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Original Contribution

Cross-Sectional and Prospective Cohort Study of Serum 25-Hydroxyvitamin D Level and Obesity in Adults

The HUNT Study

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Experimental studies suggest that vitamin D modulates the activity of adipocytes. The authors examined baseline serum 25-hydroxyvitamin D (25(OH)D) level in relation to prevalent and cumulative incident obesity in Norway. A cohort of 25,616 adults aged 19–55 years participated in both the second and third surveys of the Nord-Trøndelag Health Study (HUNT 2 (1995–1997) and HUNT 3 (2006–2008)). Serum 25(OH)D levels measured at baseline and anthropometric measurements taken at both baseline and follow-up were available for a random sample of 2,460 subjects. Overall, 40% of the 2,460 subjects had a serum 25(OH)D level less than 50.0 nmol/L, and 37% had a level of 50.0–74.9 nmol/L. The prevalence and cumulative incidence of obesity, defined as body mass index (weight (kg)/height $(m)^2$) $\geq$30, were 12% and 15%, respectively. Lower serum 25(OH)D level was associated with a higher prevalence of obesity. In the 2,165 subjects with baseline BMI less than 30, a serum 25(OH)D level less than 50.0 nmol/L was associated with a significantly increased odds ratio for incident obesity during follow-up (adjusted odds ratio = 1.73, 95% confidence interval: 1.24, 2.41). When prevalent and incident obesity were classified according to waist circumference ($\geq$88 cm for women, $\geq$102 cm for men), similar results were obtained. In addition to prevalent obesity, a serum 25(OH)D level less than 50.0 nmol/L was significantly associated with new-onset obesity in adults.

body mass index; cross-sectional studies; 25-hydroxyvitamin D; obesity; prospective studies; vitamin D; waist circumference

Abbreviations: BMI, body mass index; CI, confidence interval; HUNT, Nord-Trøndelag Health Study; 25(OH)D, 25-hydroxyvitamin D; $1,25(OH)_2D$, 1,25-dihydroxyvitamin D; OR, odds ratio; WC, waist circumference.

Both obesity and vitamin D insufficiency are highly prevalent worldwide (1–3). The two conditions are associated with each other (4–6), but the nature of the association requires clarification. Obesity has been proposed to lead to low body vitamin D status, although this directional association has been investigated in very few prospective epidemiologic studies (5). Because of its hydrophobic characteristics, vitamin D may move out of the circulation into the large amount of adipose tissue in obese persons, resulting in low serum levels of 25-hydroxyvitamin D (25(OH)D) even if the total body storage of vitamin D might be adequate (7). There is also a possibility that low vitamin D status increases the risk of obesity (8), since vitamin D appears to modulate the catabolic and anabolic activity of adipocytes in experimental studies (9). A recent study of Colombian children demonstrated that low serum 25(OH)D level was associated with a significant increase in adiposity, measured by changes in body mass index (BMI; weight (kg)/height $(m)^2$), skinfold thickness, and waist circumference (WC), during a follow-up period of approximately 3 years (10). By contrast, another prospective epidemiologic study from the United States did not observe any significant associations of 25(OH)D with changes in BMI and adipose tissue values in Hispanic and African-American adults after a 5-year follow-up (11). In the

present study, we used data from the Nord-Trøndelag Health Study (HUNT) to investigate the cross-sectional and prospective associations of serum 25(OH)D level and obesity in adults, who were followed up for 11 years, on average.

MATERIALS AND METHODS

Study population

HUNT is the largest and most comprehensive population health survey conducted in Norway to date. In the adult part of HUNT, investigators invited all inhabitants aged 19 years or older in the county of Nord-Trøndelag to participate in 3 separate surveys: HUNT 1 (1984–1986), HUNT 2 (1995–1997), and HUNT 3 (2006–2008) (12). Briefly, in 1995–1997, approximately 93,000 adults were invited to participate in HUNT 2, and 65,215 persons participated (response rate: 70%). Among those subjects, 57% ($n = 37{,}059$) took part in HUNT 3 in 2006–2008 (Figure 1).

