR): 3.16, 95% confidence interval (CI): 2.42 - 4.12] and obesity (BMI ≥30.0 kg/m^2) (PR: 1.74, 95% CI: 1.45-2.10) were strongly associated with prevalent vitamin D deficiency. Current smoking also demonstrated an increased PR (1.41, 95% CI: 1.21-1.65). Daily intake of cod liver oil (PR: 0.60, 95% CI: 0.41-0.77), increased physical activity (PR: 0.80, 95% CI: 0.68-0.95) and more frequent alcohol consumption (PR: 0.76, 95% CI: 0.60-0.95) were associated with a reduced PR. The prevalence of vitamin D deficiency was high in Norwegian adults. Winter season, high BMI and current smoking were positively associated, and intake of cod liver oil, increased physical activity and more frequent alcohol consumption were inversely associated with vitamin D deficiency.

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INTRODUCTION

Vitamin D plays a critical role in bone health and mineral homeostasis via calcium metabolism. Adequate vitamin D status is widely understood to be essential for the prevention of rickets, osteomalacia, and osteoporosis, and fracture risk. Increasing evidence suggests an association of vitamin D deficiency with a range of diseases including autoimmune diseases, cancer, diabetes and cardiovascular disease, and with all-cause mortality[1-3].

Vitamin D can be obtained via dermal synthesis after exposure to ultraviolet B (UVB) irradiation, and through diet or supplements. Measurement of serum 25-hydroxyvitamin D [25(OH)D] levels is recognized as the best approach to estimate body vitamin D status, as the serum level integrates sun exposure, dietary intake, supplement use, and storage[4, 5]. Low body vitamin D status is common worldwide[6-10].

High latitude and winter season are established risk factors for low vitamin D status[10-13]. High body mass index (BMI) is inversely associated with circulating 25(OH)D levels[14-16]. However, lifestyle factors have not been intensively studied and show inconsistent associations with vitamin D status[9, 10].

Vitamin D supplementation through regular intake of cod liver oil is perceived as a cultural norm in Norway. The prevalence of vitamin D deficiency and associated factors with the deficiency in the Norwegian population remain unclear. The purpose of this study was to estimate the prevalence of vitamin D deficiency in a Norwegian adult population using data from the Nord-Trøndelag Health Study (HUNT), and to examine the factors associated with low serum 25(OH)D level and vitamin D deficiency.

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MATERIALS AND METHODS

Study Area and Population

Participants were from the HUNT study; one of the largest population health studies conducted in Norway to date. The Nord-Trøndelag study area is located at latitude 64 degrees north, situated in the middle of Norway[17]. The study population was mostly Caucasian (97%), with socio-demographic characteristics generally representative of Norway.

Three adult HUNT surveys have been completed to date: HUNT 1 (1984-1986), HUNT 2 (1995-1997), and HUNT 3 (2006-2008) [17, 18]. The target population for HUNT 2 consisted of approximately 93,000 adults living in Nord-Trøndelag with a participation rate of 70% (n=65,237). Among the HUNT 2 participants, 57% (n=37,059) also took part in HUNT 3.

We established a cohort of 25,616 adults aged 19-55 years who were followed up from HUNT 2 to HUNT 3 over an approximately 11-year period. This cohort was initially selected to study serum 25(OH)D levels and other factors associated with asthma development[19]. A 10% random sample of the cohort participants (n=2584) was selected for measurement of serum 25(OH)D levels in blood samples collected during HUNT 2[20], and the current analysis was based on cross-sectional data from this sample.

