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ORIGINAL ARTICLE

Vitamin D deficiency and lifestyle risk factors in a Norwegian adolescent population

JOHANNA ÖBERG[1], ROLF JORDE[1,2], BJØRG ALMÅS[3], NINA EMAUS[4] & GURI GRIMNES[1,2]

[1]Tromsø Endocrine Research Group, Department of Clinical Medicine, UiT The Arctic University of Norway, Tromsø, Norway, [2]University Hospital of North Norway, Division of Internal Medicine, Tromsø, Norway, [3]Haukeland University Hospital, The Hormone Laboratory, Bergen, Norway, and *[4]Department of Health and Care Sciences, UiT The Arctic University of Norway, Tromsø, Norway*

Abstract

*Aim:*The aim was to study vitamin D status in a healthy adolescent Norwegian population at 69°N. *Methods*: The data presented come from The Tromsø Study: *Fit Futures*, during the school year 2010/2011 (not including the summer months), where 1,038 (92% of those invited) participated. Physical examinations, questionnaires and blood samples were collected, and serum 25-hydroxyvitamin D (25(OH)D) were analyzed using LC-MS/MS. *Results*: Results are presented from 475 boys and 415 girls (15–18 years old) with available blood samples. A total of 60.2% had vitamin D deficiency or insufficiency (serum 25(OH)D <50 nmol/l), 16.5% were deficient (<25 nmol/l) and 1.6% had severe vitamin D deficiency (<12.5 nmol/l). Only 12.4% had levels >75 nmol/l. A significant gender difference with a mean (SD) serum 25(OH)D level of 40.5 (20.5) nmol/l in boys and 54.2 (23.2) nmol/l in girls (p <0.01) was present. Furthermore, 51.3% of girls had levels >50 nmol/l in comparison to 29.7% of boys (p <0.01). There was an inverse correlation between parathyroid hormone levels and 25(OH) D, r_s= −0.30 (p<0.01). Explanatory factors that were significantly associated with serum 25(OH)D levels in multivariate models were use of snuff, consumption of vitamin D fortified milk, cod liver oil and vitamin/mineral supplements, physical activity, sunbathing holiday and use of solarium in boys, and vitamin/mineral supplements, physical activity, sunbathing holiday and use of solarium in girls . ***Conclusions*: Vitamin D deficiency is prevalent during the school year among adolescents in northern Norway, particularly among boys.**

Key Words: *Adolescents, epidemiology, parathyroid hormone, population-based study, risk factors, vitamin D, vitamin D deficiency*

Introduction

Research on vitamin D has increased dramatically over the past 10 years and many studies report high frequencies of vitamin D deficiency around the globe [1,2].

The traditional, well established role of vitamin D is in regulation of intestinal calcium absorption and calcium homeostasis. The strongest regulator for this process is parathyroid hormone (PTH). To maintain calcium within physiological limits, PTH increases the conversion of 25-hydroxyvitamin D (25(OH)D) to its active form 1.25-dihydroxyvitamin D ($1,25(OH)_2D$) through 1-α-hydroxylation in the kidneys. Severe 25(OH)D deficiency (25(OH)D <12.5 nmol/l) may lead to improper mineralization of the newly synthesized osteoid, eventually leading to rickets in children and osteomalacia in adults [3].

Adolescence is an important time for skeletal growth and optimization of peak bone mass. Insufficient levels of vitamin D and calcium could impair these processes, leading to skeletal problems in adulthood. Although less established, vitamin D deficiency in adolescence has also been linked to

Correspondence: Johanna Öberg, UiT The Arctic University of Norway, Tromsø Endocrine Research Group, Department of Clinical Medicine, Tromsø, Norway. E-mail: johanna.oberg@hotmail.com