We established a cohort that included all subjects who participated in both HUNT 2 and HUNT 3 and were aged <65 years in HUNT 3 ($n = 25{,}616$). This cohort was initially designed to study incident asthma. The age limit was set to decrease misclassification of asthma and chronic obstructive pulmonary disease.

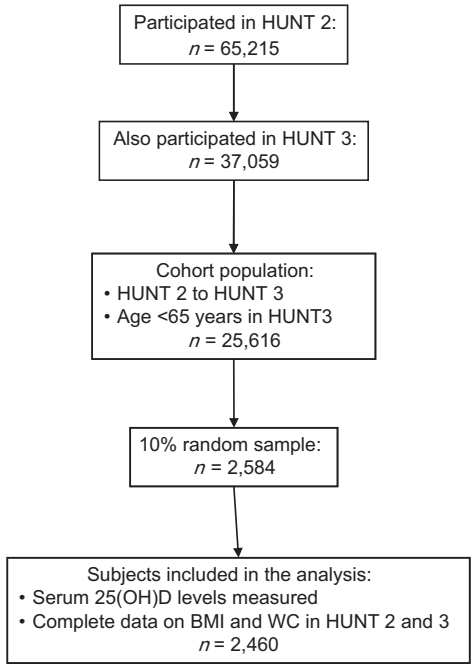

Figure 1. Selection of the study population, Nord-Trøndelag Health Study (HUNT), 1995–1997 to 2006–2008. HUNT 1 was conducted in 1984–1986, HUNT 2 in 1995–1997, and HUNT 3 in 2006–2008. (BMI, body mass index; 25(OH)D, 25-hydroxyvitamin D; WC, waist circumference).

Serum 25(OH)D level

Blood samples were collected from the HUNT 2 participants and stored in freezers at −20°C for later use. A 10% random sample of the cohort participants was selected for baseline serum 25(OH)D measurements ($n = 2{,}584$), and of these participants, 2,505 subjects had a sufficient volume of serum. Baseline serum 25(OH)D levels were measured using LIAISON 25-OH Vitamin D TOTAL (DiaSorin, Saluggia, Italy), a fully automated antibody-based chemiluminescence assay. The detection range of the assay is 10–375 nmol/L. The assay has an intraassay coefficient of variation of 4% and an interassay coefficient of variation of 8%.

Exposure variable and covariates

Baseline serum 25(OH)D levels were classified into 3 groups: <50.0 nmol/L, 50.0–74.9 nmol/L, and ≥75.0 nmol/L. These are widely used cutoff points in scientific literature (13–15). Data on other important variables, such as age, smoking habits, education, physical activity, and socioeconomic status, were collected in HUNT 2. These covariates were categorized as follows: age (19–29, 30–39, 40–49, or 50–55 years), daily smoking (yes/no), years of education (<10, 10–12, or ≥13 years), average number of hours of light physical activity per week (<1, 1–2, or ≥3 hours), receipt of social benefits (yes/no), and economic difficulties during the past year (yes/no). Social benefit recipients were those who reported receiving any public welfare benefits, such as sick pay/rehabilitation/retraining/unemployment/transitional benefits, a disability/retirement/widow's pension, a family income supplement, and/or other benefits. Subjects who were having economic difficulties were identified by their affirmative answer to the question, ''During the last year, has it at any time been difficult to meet the costs of food, transportation, housing and such?'' People with missing information on smoking, education, physical activity, and socioeconomic status were grouped into an ''unknown'' category for each variable and included in analyses.

Outcome variables

Body weight, height, and WC were measured by health professionals in both HUNT 2 and HUNT 3 (12). Height and weight were measured with the participant wearing light clothes without shoes; height was measured to the nearest 1.0 cm and weight to the nearest 0.5 kg. Waist circumference was measured horizontally at the umbilicus to the nearest 1.0 cm. Obesity was classified using 2 definitions in accordance with the recommendations of the World Health Organization (1) and the US National Institutes of Health (16): 1) BMI ≥30 for both women and men and 2) WC ≥88 cm for women and ≥102 cm for men. Prevalent obesity at baseline was classified according to BMI and WC, respectively, in HUNT 2. Incident obesity was new-onset obesity during the 11-year follow-up period among subjects who were not obese in HUNT 2.