Socio-demographics, season, BMI, and lifestyle variables

Data on socio-demographics, season, BMI, and lifestyle variables were collected in HUNT 2. Socio-demographic variables included age (19-29, 30-39, 40-49 or 50-55 years), sex (male or female), years of education (<10, 10-12, ≥13 years or unknown [1%]), receipt of social

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benefits (yes, no or unknown [17%]), and economic difficulties in the past year (yes, no or unknown [13%]). Season of blood sample collection was categorized according to the Norwegian Meteorological Institute standard as summer (June through August), autumn (September through November), winter (December through February), and spring (March through May)[21]. Body weight and standing height of participants were measured in light clothing and without shoes by health professionals[17]. BMI (kg/m^2) was calculated and categorized into four groups: (<25.0, 25.0-29.9, 30.0 or unknown [<1%]). Lifestyle factors included daily intake of cod liver oil (5ml/400IUs of vitamin D per day by recommendation) for at least one month (yes, no or unknown [25%]), average hours of light physical activity per week (<1, 1-2, ≥3 or unknown [12%]), daily smoking (never, current, former or unknown [6%]), and average alcohol consumption per month (abstain/<1, 1-4, ≥5 times or unknown [6%]). The unknown category for education, social benefits, economic difficulties, BMI, cod liver oil intake, physical activity, smoking, or alcohol consumption, was included in the analysis. Missing data were assumed missing at random. Multiple imputations of missing data using auxiliary information were performed showing similar results (data presented as supplemental file online).

Measurement of Serum 25(OH)D Levels

Blood samples were collected in HUNT 2 and stored at -70°C for later use. From the 10% random sample (n=2584) of cohort participants, 2505 subjects (97%) had sufficient serum volume for analysis. Serum 25(OH)D levels were measured using a fully automated antibody-based chemiluminescence assay (LIASON 25-OH Vitamin D TOTAL; DiaSorin, Saluggia, Italy) with detection range 10-375nmol/L, intraassay coefficient of variation (CV) 4%, and interassay CV 8%. Assay imprecision was evaluated and in compliance with standard

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according to CLSI EP5-A2[22, 23]. Serum 25(OH)D levels ranged from 10 to 251 nmol/L. Vitamin D deficiency was defined as serum 25(OH)D level <50 nmol/L[11, 24].

Statistical Analysis

The distribution of serum 25(OH)D levels was demonstrated by histogram. The prevalence of vitamin D deficiency was calculated overall, and by season of blood sample collection. Poisson regression[25] was used to estimate the prevalence ratio (PR) for factors associated with vitamin D deficiency. Crude and adjusted PRs and 95% confidence intervals (CI) were calculated for socio-demographics, season, BMI, and lifestyle variables. We also conducted analysis of variance to examine associations of these covariates with serum 25(OH)D levels. The multivariable models included age, sex, education, receipt of social benefits, economic difficulties, season of blood sample collection, BMI, cod liver oil intake, physical activity, smoking and alcohol consumption. Stata version 12.1 (StataCorp LP, College Station, Texas) was used to conduct all statistical analyses.

Ethics

The Regional Committee for Medical and Health Research Ethics approved this study. All study participants provided informed written consent.

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RESULTS

Serum 25(OH)D levels in the study population showed a relatively normal distribution (Figure 1). The median and mean serum 25 (OH)D levels were 56 and 59 nmol/L, respectively.

The overall prevalence of vitamin D deficiency was 40% (Table 1). The prevalence varied by season, ranging from 20% in the summer to 64% in the winter (<0.001).

Tables 2 and 3 show that both mean serum 25(OH)D level and the prevalence of vitamin D deficiency varied little across age and sex groups. However, other socio-demographic variables including education, receipt of social benefits and economic difficulties, as well as season, BMI, and lifestyle variables including intake of cod liver oil, physical activity, smoking and alcohol consumption, were all significantly associated with both mean serum 25(OH)D level and prevalence of vitamin D deficiency before adjustment for covariates (Table 3).

