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ORIGINAL ARTICLE

Impact of gender on vitamin D deficiency in morbidly obese patients: a cross-sectional study

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Background/Objective: Obesity is associated with vitamin D deficiency (25-hydroxyvitamin D (25(OH)D) <50 nmol/l). We aimed to examine the effect of gender on vitamin D status in severe obesity.
Subjects/Methods: Cross-sectional study of 2026 morbidly obese patients examined consecutively at a tertiary care centre between November 2005 and June 2010. Serum 25(OH)D concentration and use of vitamin D supplements were registered in all patients. Total vitamin D intake (μg/day) was assessed in a subgroup of 154 patients using a validated food frequency questionnaire.
Results: The male ($n = 690$) and female ($n = 1336$) patients had a mean (s.d.) age of 45.0 (12.1) years and 42.2 (12.2) years ($P < 0.001$), body mass index (BMI) of 44.6 (6.0) kg/m^2 and 44.3 (5.9) kg/m^2 ($P = 0.30$) and waist circumference (WC) of 140 (13) cm and 127 (13) cm ($P < 0.001$), respectively. Male patients had significantly lower mean 25(OH)D concentrations than female patients 50.0 (22.0) nmol/l versus 53.6 (22.4) nmol/l ($P = 0.001$) and a higher rate of vitamin D deficiency (56% versus 47%; $P < 0.001$). Obese men had significantly higher odds of vitamin D deficiency than women (odds ratio = 1.41; 95% confidence interval: 1.17–1.70, $P < 0.001$), also after adjustment for season, age, current smoking, intake of vitamin D supplements, BMI and WC (odds ratio = 1.39; 95% confidence interval: 1.10–1.76).
Conclusions: Morbidly obese Norwegian men seeking weight loss treatment have significantly higher odds of vitamin D deficiency than women. Monitoring of 25(OH)D concentrations in obese patients should therefore take gender into account.
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Keywords: vitamin D (25(OH)D) deficiency; morbid obesity; gender

Introduction

Vitamin D is not only essential for calcium metabolism and bone mineralization but may also have a role in the maintenance of neuromuscular function and prevention of coronary heart disease (Zittermann and Koerfer, 2008; Giovannucci, 2009), some forms of cancer (Bertone-Johnson, 2009; Chiang and Chen, 2009) and other chronic diseases (Holick, 2007; Peterlik and Cross, 2009). Obesity is associated with increased risk of vitamin D deficiency. The inverse relationship between obesity and serum vitamin D concentrations may have several explanations, including deposition of vitamin D in body fat compartments, reduced release of vitamin D into systemic circulation and low exposure to sun light (Wortsman *et al*., 2000). Both subcutaneous and visceral adiposity are associated with low vitamin D concentrations (Cheng *et al*., 2010).

Morbid obesity (body mass index (BMI) $\geqslant$ 40 kg/m^2 or BMI $\geqslant$ 35 kg/m^2 with at least one obesity related comorbidity) is associated with a two- to threefold increased morbidity and mortality (Must *et al*., 1999; Flegal *et al*., 2005; Berrington de Gonzalez *et al*., 2010). In all, 5% of the United States population and 2% of the Norwegian

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population can be classified as either morbidly or extremely obese (BMI⩾40 kg/m^2; Ogden *et al*., 2006; Graff-Iversen *et al*., 2007). Globally, extreme obesity is more prevalent among women than men, with up to 70% of extremely obese persons being women (Ogden *et al*., 2006). Women have relatively more body fat than men and store more fat in the gluteal–femoral region, while men typically store more fat in the visceral (abdominal) depot (Blaak, 2001; Hofso *et al*., 2009a). Some studies have found a higher prevalence of vitamin D deficiency among men than women (Aasheim *et al*., 2008; Lagunova *et al*., 2009). As vitamin D is a fat soluble vitamin that may potentially be sequestrated in adipose tissue (Wortsman *et al*., 2000), one could hypothesize that a gender difference in the prevalence of vitamin D deficiency is related to differences in the amount of body fat and/or its distribution. To address this hypothesis, we analyzed the effect of gender on vitamin D status in a large cohort of morbidly obese Norwegian patients. In addition, we explored whether a possible gender based difference in vitamin D status might be explained by variations in overall (BMI) and/or abdominal (waist circumference (WC)) obesity.