Statistical analysis

The analysis was based on the random sample of 2,460 subjects who had complete information on serum 25(OH)D

levels in HUNT 2 and data on BMI and WC in both HUNT 2 and HUNT 3 (Figure 1). The cross-sectional association between serum 25(OH)D level and prevalent obesity was evaluated in this random sample of 2,460 subjects. The prospective association between serum 25(OH)D level and incident obesity defined by BMI was analyzed in a subsample of 2,165 subjects who had BMI <30 at baseline. Another subsample of 2,114 subjects who had WC <88 cm for women and <102 cm for men at baseline was used to study the prospective association between 25(OH)D level and incident obesity defined by WC.

Baseline characteristics in the random sample of 2,460 subjects were compared with those in the rest of the cohort population ($n = 23,156$) using chi-square tests. We calculated the prevalence of obesity in the cross-sectional analysis and the cumulative incidence of obesity in the prospective analysis according to the categories of serum 25(OH)D level. Logistic regression models were used to evaluate the associations of serum 25(OH)D level with prevalent and incident obesity, and crude and adjusted odds ratios and their 95% confidence intervals were calculated. The multivariable model included sex, age, smoking, education, physical activity, social benefits, and economic difficulties at baseline as important covariates. The analyses were further stratified by season of blood sample collection (December to May vs. June to November). In addition, we evaluated 25(OH)D levels as continuous values in association with BMI, WC, and body weight values in HUNT 2, as well as with changes in BMI, WC, and body weight between HUNT 2 and HUNT 3 (i.e., HUNT 3 minus HUNT 2), in the random sample of 2,460 subjects by means of multiple linear regression analyses (4 subjects with 25(OH)D values greater than 150 nmol/L were excluded as outliers). All statistical analyses were performed with Stata, release 11.1 (StataCorp LP, College Station, Texas).

Ethics

The study was approved by the Regional Committee for Medical Research Ethics. All participants gave their informed written consent.

RESULTS

Table 1 shows the baseline characteristics of the 2,460 random sample participants and the rest of the cohort population ($n = 23,156$). There were no significant differences in baseline characteristics between the two groups (for all, $P > 0.05$).

The prevalence of BMI-defined obesity was 12% at baseline in the random sample, and the cumulative incidence of obesity during the 11-year follow-up period was 15% in the 2,165 subjects without baseline obesity. Older age and a difficult economic situation were significantly associated with an increased odds ratio for prevalent obesity at baseline (Table 2), whereas higher education and more hours of light physical activity per week were significantly associated with a reduced odds ratio. With regard to incident obesity, a difficult economic situation at baseline was the only statistically significant risk factor (odds ratio (OR) = 1.45, 95% confidence interval (CI): 1.12, 1.88).

At baseline, 40% of the 2,460 subjects had a serum 25(OH)D level less than 50.0 nmol/L, 37% had a level of 50.0–74.9 nmol/L, and the rest had a level of 75.0 nmol/L or higher. A lower serum 25(OH)D level was associated with a higher prevalence of obesity defined by BMI ≥30 in the random sample (Table 3). A similar trend was observed for cumulative incidence of obesity in the 2,165 subjects without obesity at baseline. Figure 2 shows the unadjusted associations between serum 25(OH)D levels and prevalent and incident obesity. The smoothed line shows the probability of prevalent or incident obesity for each observed 25(OH)D level. Serum 25(OH)D level had an inverse association with both prevalent and incident obesity. After adjustment for sex, age, smoking, education, physical activity, social benefits, and economic difficulties at baseline in multivariable logistic regression analysis, a serum 25(OH)D level less than 50.0 nmol/L was associated with an increased odds ratio of 3.96 for prevalent obesity and an increased odds ratio of 1.73 for incident obesity (Table 3). Apart from 25(OH)D, economic difficulty was the only significant risk factor for incident obesity in the multivariable model (OR = 1.34, 95% CI: 1.02, 1.76).