In adjusted Poisson regression analysis (Table 3), there was a strong association between season and vitamin D deficiency and the prevalence of vitamin D deficiency was significantly higher in winter compared to summer months (PR: 3.16, 95% CI: 2.42-4.12). High BMI and current smoking also demonstrated higher PRs compared to normal BMI and non-smoking (PR for BMI $\geq$ 30.0 kg/m^2: 1.74, 95% CI: 1.45-2.10; PR for current smoking:1.41,95% CI: 1.21-1.65). In contrast, a 40% lower PR was estimated in participants who reported daily

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intake of cod liver oil for at least one month. A lower PR for vitamin D deficiency was also significantly associated with increased hours of light physical activity and more regular alcohol consumption (PR for physical activity ≥3 hours: 0.80, 95% CI: 0.68-0.90; PR for alcohol consumption ≥ 5 times per month: 0.76, 95% CI: 0.60-0.95). There were no significant associations between socio-demographic variables and vitamin D deficiency in multiple Poisson regression analysis.

Analysis of variance was used to calculate the mean difference in 25(OH)D level by socio-demographics, season, BMI, and lifestyle variables (Table 3). The adjusted mean serum 25(OH)D level was 23 nmol/L lower when blood samples were collected during winter versus summer months. Participants with BMI ≥30 kg/m^2 had serum 25(OH)D levels 14 nmol/L lower when compared to subjects with BMI <25 kg/m^2. Current smokers had a significantly lower 25(OH)D level compared with non-smokers, whereas higher levels of serum 25(OH)D were observed in participants who took cod liver oil regularly or were physically active, and in participants who reported more regular alcohol consumption. There were no significant differences in 25(OH)D levels among socio-demographic subgroups.

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DISCUSSION

In our cross-sectional study of Norwegian adults living at latitude 64 degrees North, the prevalence of vitamin D deficiency was 40% overall, ranging from 20% in the summer to 64% in the winter. Winter season and high BMI were the two strongest factors associated with vitamin D deficiency. Our results indicate that potentially modifiable lifestyle factors including intake of cod liver oil, physical activity, smoking, and alcohol consumption were also independently associated with vitamin D status.

The mean level of serum 25(OH)D in the current study (59 nmol/L) was comparable to that from another population based study of adults aged 25-84 years conducted in Northern Norway (55 nmol/L)[26]. However, the prevalence of vitamin D deficiency in our study tended to be higher than was found in some other studies. For example, the prevalence of vitamin D deficiency (<50 nmol/L) between May and January was 14% in a cross-sectional study of healthy Norwegian adults living in Oslo[27] compared to 34% in our study. The Oslo study selected a random sample of participants aged 45, 60, and 75. Older participants may be more likely to supplement with vitamin D[19]. A recent Canadian study reported a 20% overall prevalence of vitamin D deficiency in adults aged over 35, but a larger proportion of the Canadian study participants reported regular intake of vitamin D through supplementation or fortified food intake[28]. In contrast, our earlier study estimated that only 18% of HUNT participants took cod liver oil regularly[19]. The blood sample collection in our study (1995-97) was 10 years previous to the Canadian study (2005-07). However, results from a recent prospective study in the United States suggested high intra-individual reproducibility[29]. This may indicate that the two studies can be compared despite serum 25(OH)D levels being measured at different time points.

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Winter season was the strongest factor associated with vitamin D deficiency in our study, as in many other studies[10, 26, 27, 30].

High BMI was the second strongest factor associated with low vitamin D status. We cannot infer causality from our cross-sectional data, but literature suggests that there might be a harmful cycle between high BMI and low 25(OH)D levels. On one hand obesity leads to low vitamin D levels due to the fat soluble character of vitamin D[11, 14] and on the other hand low vitamin D may lead to obesity due to the promotion of lipogenesis in adipocyte tissue[20, 31]. A recent study used genetic markers as an instrumental variable to explore the causality and direction of the relationship between BMI and circulating 25(OH)D levels[32]. Results from this bi-directional genetic approach suggested that higher BMI led to lower 25(OH)D levels, but the reverse was not true. Further research is warranted to clarify the causal relationship and direction between BMI and vitamin D status.