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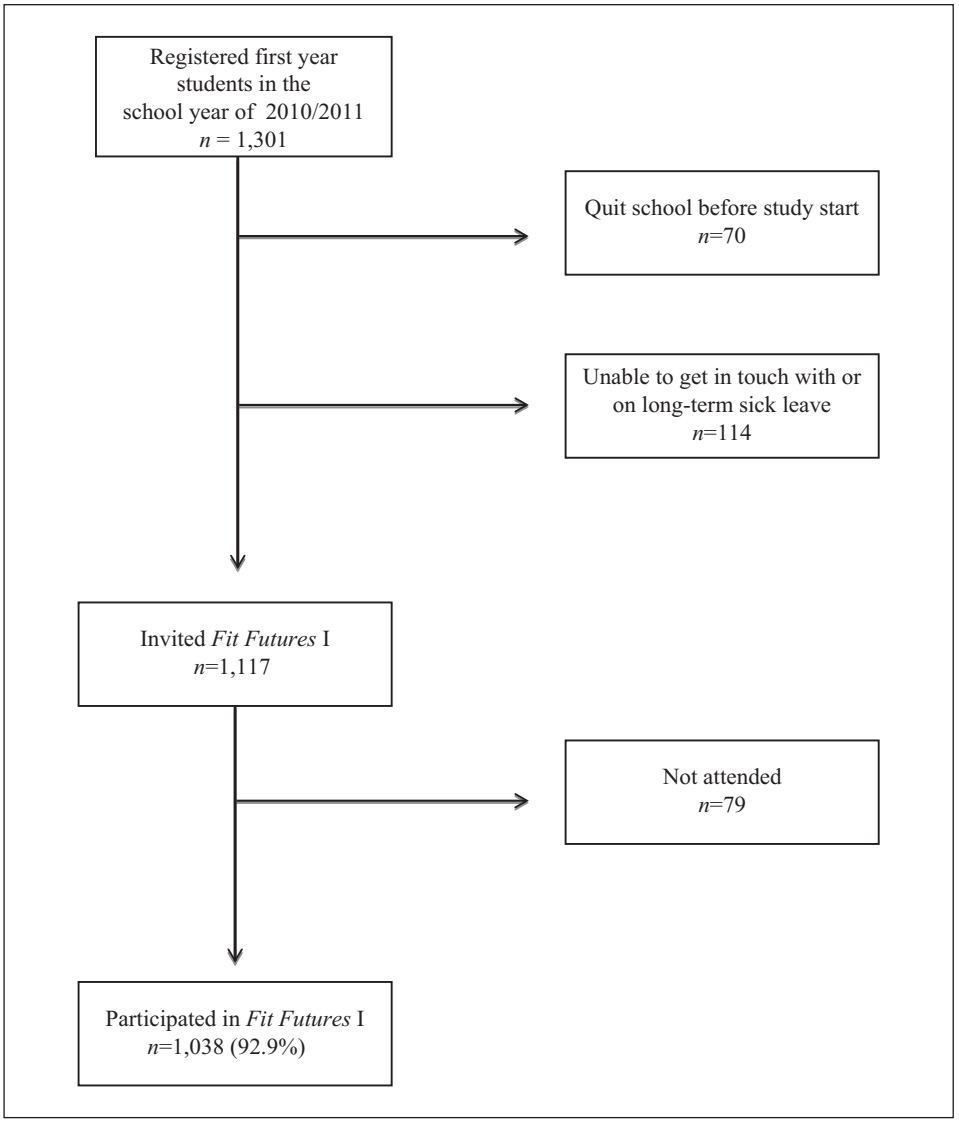

Figure 1. Flow-chart of the study selection process in The Tromsø Study: *Fit Futures*

other diseases [4,5]. Knowledge about the levels of 25(OH)D in the youth population is thus of importance. As yet, there is no consensus regarding optimal levels of 25(OH)D, and suggestions range from 50 nmol/l up to 75 nmol/l [1,2]. The Norwegian health authorities define sufficiency as levels >50 nmol/l, which is in line with other European countries [6].

Compared to countries further south, the adult Norwegian population has been surprisingly vitamin D sufficient [7]. This has been attributed to a wholesome diet including frequent fish consumption [8]. However, vitamin D status in the Norwegian general adolescent population has not yet been reported. Most studies in this age group from other countries are also small-sized, with a great variation in the prevalence of vitamin D deficiency. Cultural and geographical differences also make application from other studies to the Norwegian adolescent population difficult [9–15].

The city of Tromsø has a unique position, situated above the Arctic Circle at 69°N. People living above 50°N have decreased production of vitamin D in the skin due to the natural refraction of sunlight, which increases according to distance from the equator. At 69°N, the UVB radiation is below the limit of dermal vitamin D production for approximately six months a year (October–March) [16]. Traditionally, the low accessibility to sun in this area has been compensated by a culture of daily cod liver oil intake. Another source of vitamin D has been diet, consisting to a large extent of local fish. In particular, at the end of the winter darkness period, a traditional meal, "mølje", (cod, cod liver and roe) has been consumed. This meal is a rich source of vitamin D [8].