When obesity was defined by WC (≥88 cm for women, ≥102 cm for men), the prevalence of obesity was 14% in the random sample, and the cumulative incidence of obesity during the 11-year follow-up period was 38% in the 2,114 subjects without baseline obesity (by WC criteria). The associations of baseline serum 25(OH)D level with prevalent and incident obesity defined by WC were similar to those for obesity defined by BMI. In the multivariable logistic regression model, serum 25(OH)D level <50.0 nmol/L was significantly associated with 2.6 times' increased odds for prevalent obesity and 1.6 times' increased odds for incident obesity (Table 4). Besides 25(OH)D, male sex was the only variable that was significantly associated with WC-defined incident obesity in the final model (OR = 0.36, 95% CI: 0.29, 0.43).

Significant associations were found between 25(OH)D <50 nmol/L and BMI-defined incident obesity in subjects whose blood samples were collected in December–May ($n = 1,207$; adjusted OR = 2.78, 95% CI: 1.44, 5.36) and in June–November ($n = 958$; adjusted OR = 1.81, 95% CI: 1.11, 2.94). The corresponding odds ratios for WC-defined incident obesity were 1.41 (95% CI: 0.96, 2.07) in December–May and 1.93 (95% CI: 1.31, 2.86) in June–November. The interaction between 25(OH)D <50 nmol/L and season of blood collection was not statistically significant for either BMI- or WC-defined incident obesity.

In general, 25(OH)D levels as continuous values were inversely and significantly associated with the values of BMI, WC, and body weight at baseline. For follow-up, each 25-nmol/L reduction in 25(OH)D level was associated with +0.14 units in BMI change ($P = 0.042$) and +0.4 kg in body weight change ($P = 0.037$) among subjects who had normal baseline BMI (<25). Each 25-nmol/L reduction in 25(OH)D level was associated with +0.5 cm in WC change ($P = 0.001$) among subjects who had normal baseline WC (<80 for women, <94 for men). Among subjects who were overweight or obese at baseline, however, 25(OH)D levels were not significantly associated with changes in BMI, body weight, or WC.

Table 1. Baseline Characteristics of a Random Sample and the Rest of the Cohort Population, Nord-Trøndelag Health Study, 1995–1997 to 2006–2008

	Random Sample (n = 2,460)			Rest of Cohort (n = 23,156)		
	No.	%	Mean (SD)	No.	%	Mean (SD)
Age, years						
19–29	363	15		3,675	16	
30–39	729	30		6,887	30	
40–49	978	40		8,953	39	
50–55	390	16		3,641	16	
Sex						
Female	1,342	55		12,851	56	
Male	1,118	45		10,305	45	
Smoking						
No	1,638	67		15,283	66	
Yes	685	28		6,701	29	
Unknown	137	6		1,172	5	
Education, years						
<10	483	20		4,624	20	
10–12	1,327	54		12,307	53	
≥13	628	26		6,021	26	
Unknown	22	<0.1		204	<0.1	
Physical activity, hours/week						
<1	556	23		5,270	23	
1–2	847	34		8,371	36	
≥3	762	31		7,169	31	
Unknown	295	12		2,346	10	
Social benefits						
Nonrecipient	1,585	64		14,464	63	
Recipient	446	18		4,161	18	
Unknown	429	17		4,531	20	
Economic difficulties in past year						
No	1,452	59		13,214	57	
Yes	695	28		6,461	28	
Unknown	313	13		3,481	15	
Body mass index[a]			25.8 (3.7)			25.8 (3.8)
Waist circumference, cm			84.1 (11.2)			84.0 (11.2)

Abbreviation: SD, standard deviation.
[a] Weight (kg)/height (m)^2.