Dietary sources of vitamin D are not common, but it can be found in fatty fish, cod liver oil, and fortified products such as butter, margarine and extra light milk in Norway. As expected, regular intake of cod liver oil was associated with higher serum 25(OH)D levels as shown in other studies[33-35]. However, our study had a lower than expected proportion of participants who reported daily intake of cod liver oil which may be a good target for public health messaging considering the historic tradition of cod liver oil use in the Norwegian population.

Increased hours of light physical activity was associated with higher serum 25(OH)D levels. We also explored the association between vigorous physical activity and 25(OH)D levels

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(data not shown), and while the magnitude of the association increased when compared to light physical activity, our data lacked well defined responses allowing discrimination between indoor and outdoor activity. Both light and vigorous physical activity may be proxy measures for sun exposure due to increased leisure time spent outdoors, as found in other studies[16, 28, 36]. Still, some evidence suggests that increased physical activity may be a factor associated with vitamin D status independent of the effect of sun exposure[15]. Thus, the role of physical activity in modulating circulating 25(OH)D levels, independent of sun exposure, is a potential area for future research.

In our study, current smoking was associated with an increased PR for vitamin D deficiency. Previous European studies have shown a positive association between smoking and vitamin D deficiency[37-39]. One study in Northern Norway found higher serum 25(OH)D levels in smokers, which the authors believed to be most likely due to measurement error and smokers were therefore excluded from further analysis[26]. Other studies found no association between smoking and vitamin D status[15, 40].

Interestingly, we found that more frequent alcohol consumption was associated with higher levels of serum 25(OH)D. Although the mechanism for how alcohol consumption might affect serum 25(OH)D level is unclear, alcohol is suggested to suppress parathyroid hormone (PTH) secretion which is responsible for converting serum 25(OH)D to 1,25-dihydroxy vitamin D[31]. Unconverted serum 25(OH)D may lead to higher serum 25(OH)D levels in the circulation when measured. However, this mechanistic theory is highly speculative and the association between serum 25(OH)D levels and alcohol consumption should be further

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evaluated using well defined variables including quantity and frequency of alcohol consumption.

None of the socio-demographic markers were significantly associated with vitamin D deficiency in this Norwegian population. Considering the relatively narrow age range of our study population, this finding is plausible, and our results were consistent with findings from two other Norwegian studies in which no difference between women and men were found[26, 27]. Marginalized socio-demographic status has been identified as a risk factor for low vitamin D status in other populations[6]. However, Norway can be considered a social democratic welfare state that promotes equality and provides generous benefits and commitment to full employment[41, 42]. The social policies of Norway may provide one explanation for why socio-demographics were not significantly associated with vitamin D deficiency in our study. Another explanation may be that the potential association between socio-demographics and vitamin D deficiency was mediated by lifestyle factors.

Our large cross-sectional study had several strengths including the provision of data on vitamin D status in a large random sample of Norwegian adults. The mean serum 25(OH)D level in our study is comparable to the value in another study conducted in Northern Norway, indicating good external validation of our results[26]. Blood samples were collected across all four seasons, BMI was objectively measured, and a broad range of socio-demographic and lifestyle variables were available in the questionnaire data, thereby giving the opportunity to include important potential confounders in the analysis, thus increasing the validity of our results.

This study also has potential limitations. Due to the narrow age range of participants in our study (19-55 years), these findings may not be generalized to the youngest or oldest subpopulations. Our participants were mainly Caucasian which may reduce the generalizability to more ethnically diverse populations. Blood samples were not collected in July and vitamin D deficiency may be overestimated in summer months. The determination of vitamin D deficiency using a single serum 25(OH)D measure may have contributed to measurement error. Although international consensus on standard cut-points for vitamin D insufficiency or deficiency has not yet been reached, our data did show consistent findings when analyzed using different cut-points[24]. Finally, due to the cross-sectional analysis of our study, it was not possible to infer causality.

In summary, our data suggests a high prevalence of vitamin D deficiency in a Norwegian adult population and demonstrates significant associations of season, BMI, and lifestyle factors with vitamin D deficiency. For future research, it would be interesting to investigate how these factors affect the change of serum 25(OH)D levels over time in this Norwegian population.