A changing lifestyle among adolescents with less physical activity, increased screen time and a diversion from the traditional north-Norwegian/Norwegian diet has raised concern regarding Norwegian adolescents' levels of vitamin D [6]. Dietary studies have reported low intake of vitamin D among the Norwegian adolescent population, below national recommendations of 7.5 μg daily [17,18]. With a large, representative youth sample available, we had the opportunity to study levels of 25(OH)D among adolescents in the age span between 15 and 18 years, to establish the deficiency prevalence and to examine factors influencing the levels of vitamin D in this representative adolescent population.

Subjects and methods

Study population

The Tromsø Study: *Fit Futures* is a population-based study among adolescents, evolving from The Tromsø Study, which has been ongoing since 1974 in the adult population [19]. All first year students attending upper secondary school (compulsory in Norway) in the two neighbouring municipalities of Tromsø and Balsfjord (69°N) were invited to participate throughout the school year (September 2010–April 2011) (Figure 1). The school nurse/contact person gave oral and written information about the study to potential participants. Information about the study was also available for the students and parents online. All students interested in participating in the study signed up online with a personal code. Written consent had to be given by the students before any examination was performed. For students under 16 years, the parent/proxy had to sign an additional consent. The participants were allowed to withdraw from the study at any time. Well-trained nurses performed all examinations at the Research Unit at the University Hospital of North Norway. The Regional Committee for Medical and Health Research Ethics North Norway approved the study.

Measurements

Physical examination. Anthropometric measures included height and weight measured with light clothing and no shoes to the nearest cm and hectogram at screening. These were used to compute the variable body mass index (BMI) (kg/m^2), which was then compared with the age and gender specific BMI cut-off curves developed by Cole et al. [20]. The participants were further categorized into one of four categories used in the analyses: thin, normal, overweight or obese.

Questionnaire. Quest-backs were filled in providing extensive information about the participants' lifestyle and eating habits. In the present study we used information on self-reported data on smoking and snuff habits, intake of fatty fish, cod liver and roe ("mølje"), extra semi-skimmed milk (fortified with vitamin D 0.4 μg pr. 100 g), cod liver oil and vitamin/mineral supplements. As an inverse proxy for outdoor activity, screen time, defined by hours used in front of computer or TV outside school during weekends, was included. The similar question regarding weekdays was considered less relevant as vitamin D production during afternoons in the school year will be negligible at this latitude, and was therefore not included in the analyses. Sexual maturation was assessed by Pubertal Development Scale in boys dividing the participants into four categories (have not begun, barely started, underway and completed) [21]. The questions used for this categorization were not available to all male participants due to logistic problems, and were therefore reported in 377 boys (79.4%). In girls, age of menarche was used for division into three categories (early (<12.5 years), intermediate (12.5–13.9 years), late (>14 years)) [22]. Physical activity was assessed using a question regarding exercise and physical exertion in leisure time. The participants could choose one of four categories based on average activity during the last 12 months: "Reading, watching TV, or other sedentary activity?", "Walking, cycling, or other forms of exercise at least 4 hours a week? (Including walking or cycling to place of school)", "Participation in recreational sports, heavy outdoor activities, snow clearing etc?", or "Participation in hard training or sports competitions, regularly several times a week?" [23]. Sun habits included skin type (classified by reaction to sunlight; "Always red, never brown", "Almost always red, sometimes brown", "Almost always brown, sometimes red", "Always brown, never red"), sunbathing holidays during the last two months and solarium used over the last four weeks. UVB exposure was defined as recent sunbathing holiday and/or use of solarium.

Laboratory analyses. Non-fasting blood samples were collected at the station. Serum 25(OH)D was analyzed in stored sera (−80 degrees C) using high pressure liquid chromatography mass spectroscopy (LC-MS/MS) at The Hormone Laboratory, Haukeland University Hospital [24]. The laboratory participates in the DEQAS quality programme. Reference values ranges from 50–113 nmol/l, and the coefficients of variation (CV) were <6%. The method allowed discrimination between 25(OH)D_2 and 25(OH)D_3, and the laboratory reported 25(OH)D_2

if levels were >10nmol/l. Serum PTH was analyzed consecutively using electrochemoluminescence immunoassay (ECLIA) (Roche) with Modular E170 (Roche Diagnostics) at the Department of Laboratory Medicine, University Hospital of North Norway. The reference range in adults (≤50 years) was 1.1–6.8 pmol/l with a CV of 6.4%, 3.7% and 4.6% at 1.9, 3.4 and 10.1 pmol/l, respectively. The laboratory uses Quality Management from Tieto Enator, Helsinki, Finland.