DISCUSSION

During an 11-year follow-up period, our population-based study of Norwegian adults demonstrated that serum 25(OH)D level has a cross-sectional association with prevalent obesity and a prospective association with incident obesity. The cross-sectional association is well-established (4–6) and is thought to be due to obesity-related decreases in circulating levels of 25(OH)D. By contrast, our study is one of the few prospective cohort studies to have investigated the possible effect of low vitamin D status on change in adiposity and development of obesity. We found a consistent inverse association between baseline 25(OH)D levels and incident obesity defined by either BMI or WC after 11 years of follow-up, and this inverse association was not modified by season of blood sample collection. We also observed inverse associations between 25(OH)D values and changes in BMI, WC, and body weight among subjects who had normal baseline BMI or WC.

Our results are consistent with those of a longitudinal study of school-age children in Colombia (10) which found that a plasma 25(OH)D level less than 50 nmol/L was associated

Table 2. Association of Baseline Characteristics With Prevalent Obesity at Baseline and Incident Obesity During Follow-up, With Obesity Defined by Body Mass Index,[a] Nord-Trøndelag Health Study, 1995–1997 to 2006–2008

	Prevalent Obesity at Baseline (n = 2,460)		Incident Obesity During Follow-up (n = 2,165)	
	Crude OR	95% CI	Crude OR	95% CI
Age, years				
19–29	1.00	Referent	1.00	Referent
30–39	1.39	0.89, 2.15	0.92	0.64, 1.32
40–49	1.49	0.98, 2.28	0.86	0.61, 1.21
50–55	2.34	1.49, 3.70	0.86	0.57, 1.32
Sex				
Female	1.00	Referent	1.00	Referent
Male	0.95	0.75, 1.22	1.14	0.90, 1.44
Smoking				
No	1.00	Referent	1.00	Referent
Yes	0.91	0.69, 1.20	1.18	0.91, 1.53
Education, years				
<10	1.00	Referent	1.00	Referent
10–12	0.68	0.50, 0.91	0.88	0.65, 1.20
≥13	0.57	0.40, 0.81	0.82	0.58, 1.17
Physical activity, hours/week				
<1	1.00	Referent	1.00	Referent
1–2	0.50	0.37, 0.68	0.85	0.62, 1.17
≥3	0.46	0.33, 0.63	0.77	0.56, 1.07
Social benefits				
Nonrecipient	1.00	Referent	1.00	Referent
Recipient	1.25	0.92, 1.71	1.21	0.89, 1.65
Economic difficulties in past year				
No	1.00	Referent	1.00	Referent
Yes	1.33	1.01, 1.75	1.45	1.12, 1.88

Abbreviations: CI, confidence interval; OR, odds ratio.
[a] Obesity was defined as body mass index (weight (kg)/height $(m)^2$) ≥30.

Table 3. Association of Baseline Serum 25-Hydroxyvitamin D Level With Prevalent Obesity at Baseline and Incident Obesity During Follow-up, With Obesity Defined by Body Mass Index,[a] Nord-Trøndelag Health Study, 1995–1997 to 2006–2008

25-Hydroxyvitamin D Level, nmol/L	No. of Participants	No. of Cases	%	Crude OR	95% CI	Adjusted[b] OR	95% CI
Prevalent Obesity at Baseline (n = 2,460)							
≥75.0	565	27	4.8	1.00	Referent	1.00	Referent
50.0–74.9	922	97	10.5	2.34	1.51, 3.64	2.19	1.40, 3.41
<50.0	973	171	17.6	4.25	2.79, 6.47	3.96	2.58, 6.08
Incident Obesity During Follow-up (n = 2,165)							
≥75.0	538	58	10.8	1.00	Referent	1.00	Referent
50.0–74.9	825	122	14.8	1.44	1.03, 2.00	1.38	0.99, 1.94
<50.0	802	147	18.3	1.86	1.34, 2.57	1.73	1.24, 2.41

Abbreviations: CI, confidence interval; OR, odds ratio.
[a] Obesity was defined as body mass index (weight (kg)/height $(m)^2$) ≥30.
[b] Multivariable logistic regression model including sex, age, smoking, education, physical activity, social benefits, and economic difficulties at baseline.