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What is already known about this subject

- Vitamin D deficiency is common across a number of population studies. High latitude and winter season are associated with low serum 25(OH)D levels.

What this study adds

- Our study demonstrated that vitamin D deficiency (serum 25(OH)D level <50 nmol/L) was also common in a Norwegian adult population.
- Besides season, several potentially modifiable lifestyle factors were significantly associated with serum 25(OH)D levels and vitamin D deficiency.

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Author contributions were as follows: TLL, YC, CAC, AL, PR and XMM contributed to the study design; XMM and AL contributed to data collection; TLL conducted statistical analyses, interpreted results and wrote the initial draft of the manuscript; and TLL, YC, CAC, AL, PR and XMM participated in the data interpretation and helped to write the final draft of the manuscript.

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Competing Interest: none declared.

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FIGURE LEGEND

Figure 1 Unadjusted frequency distribution of serum 25(OH)D levels in a random sample (n=2505), Nord-Trøndelag Health Study, 1995-1997.

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Table 1 Distribution of serum 25 (OH) D level and seasonal comparison, Nord-Trøndelag Health Study, 1995-1997.

25(OH)D, nmol/L	No.	%	95% CI	Summer	Autumn	Spring	Winter
				%			
<25.0	107	4.3	3.5, 5.1	0.7	1.5	4.1	8.9
25.0-49.9	888	35.5	33.6, 37.3	19.2	21.5	37.6	55.1
50.0-74.9	938	37.5	35.6, 39.4	36.2	45.0	40.8	27.0
75.0-99.9	449	17.9	16.4, 19.4	34.2	24.1	14.7	7.4
100-124.9	104	4.2	3.4, 4.9	8.1	6.5	2.5	1.5
125-149.9	15	0.6	0.3, 0.9	1.0	1.1	0.3	0.1
≥150.0	4						
Total	2505	100					

Abbreviations: 25(OH)D, 25-Hydroxyvitamin D; CI, confidence interval

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Table 2 Unadjusted mean serum 25(OH)D level and prevalence of vitamin D deficiency (<50 nmol/L) by socio-demographics, season, BMI and lifestyle characteristics, Nord-Trøndelag Health Study, 1995-1997.

		25(OH)D (nmol/L)	Vitamin D deficiency (<50 nmol/L)
	No.	**Mean (SD)**	**%**
Total	2505	58.6 (23.1)	39.7
Age, years			
19-29	378	59.7 (24.7)	39.7
30-39	751	58.0 (22.3)	39.4
40-49	984	58.2 (22.8)	41.1
50-55	392	59.9 (23.8)	37.0
Sex			
Female	1384	58.8 (23.0)	38.1
Male	1121	58.3 (23.2)	41.8
Education, years			
<10	489	56.4 (22.2)	44.6
10-12	1347	58.3 (22.9)	40.2
≥13	647	61.3 (24.1)	34.9
Unknown	22		
Social benefits			
Nonrecipient	1608	59.7 (23.3)	38.1
Recipient	466	56.1 (23.0)	40.6
Unknown	431		
Economic difficulties in past year			
No	1483	60.0 (23.1)	37.2
Yes	706	56.1 (22.8)	42.6
Unknown	316		
Season[a]			
Summer	307	71.4 (24.3)	19.9
Autumn	804	66.3 (22.7)	23.0
Winter	755	47.5 (19.1)	64.0
Spring	639	55.9 (20.7)	41.6
BMI (kg/m^2)			
<25.0	1104	62.8 (23.5)	32.2
25.0-29.9	1094	57.3 (22.7)	42.4
≥30.0	300	48.0 (18.7)	58.0
Unknown	7		
Cod liver oil intake			
No	1533	57.9 (23.2)	41.2
Yes	341	65.5 (21.8)	23.5
Unknown	631		
Physical activity, hours/week			
<1	572	52.8 (21.8)	51.2
1-2	862	59.2 (23.3)	37.9
≥3	773	61.8 (23.5)	33.9
Unknown	298		
Smoking			
Never	1031	60.9 (22.5)	34.8
Current	695	53.1 (23.0)	50.5
Former	638	60.7 (23.5)	36.5
Unknown	141		
Alcohol consumption per month, times			
Abstain or ≤1	685	54.4 (22.0)	47.0
1-4	1387	60.3 (23.7)	37.4
≥5	344	61.4 (22.5)	33.4
Unknown	89		