Statistical analyses

To test for a statistical difference between girls and boys in mean 25(OH)D values, an independent-samples *t*-test was conducted. There were outliers present when inspecting boxplots, violations of normality, and a moderate positive skewed data, however, the results did not change with a Mann-Whitney U test or by square-transformation of the data (the most successful transformation). Considering the largeness and equality of the sample sizes, and the congruent result by the non-parametric test, the independent-sample *t*-test was chosen for reporting the results. A Spearman's rank order correlation (r_s) was performed to assess the relationship between PTH and 25(OH)D. The relationship between the two variables was monotonic by visual inspection of a scatterplot. Also here there were outliers, but removing the most extreme values did not alter the value of r_s. A Chi-square test for association was used to test for a statistical difference between vitamin D sufficiency (>50 nmol/l) and insufficiency (≤50 nmol/l) between genders. General linear models were used to assess interaction between gender and the risk factors of interest and also to investigate interaction between dietary sources of vitamin D and UVB exposure. The results are presented stratified by gender due to significant interactions in some of the variables. A one-way ANOVA was conducted to test for linearity and significant difference between the risk factor groups stratified by gender. For analyses of the risk factors with two alternative answers, independent *t*-tests were conducted. There were violations of normality, but again, the result did not change when preforming the Mann-Whitney U test. The risk factors with significant effects on serum 25(OH)D levels in the univariate models or *t*-tests in at least one of the genders, were included in multiple linear regression analyses. For this model a log transformation of 25(OH)D was performed to meet the test assumptions. All analyses were performed using IBM SPSS statistics 19/21 (SPSS Inc., Chicago, IL). The limit for statistical significance was a *p*-value (α) <0.05 and all tests were two-sided. A formal power calculation was not made, but all participants available were utilized.

Table I. Baseline characteristics in 890 participants from The Tromsø Study: *Fit Futures* 2010/2011.

	Boys	Girls
n	475	415
Age (years)	16.1 (0.5)	16.2 (0.5)
25(OH)D (nmol/L)	40.5 (20.5)	54.2 (23.2)
PTH (pmol/L)	4.4 (1.6)	4.0 (1.3)
BMI (kg/m^2)	22.3 (4.0)	22.3 (4.0)
Sexual maturation[a]	2.9 (0.5)	1.9 (0.7)

BMI; body mass index, PTH; parathyroid hormone, 25(OH)D; 25-hydroxyvitamin D.
[a]Sexual maturation was assessed by age of menarche in girls and by pubertal development score in boys (available in 79.4%).

Results

Among the invited students, 92.9% participated in the study (*n*=1,038). We excluded those over 18 years (*n*=52) and those without blood samples (*n*=96) from analyses. Hence we present data from 890 participants (53% boys) between the ages of 15 to 18 years (median age 16.0 years). Nearly all participants were of Nordic Caucasian ethnicity (>95%) and their baseline characteristics are shown in Table I.

Serum 25(OH)D levels ranged from 7.2 to 133.0 nmol/l, and none of the samples contained 25(OH)D_2 >10 nmol/l. According to the Norwegian guidelines [6], a total of 60.2% had vitamin D deficiency or insufficiency (serum 25(OH)D <50 nmol/l), 16.5% were deficient (<25 nmol/l) and 1.6% had severe vitamin D deficiency (below 12.5 nmol/l). Consequently, 39.8% were vitamin D sufficient (>50 nmol/l), and only 12.4% had levels above the suggested cut-off of 75 nmol/l. There was a significant gender difference, with a mean (SD) serum 25(OH)D level of 40.5 (20.5) nmol/l in boys and 54.2 (23.2) nmol/l in girls (p<0.01) (Figure 2). Visual inspection revealed no obvious seasonal variation in 25(OH)D levels during the study period. The lowest measured levels were in November in both genders (32.6 nmol/l in boys and 48.0 nmol/l in girls), whereas the highest levels were measured in March in boys (47.4 nmol/l) and in September in girls (63.0 nmol/l).