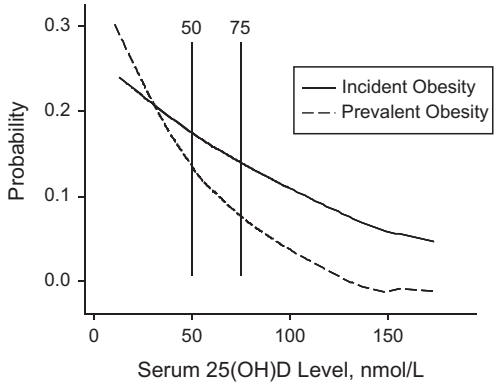

Figure 2. Unadjusted associations of serum 25-hydroxyvitamin D (25(OH)D) levels with the probabilities of prevalent obesity and cumulative incident obesity, defined by body mass index (weight (kg)/height $(m)^2$) ≥30, Nord-Trøndelag Health Study, 1995–1997 to 2006–2008. The graph was smoothed using locally weighted scatterplot smoothing. The vertical lines indicate 25(OH)D cutoff points. Four subjects with 25(OH)D levels greater than 150 nmol/L were excluded.

with a significant increase in BMI and WC values during an approximate 3-year follow-up period. In addition, both our study and this pediatric study suggest that lower 25(OH)D levels are a risk factor not only for overall obesity as defined by BMI but also for central obesity as defined by WC. By contrast, the aforementioned prospective epidemiologic study in adults does not support an association between 25(OH)D and change in adiposity as measured by the changes in BMI and adipose tissue values after a 5-year follow up (11). Difference in follow-up duration may explain the discrepancy between our current study and this previous adult study. Our findings of a different pattern with change in BMI among baseline BMI subgroups may also explain some of the inconsistent results. A larger change in BMI on average in the normal BMI group than in the overweight or obese group was a possible reason for this observed difference in our study.

Findings from clinical trials—in terms of the effect of vitamin D supplementation on weight control—also are mixed. A Norwegian randomized clinical trial showed no effect of vitamin D supplementation with 20,000 IU or 40,000 IU of cholecalciferol per week (vs. placebo) on weight loss in 334 healthy overweight or obese persons after 12 months (17). Another trial with supplementation of vitamin D and calcium versus placebo during a 3-month low-calorie diet failed to reduce additional weight in obese women (18). In contrast, in another clinical study, Ortega et al. (19) reported that overweight or obese women responded more positively to hypocaloric diets and lost more body fat if they had a better vitamin D status. In addition, in a large trial in the Women's Health Initiative, women who received 1,000 mg of calcium plus 400 IU of vitamin D per day, versus a placebo, had a significantly lower gain in BMI and WC over a 7-year follow-up period (20). Taken together, vitamin D, or vitamin D together with calcium supplementation, seemed to have an effect on restriction of weight gain in the general population, but their effect on weight reduction in subjects who had already become obese may be limited. However, we should bear in mind that control of energy balance is the predominant factor in achieving weight reduction in obese subjects (21). If energy balance was not equally controlled in the trial groups, the effect of vitamin D could be masked. In addition to this, the relatively short follow-up periods may help explain the observed lack of effect of vitamin D supplementation on weight reduction in already obese people.

Although the mechanism for how low serum 25(OH)D levels might increase the incidence of obesity is not well understood, our findings have biologic plausibility. In vitro, experimental studies suggest that 1,25-dihydroxyvitamin D ($1,25(OH)_2D$) favors lipogenesis and inhibits lipolysis, and it also modulates the distribution of fat (9, 22, 23). Subjects with clinically important low vitamin D status (defined as serum 25(OH)D level <50 nmol/L) often have secondary hyperparathyroidism and elevated levels of parathyroid hormone

Table 4. Association of Baseline Serum 25-Hydroxyvitamin D Level With Prevalent Obesity at Baseline and Incident Obesity During Follow-up, With Obesity Defined by Waist Circumference,[a] Nord-Trøndelag Health Study, 1995–1997 to 2006–2008