Abbreviations: 25(OH)D, 25-hydroxyvitamin D; BMI, body mass index (weight (kg)/height (m^2)); CI, confidence interval; SD, standard deviation.
[a]Season: summer, June-August; autumn, September-November; winter, December-February; spring, March-May.

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Table 3 Prevalence ratio and 95% confidence interval for vitamin D deficiency (<50 nmol/L) and differences in serum 25(OH)D level in association with socio-demographics, season, BMI and lifestyle characteristics, Nord-Trøndelag Health Study, 1995-1997

	Crude PR	95% CI	Adjusted[a] PR	95% CI	Crude Difference nmol/L	95% CI	Adjusted[a] Difference nmol/L	95% CI
Age, years								
19-29	1.00	Referent	1.00	Referent	0.00	Referent	0.00	Referent
30-39	0.99	0.82, 1.21	0.98	0.81, 1.20	-1.72	-4.58, 1.13	-1.54	-4.07, 0.99
40-49	1.03	0.86, 1.25	1.00	0.82, 1.22	-1.53	-4.27, 1.21	-0.73	-3.26, 1.80
50-55	0.93	0.74, 1.17	0.88	0.69, 1.12	0.16	-3.11, 3.42	1.23	-1.81, 4.27
Sex								
Female	1.00	Referent	1.00	Referent	0.00	Referent	0.00	Referent
Male	1.10	0.97, 1.24	1.08	0.95, 1.24	-0.52	-2.34, 1.30	-0.73	-2.43, 0.97
Education, years								
<10	1.00	Referent	1.00	Referent	0.00	Referent	0.00	Referent
10-12	0.91	0.78, 1.07	1.01	0.86, 1.20	1.93	-0.46, 4.31	-0.83	-3.05, 1.38
≥13	0.79	0.66, 0.95	1.01	0.83, 1.23	4.96	2.26, 7.67	-0.40	-2.94, 2.14
Social benefits								
Nonrecipient	1.00	Referent	1.00	Referent	0.00	Referent	0.00	Referent
Recipient	1.06	0.90, 1.25	0.97	0.82, 1.15	-3.56	-5.94, -1.18	-1.52	-3.69, 0.65
Economic difficulties in past year								
No	1.00	Referent	1.00	Referent	0.00	Referent	0.00	Referent
Yes	1.15	1.00, 1.32	1.01	0.88, 1.17	-3.88	-5.95, -1.82	-1.22	-3.10, 0.66
Season[b]								
Summer	1.00	Referent	1.00	Referent	0.00	Referent	0.00	Referent
Autumn	1.16	0.87, 1.55	1.18	0.88, 1.58	-5.01	-7.82, -2.20	-5.19	-7.87, -2.52
Winter	3.22	2.47, 4.20	3.16	2.42, 4.12	-23.84	-26.7, -21.0	-23.2	-25.9, -20.5
Spring	2.10	1.59, 2.77	2.09	1.58, 2.76	-15.46	-18.4, -12.6	-15.5	-18.3, -12.8
BMI (kg/m^2)								
<25.0	1.00	Referent	1.00	Referent	0.00	Referent	0.00	Referent
25.0-29.9	1.32	1.15, 1.51	1.34	1.16, 1.54	-5.44	-7.33, -3.54	-6.01	-7.75, -4.27
≥30.0	1.80	1.50, 2.16	1.74	1.45, 2.10	-14.70	-17.6, -11.8	-13.87	-16.5, -11.2
Cod liver oil intake								
No	1.00	Referent	1.00	Referent	0.00	Referent	0.00	Referent
Yes	0.60	0.45, 0.72	0.60	0.47, 0.77	7.62	4.93, 10.3	6.54	4.14, 8.95
Physical activity, hrs/week								
<1	1.00	Referent	1.00	Referent	0.00	Referent	0.00	Referent
1-2	0.74	0.63, 0.87	0.81	0.69, 0.95	6.39	3.97, 8.81	4.38	2.19, 6.57
≥3	0.66	0.56, 0.78	0.80	0.68, 0.95	8.92	6.45, 11.4	5.25	3.00, 7.51
Smoking								
Never	1.00	Referent	1.00	Referent	0.00	Referent	0.00	Referent
Current	1.45	1.25, 1.68	1.41	1.21, 1.65	-7.77	-9.97, -5.57	-6.64	-8.71, -4.57
Former	1.05	0.89, 1.24	1.03	0.87, 1.22	-0.13	-2.39, 2.13	0.77	-1.28, 2.81
Alcohol consumption per month, times								
Abstain or ≤1	1.00	Referent	1.00	Referent	0.00	Referent	0.00	Referent
1-4	0.80	0.69, 0.91	0.79	0.68, 0.91	5.97	3.87, 8.07	5.53	3.62, 7.45
≥5	0.71	0.57, 0.88	0.76	0.60, 0.95	7.08	4.10, 10.1	4.81	2.04, 7.57