A statistically significant difference between boys and girls regarding sufficient/insufficient levels of 25(OH)D was also present. Thus, 51.3% of girls had levels above 50 nmol/l, while this was true for only 29.7% of the boys (p<0.01). PTH measurements were available in 870 participants, and 44 (5.1%) had levels above the adult upper normal range of 6.8 pmol/l. Also, a negative correlation between PTH

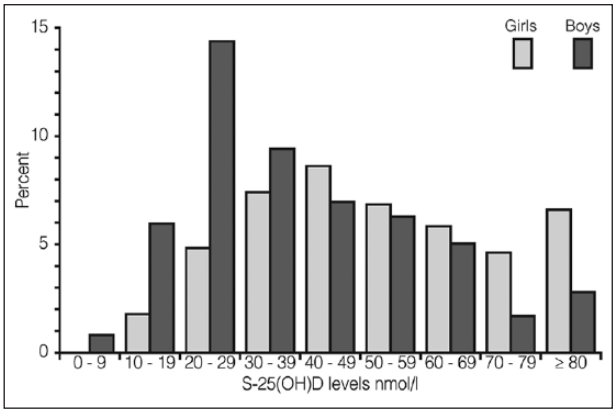

Figure 2. Distribution of serum 25(OH)D levels by gender

and 25(OH)D was detected, r_s = - 0.30 (p <0.01), with 25(OH)D explaining 9.2% of the variation in PTH.

Table II shows the associations between risk factors and serum 25(OH)D levels in univariate analyses. After adjustment in the multiple linear regression model, use of snuff; consumption of vitamin D fortified milk, cod liver oil and vitamin/mineral supplements; physical activity; sunbathing holiday and use of solarium were significantly associated with serum 25(OH)D in boys, whereas vitamin/mineral supplements, physical activity, sunbathing holiday and use of solarium were associated with serum 25(OH)D levels in girls. The models explained 30% of the variance (adjusted R^2) in both genders (Table III).

When examining both genders together there was a significant interaction between dietary sources of vitamin D and UVB exposure. None of the common dietary sources of vitamin D, with the exception of vitamin/mineral supplements, was associated with 25(OH)D levels in those who had recently been on a sunbathing holiday and/or used a solarium. In those without UVB exposure there were significant linear associations between dietary sources (cod liver oil, semi-skimmed milk, fatty fish and vitamin/mineral supplements) and 25(OH)D levels (data not shown).

Discussion

In this population-based study among Norwegian adolescents living at 69°N we found a high prevalence of serum 25(OH)D deficiency. There was a significant gender difference in 25(OH)D levels, with a higher rate of deficiency among boys. As expected, a negative correlation between PTH and 25(OH)D was found [15].

The prevalence of vitamin D deficiency is in line with results from other studies in adolescent populations [9–15], including small studies of subgroups at similar latitude [25]. However, the observed rate of deficiency is surprisingly high when compared with results from the adult population [7]. Several factors, such as a different diet, sun exposure, outdoor time and intake of cod liver oil can contribute to this observed difference between adults and adolescents. In addition, no 25(OH)D measurements were taken during the summer months (May–August).

The low levels of 25(OH)D demonstrated in this adolescent population could lead to health implications if not corrected. Particular emphasis should be given to the small (1.6%) but important group with severe vitamin D deficiency (<12.5 nmol/L), where the adolescents are at increased risk of rickets or osteomalacia [26]. Also, 5.1% of the participants had secondary hyperparathyroidism as defined by PTH levels above the adult reference range of 6.8 pmol/l. However, as PTH levels are normally raised during adolescence, these results are difficult to interpret [27]. Further health impact relating to low vitamin D levels in adolescence is an unsettled subject. As indicated by Munger et al., low serum 25(OH)D levels may be associated with increased risk of later development of multiple sclerosis, with an especially strong association with serum 25(OH)D measurements performed before the age of 20 years [4]. Also, an intervention trial with vitamin D or placebo in school children showed a reduced risk of influenza A or asthma in the intervention group compared with the placebo group [5].