25-Hydroxyvitamin D Level, nmol/L	No. of Participants	No. of Cases	%	Crude OR	95% CI	Adjusted[b] OR	95% CI
Prevalent Obesity at Baseline (n = 2,460)							
≥75.0	565	45	8.0	1.00	Referent	1.00	Referent
50.0–74.9	922	112	12.2	1.60	1.11, 2.30	1.43	0.99, 2.08
<50.0	973	189	19.4	2.79	1.98, 3.93	2.63	1.84, 3.76
Incident Obesity During Follow-up (n = 2,114)							
≥75.0	520	170	32.7	1.00	Referent	1.00	Referent
50.0–74.9	810	298	36.8	1.20	0.95, 1.51	1.13	0.89, 1.44
<50.0	784	340	43.4	1.58	1.25, 1.99	1.56	1.22, 1.99

Abbreviations: CI, confidence interval; OR, odds ratio.

[a] Obesity was defined as waist circumference ≥88 cm for women and ≥102 cm for men.

[b] Multivariable logistic regression model including sex, age, smoking, education, physical activity, social benefits, and economic difficulties at baseline.

and $1,25(OH)_2D$ (15, 24, 25). Parathyroid hormone itself has also been suggested to play a role in fat accumulation by increasing the risk of insulin resistance and inhibiting lipolysis, and it may be mediated by $1,25(OH)_2D$ (8, 26). This might help to explain why serum 25(OH)D levels less than 50 nmol/L were most strongly associated with cumulative incident obesity in our study and with a greater increase in adiposity values in the Colombian pediatric study (10).

Our large, population-based study had several strengths. We performed a cross-sectional analysis to confirm the previously suggested association between serum 25(OH)D level and prevalent obesity, and we also conducted a prospective analysis to elucidate the role of body vitamin D status in the development of obesity. Moreover, baseline serum 25(OH)D levels were measured in a large random sample which was highly representative of the cohort population, and there was large variation in the serum 25(OH)D levels (e.g., the 10th and 90th percentiles were 31.6 nmol/L and 89.8 nmol/L, respectively). The mean 25(OH)D value in our study (58.8 nmol/L; standard deviation, 23.1) is compatible with values from another Norwegian study (27) and Scandinavian studies in general (28). In addition, a previous study provided some evidence for a small variation of 25(OH)D levels over time in adults after season was taken into consideration (27). Body weight, height, and WC were objectively measured, and obesity was classified using standard definitions. The prevalence of obesity in the present study was in line with that in the general population of Norway (29).

Although the independent association between serum 25(OH)D level and incident obesity remained after adjustment for several important covariates, there is a possibility of additional confounding. For example, the measurement of some covariates, such as physical activity, is not perfect, and we also lacked data on energy intake and dietary intake in general. Socioeconomic status can be used as a proxy measure for dietary factors, since low social status is associated with diet insecurity (30). Our study demonstrated that the association of 25(OH)D with obesity development was independent of low socioeconomic status. However, this confounding, if it existed, would need to be quite large to explain the observed odds ratios. Furthermore, our finding may have limited generalizability to the entire adult population because of the age limit at enrollment. Studies on the association between vitamin D level and obesity development in elderly people are called for.

To summarize, obesity is widely recognized to lead to lower vitamin D status in the body because of the fat-soluble property of vitamin D and other factors (7). This inference was mainly made from cross-sectional associations (4–6) and a few prospective observations and clinical trials (5, 31, 32). Our study confirmed the cross-sectional association but also provided new evidence that lower 25(OH)D levels may contribute to new-onset obesity in adults. We also found that central obesity increased more rapidly than overall obesity (38% vs. 15%) and that lower serum 25(OH)D level was a risk factor for both overall and central obesity. The detrimental effects of overall obesity have been shown worldwide (33–35). Central obesity is an important component of and risk factor for the metabolic syndrome (36). Recent research has also provided evidence for multiple adverse effects of central abdominal obesity (37–39). Thus, the implications could be profound if improvement of vitamin D status could reduce both overall and central obesity. We suggest that there might be a harmful cycle (i.e., low vitamin D → obesity → low vitamin D) that complicates obesity prevention and treatment efforts. This possibility merits further research in well-designed large prospective studies.

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Conflict of interest: none declared.

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