Abbreviations: BMI, body mass index (weight (kg)/height (m^2)); CI, confidence interval; PR, prevalence ratio.
[a]Multivariable regression model including season, age, sex, season, BMI, cod liver oil, physical activity, smoking, alcohol consumption, education, social benefits, economic difficulties at baseline.
[b]Season: summer, June-August; autumn, September-November; winter, December-February; spring, March-May.

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Supplementary Table 1 Multiple imputations of missing data for adjusted prevalence ratio and 95% confidence interval for vitamin D deficiency (<50 nmol/L), Nord-Trøndelag Health Study, 1995-1997.

	Crude PR	95% CI	Adjusted[a] PR	95% CI
Age, years				
19-29	1.00	Referent	1.00	Referent
30-39	0.99	0.82, 1.21	0.99	0.81, 1.21
40-49	1.03	0.86, 1.25	1.01	0.83, 1.23
50-55	0.93	0.74, 1.17	0.90	0.71, 1.15
Sex				
Female	1.00	Referent	1.00	Referent
Male	1.10	0.97, 1.24	1.08	0.95, 1.24
Education, years				
<10	1.00	Referent	1.00	Referent
10-12	0.91	0.78, 1.07	1.01	0.86, 1.20
≥13	0.79	0.66, 0.95	1.01	0.83, 1.23
Social benefits				
Nonrecipient	1.00	Referent	1.00	Referent
Recipient	1.06	0.90, 1.25	0.98	0.84, 1.16
Economic difficulties in past year				
No	1.00	Referent	1.00	Referent
Yes	1.15	1.00, 1.32	1.01	0.88, 1.17
Season[b]				
Summer	1.00	Referent	1.00	Referent
Autumn	1.16	0.87, 1.55	1.17	0.88, 1.57
Winter	3.22	2.47, 4.20	3.13	2.40, 4.09
Spring	2.10	1.59, 2.77	2.09	1.58, 2.77
BMI				
<25.0	1.00	Referent	1.00	Referent
25.0-29.9	1.32	1.15, 1.51	1.34	1.16, 1.54
≥30.0	1.80	1.50, 2.16	1.75	1.45, 2.11
Cod liver oil intake				
No	1.00	Referent	1.00	Referent
Yes	0.60	0.45, 0.72	0.61	0.49, 0.76
Physical activity, hrs/week				
<1	1.00	Referent	1.00	Referent
1-2	0.74	0.63, 0.87	0.81	0.69, 0.95
≥3	0.66	0.56, 0.78	0.80	0.68, 0.95
Smoking				
Never	1.00	Referent	1.00	Referent
Current	1.45	1.25, 1.68	1.40	1.20, 1.63
Former	1.05	0.89, 1.24	1.03	0.87, 1.21
Alcohol intake per month, times				
Abstain or ≤1	1.00	Referent	1.00	Referent
1-4	0.80	0.69, 0.91	0.79	0.69, 0.91
≥5	0.71	0.57, 0.88	0.75	0.60, 0.94