Another important finding is the high frequency of vitamin D deficiency among boys, with only 30% measured with serum 25(OH)D levels above 50 nmol/l. The absolute difference of 13.7 nmol/l between genders was attenuated, but still significant, after adjustments for the statistically significant lifestyle factors from the univariate analyses (Table II) in a multiple linear regression model which included gender as an independent variable (adjusted difference 9.6 nmol/l) (data not shown). This could be due to biological differences, because increased oestrogen levels in puberty among females might lead to an increase in vitamin D binding protein and 25(OH)D levels [9]. Also in the HELENA study slightly higher levels of 25(OH)D were reported among girls 12–17 years old. [9]. However, since other studies report higher prevalence of vitamin D deficiency among girls, differences in lifestyle factors not captured by our questionnaire cannot be ruled out as an explanation for the lower serum 25(OH)D in boys [11,12]. Traditionally, due to the impact of 25(OH)D on bone health, the focus of 25(OH)D deficiency has been on the female population. Here, we find a poorer vitamin D profile among boys, suggesting that

Table II. Results from univariate analyses: serum 25(OH)D levels by risk factors and gender against lifestyle factors, in 890 participants from The Tromsø Study: *Fit Futures* 2010/2011.

Question	Alternatives	Boys			Girls			Interaction between gender and risk factor, *p*
		Serum 25(OH)D	*n*	Linear trend, *p*	*Serum 25(OH)D*	*n*	Linear trend, *p*	
Smoking	No, never	41.4 (20.7)	361	<0.01	53.2 (22.5)	331	0.79	<0.01
	Sometimes	37.6 (18.7)	91		60.9 (25.1)	66		
	Daily	27.0 (15.3)	17		54.9 (25.0)	13		
Snuff	No, never	42.5 (20.8)	279	0.01	51.4 (20.5)	279	0.10	<0.01
	Sometimes	36.7 (18.2)	58		67.1 (26.7)	58		
	Daily	37.0 (19.8)	131		56.2 (26.3)	74		
Fatty fish	Rarely/never	34.4 (17.5)	105	<0.01	53.8 (23.0)	76	0.57	0.06
	1–3 times per month	41.6 (21.3)	213		56.3 (25.1)	207		
	Weekly fish	42.4 (20.3)	149		51.9 (19.6)	126		
Mølje (cod liver and roe meal)	Rarely/never	40.0 (20.1)	276	0.35	54.4 (23.4)	257	0.52	1.00
	1–3 times per year	39.5 (21.7)	126		54.0 (22.4)	118		
	>4 times per year	42.6 (18.9)	63		57.1 (24.7)	35		
Extra semi-skimmed milk	Rarely/never	38.7 (20.4)	245	<0.01	51.5 (21.8)	189	0.20	0.27
	1–6 glasses per week	39.6 (19.9)	93		59.2 (24.8)	96		
	1 glass per day	40.1 (19.8)	58		53.8 (23.1)	66		
	>1 glass per day	46.9 (20.3)	70		58.1 (24.0)	56		
Cod liver oil	No	33.7 (16.7)	229	<0.01	51.5 (23.5)	193	<0.01	0.04
	Sometimes	42.8 (21.1)	158		54.4 (23.3)	144		
	Yes, daily	53.4 (20.8)	79		62.3 (19.8)	71		
Vitamin/mineral supplements	No	34.5 (17.4)	194	<0.01	49.1 (21.4)	134	<0.01	0.82
	Sometimes	40.6 (20.4)	195		53.7 (24.0)	188		
	Yes, daily	52.5 (21.4)	78		64.6 (20.8)	87		
Screen time weekends in hours per day	0–1.5 hours	41.8 (20.7)	46	0.06	55.4 (21.0)	62	0.03	<0.01
	2–3 hours	42.5 (20.4)	110		58.4 (23.2)	143		
	4–6 hours	42.3 (20.1)	175		52.8 (24.3)	149		
	>7 hours	35.1 (19.8)	137		47.5 (21.5)	55		
Sexual maturation, girls	Early				54.7 (23.6)	124	0.54	-
	Intermediate				55.0 (22.8)	191		
	Late				52.7 (23.8)	91		
Sexual maturation, boys	Has not started	N.A	0					-
	Barely started	37.3 (19.6)	62	0.85				
	Underway	42.0 (21.1)	280					
	Completed	38.1 (21.8)	35					
Weight group[a]	Thin	38.2 (23.4)	36	0.03	51.1 (27.6)	24	0.06	0.99
	Normal	42.9 (20.8)	322		56.5 (23.4)	303		
	Overweight	38.0 (18.5)	76		51.2 (20.2)	57		
	Obese	29.0 (13.1)	32		40.4 (14.8)	24		
Physical activity	Sedentary	32.2 (15.9)	138	<0.01	42.6 (21.4)	53	<0.01	0.74
	≥4 hours a week	36.5 (17.4)	114		51.5 (22.6)	166		
	Recreational sports	43.9 (22.9)	108		58.2 (22.7)	122		
	Hard training	50.4 (20.4)	109		63.3 (22.2)	71		

Table II. (Continued)

Question	Alternatives	Boys			Girls			Interaction between gender and risk factor, *p*
		Serum 25(OH)D	*n*	Linear trend, *p*	*Serum 25(OH)D*	*n*	Linear trend, *p*	
Skin colour when exposed to sun	Always red, never brown	27.5 (13.2)	25	<0.01	43.5 (14.8)	16	0.11	0.93
	Almost always red, sometimes brown	36.6 (17.9)	93		49.0 (19.2)	89		
	Almost always brown, sometimes red	44.0 (20.6)	236		57.7 (24.2)	229		
	Always brown, never red	38.9 (22.1)	102		50.7 (22.9)	71		
Sunbathing holiday	Yes	56.7 (23.8)	34	<0.01[b]	67.7 (23.1)	33	<0.01	0.63
	No	39.0 (19.7)	424		52.6 (22.7)	374		
Use of solarium	Yes	58.8 (19.5)	66	<0.01[b]	70.0 (22.5)	126	<0.01	0.60
	No	37.2 (19.0)	393		46.6 (19.5)	281		

[a]Weight groups calculated from gender and age specific BMI curves by Cole et al. [20].
[b]*p*-value from independent *t*-test between yes/no groups

focus on prevention might be especially important in this group.

The significant interactions between several of the risk factors and gender regarding serum 25(OH)D levels, might be due to differences in sun seeking behaviour, which is more frequent among girls, as most of the significant interactions disappeared when excluding the UVB-exposed from the interaction analyses (data not shown). There was also a gender difference in the risk factors associated with 25(OH)D levels in the adjusted analysis. In both genders vitamin/mineral supplements, physical activity, sunbathing holiday and solarium were associated with 25(OH)D levels, whereas use of snuff, consumption of fortified milk and cod liver oil were associated with 25(OH)D levels in boys only.

To our knowledge, a relation between snuff use and low serum 25(OH)D levels has not been reported previously. Whether snuff affects serum 25(OH)D levels by biological mechanisms or is a marker of an unhealthy lifestyle cannot be settled by this study, as there could be residual confounding factors not included in the model. Smoking was not associated with serum 25(OH)D levels in this study, but the number of smokers – as opposed to snuffers – were few. In adults, smokers have been reported to have equal or lower levels than non-smokers [24].

Intake of vitamin D supplements had a positive effect on 25(OH)D levels in both genders, in addition to fortified milk and cod liver oil, which was associated with higher 25(OH)D levels in boys. These results show that oral intake of such vitamin D rich substances could be a useful strategy for improvement of vitamin D status. This seems to be especially important in subjects exposed to little sunlight.

Both physical activity and screen time was associated with 25(OH)D levels in univariate analyses. Physical activity and screen time might both be markers of UVB exposure and only physical activity remained statistically significantly associated in the multiple regression model. However, since the data on physical activity and lifestyle were self-reported, bias due to misreporting may be possible.

Also, weight groups were only borderline associated with serum 25(OH)D levels in univariate analyses, and were not significant after adjustment. It has been postulated that the often reported lower serum 25(OH)D levels in overweight and obese persons are due to sequestration of serum 25(OH)D in fatty tissue [28]. We chose to use age- and gender-adjusted weight groups, which therefore may be less correlated with fat mass than BMI. Supporting this theory is the fact that when using unadjusted BMI in multivariate analyses, BMI was negatively correlated with 25(OH)D, significantly in boys (data not shown).

Table III. Results from multivariate linear regression analysis: predictors for serum 25(OH)D levels among 890 adolescents in The Tromsø Study: *Fit Futures* 2010/2011.