Abbreviations: BMI, body mass index (weight (kg)/height (m^2)); CI, confidence interval; PR, prevalence ratio
[a]Multivariable regression model including sex, age, season, BMI, cod liver oil, physical activity, smoking, alcohol intake, education, social benefits, economic difficulties at baseline
[b]Season: summer, June-August; autumn, September-November; winter, December-February; spring, March-May

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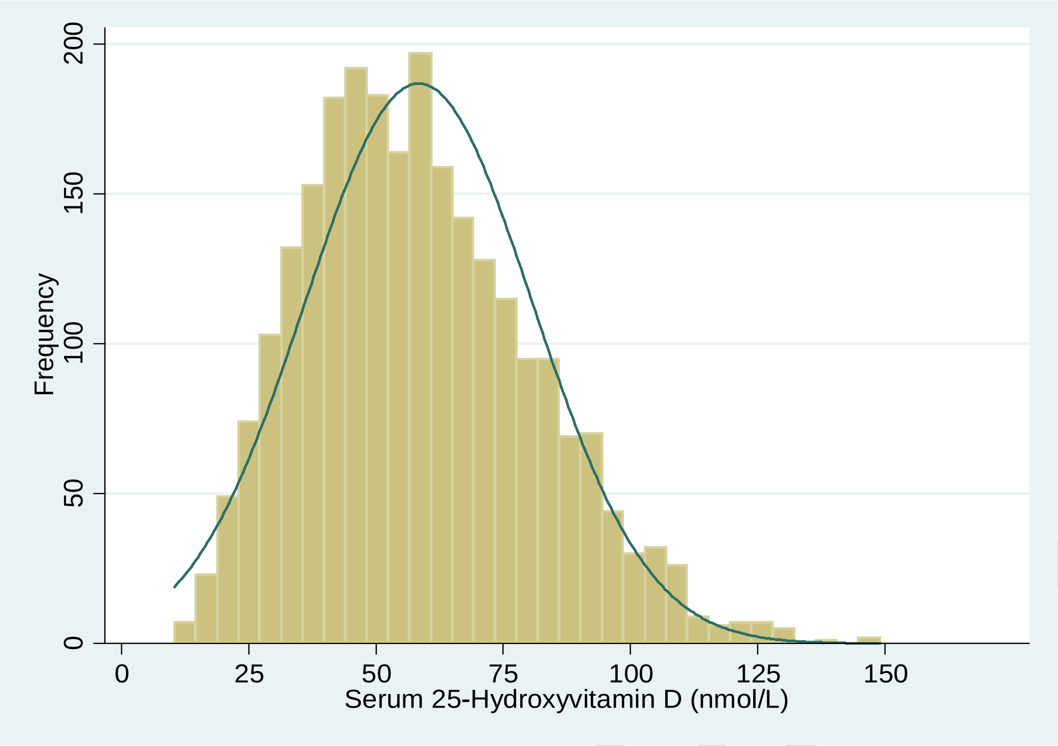
Fig. 1 Unadjusted frequency distribution of serum 25(OH)D levels in a random sample (n=2505), Nord-Trøndelag Health Study, 1995-1997. The graph was smoothed using kernel-smoothing density for normal distribution. Four subjects with serum 25(OH)D levels greater than 150nmol/L were excluded from the figure.



Abbreviation: 25(OH)D, 25-Hydroxyvitamin D

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