Independent variables	Boys			Girls		
	Standardized Beta (CI)	*t*-value	*p*-value	Standardized beta (CI)	*t*-value	*p*-value
Smoking (never, sometimes, daily)	−0.01 (−0.05 to 0.04)	−0.18	0.86	0.07 (−0.01 to 0.07)	1.41	0.16
Snuff (never, sometimes, daily)	−0.11 (−0.05 to 0.00)	−2.21	0.03	0.08 (0.00–0.04)	1.52	0.13
Fatty fish (rarely/never, 1–3 times per month, weekly fish)	0.03 (−0.02 to 0.04)	0.67	0.50	0.01 (−0.02 to 0.03)	0.21	0.83
Extra semi-skimmed milk (rarely/never, 1–6 glasses per week, 1 glass per day, >1 glass per day)	0.12 (0.00–0.05)	2.83	<0.01	0.05 (0.00–0.03)	1.22	0.23
Cod liver oil (no, sometimes, daily)	0.18 (0.03–0.08)	3.67	<0.01	0.07 (−0.00 to 0.04)	1.39	0.17
Vitamin/mineral supplements (no, sometimes, daily)	0.13 (0.01–0.07)	2.68	<0.01	0.14 (0.01–0.06)	3.14	<0.01
Screen time (0–1.5 hours, 2–3 hours, 4–6 hours, >7 hours)	−0.01 (−0.02 to 0.02)	−0.23	0.82	−0.05 (−0.03 to 0.00)	−1.03	0.30
Weight group (thin, normal, overweight, obese)	−0.07 (−0.05 to 0.00)	−1.62	0.11	−0.04 (−0.04 to 0.02)	−0.81	0.42
Physical activity (sedentary, ≥4 hours a week, recreational sports, hard training)	0.14 (0.00–0.05)	2.92	<0.01	0.23 (0.03–0.07)	4.58	<0.01
Skin colour when exposed to sun (always red, never brown. Almost always red, sometimes brown. Almost always brown, sometimes red. Always brown, never red)	−0.00 (−0.03 to 0.02)	−0.08	0.94	−0.04 (−0.04 to 0.01)	−0.98	0.33
Sunbathing holiday (no, yes)	0.15 (0.06–0.20)	3.54	<0.01	0.15 (0.05–0.18)	3.52	<0.01
Use of solarium (no, yes)	0.30 (0.14–0.25)	6.82	<0.01	0.36 (0.11–0.19)	8.02	<0.01
Adjusted R^2	**0.30**			**0.30**		

A recent sunbathing holiday and use of solarium were both strongly associated with 25(OH)D levels. Thus, dermal production through UVB exposure is also an important source of vitamin D in this population at high latitude, which is in accordance with previous studies [29]. Complicating such a message at a population level, is the increased risk of skin malignancies associated with UV radiation, and, currently, solarium use is at least in law restricted to persons above the age of 18 years in Norway. In the groups of participants who had recently been exposed to UVB radiation, there was no association between dietary sources of vitamin D and 25(OH)D levels, suggesting that dermal production surpasses dietary intake as the main source of vitamin D when sufficient UVB radiation is present. On the other hand, intake of vitamin D through dietary sources was strongly associated with 25(OH)D levels in the non UVB exposed group, underlining the importance of dietary awareness to ensure vitamin D sufficiency when dermal vitamin D production is minimal. There was no clear trend of seasonal variation in 25(OH)D levels, which could be explained by the lack of samples taken during the summer months. Furthermore, skin type was not significant in multiple analyses. Such an association is likely to be more pronounced if examined during the summer months.

The main strength of the study is the large, representative youth sample. This is the first study reporting serum 25(OH)D levels in Norwegian adolescents, and the high attendance rate allows the results of the study to be applied to populations with similar characteristics. However, the adolescent population further south might have higher levels of 25(OH)D due to the difference in latitude. The questionnaire used to assess risk factors was thorough and contained many of the known risk factors for vitamin D deficiency, and we thereby had the opportunity to study many risk factors at once. Also, we used a validated method for serum 25(OH)D measurements [24].

A weakness of the study is that inclusion was organized through the schools only. Therefore the adolescents not attending school were not invited and included in the study. Three years in upper secondary school is compulsory in Norway and persons not attending school most probably differ regarding socioeconomic status. In this group it would be expected that serum 25(OH)D levels would be lower, implying that the results from this study do not overestimate the prevalence of vitamin D deficiency in this adolescent population.

Conclusions

In conclusion, vitamin D deficiency is prevalent in this Norwegian adolescent population during the school year and seems to be especially prevalent among boys. The long-term health consequences are not known, and should be further studied. Preventative efforts at a population level could include fortification of a greater variety of commonly used dietary products, and should be considered, particularly as a large part of the population does not receive enough vitamin D through sun exposure. The association with taking snuff warrants further exploration; however, the association was only found in boys in this study.

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Conflict of interest

None declared.

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