Subjects and methods

Study population, design and setting

The Morbid Obesity Centre in Vestfold is a public tertiary care centre, which serves approximately one million inhabitants in southern Norway. A total of 2140 consecutive morbidly obese patients who attended the Morbid Obesity Centre between November 2005 and June 2010 were considered for inclusion in this cross-sectional study. We excluded 39 patients with BMI < 35 kg/m^2 and 75 patients because of missing measurements for either 25-hydroxyvitamin D (25(OH)D) ($n = 48$), BMI ($n = 11$) or both ($n = 16$). The remaining 2026 patients were included in the analysis. In addition, a subgroup of 154 patients (Hofso *et al*., 2009b) examined between December 2005 and May 2006 was evaluated in order to assess total vitamin D intake and macronutrient composition. All patients gave written consent before enrollment and the study was approved by the Regional Committee for Medical Research Ethics and conducted in accordance with the Declaration of Helsinki (World Medical Association, 1997).

Variables

The main outcome variables were the prevalence of vitamin D deficiency (serum concentration of 25(OH)D < 50 nmol/l) and serum 25(OH)D concentration. Explanatory variables were gender, age, season of blood sampling (winter (1 November through till 28 February) or summer (1 March through till 31 October)), intake of vitamin D supplements, total vitamin D intake (in a subgroup analysis, see below), current smoking, central obesity (WC) and overall obesity (BMI).

Physical examination

All patients were examined by a physician at their first visit to the centre. Demographic data, medical history, smoking habit, physical activity level and intake of vitamin D containing supplements were recorded using standardized forms. Weight and height were measured with patients wearing light clothing and no shoes. Waist, hip and neck circumferences were measured with a tape measure to the nearest cm. Waist and hip circumference were measured with the patient standing; at the midpoint between the lowest rib margin and the iliac crest, and at the level of the major trochanter, respectively.

Definitions

Patients who had a history of type 2 diabetes or a fasting serum glucose concentration ⩾7 mmol/l were classified as having type 2 diabetes (American Diabetes Association, 2009).

Ischemic heart disease was defined as a history of percutaneous coronary intervention, coronary artery bypass graft surgery or myocardial infarction.

Vitamin D deficiency was defined as serum 25(OH)D < 50 nmol/l (< 20 ng/ml; Bischoff-Ferrari *et al*., 2006, Holick, 2007). Elevated C-reactive protein concentration was defined as fasting C-reactive protein ⩾7 mg/l, which was the lowest detection limit for the essay used.

Secondary hyperparathyroidism was diagnosed in patients with a serum parathyroid hormone concentration > 6.9 pmol/l and concomitant serum calcium < 2.54 mmol/l (upper limits of reference ranges).

Intake of vitamin D supplements was defined as daily intake of supplements containing ⩾5 μg vitamin D (cod liver oil, fish oil capsules, multivitamin supplements or pure vitamin D supplements).

Data on physical activity was available in 1451 consecutive patients examined from May 2007 until June 2010. Patients were classified as physically active if they conducted ⩾60 min of vigorous intensity aerobic physical activity per week (Kurtze *et al*., 2007).

In Northern latitudes, ultraviolet B radiation varies with season. During the winter season ultraviolet B radiation is insufficient for vitamin D to be synthesized in the skin. Patients were recruited from Southern Norway (58–60°N), where solar exposure and ultraviolet B radiation is low during winter.

Laboratory analyses

Blood samples were obtained after an overnight fast. Serum 25(OH)D was measured at the Hormone Laboratory, Oslo University Hospital by radioimmunoassay (DiaSorin, Stillwater, MN, USA). The interassay coefficient of variation for 25(OH)D was 14%. C-reactive protein was analyzed using dry reagent slide technology on the Vitros 950 Analyzer until November 2006 and thereafter using Vitros

FS 5.1 (Ortho-Clinical Diagnostics, New York, NY, USA). Intact parathyroid hormone was essayed using an electro-chemiluminescence immunoassay on the Elecsys 2010 (Roche Diagnostics GmbH, Mannheim, Germany; Hjelmesaeth *et al*., 2009).

Dietary data
Vitamin D intake was estimated in a subgroup of 154 patients who participated in a clinical intervention study (ClinicalTrials.gov:. NCT00273104; Hofso *et al*., 2009b) using a validated food frequency questionnaire (Nes *et al*., 1992; Solvoll *et al*., 1993; Andersen *et al*., 1996; Andersen *et al*., 1999). The food frequency questionnaire is designed to measure the habitual food intake of the adult population in Norway and is suitable for estimating the intake of a variety of macro- and micronutrients, including intake from dietary supplements (Nes *et al*., 1992). The food frequency questionnaire was completed in structured dietary interviews conducted by registered dieticians, with patients asked to describe their dietary habits during the last year. Questionnaires were scanned (Teleform 10.0; Cambridge, UK) and the daily intake of foods, energy and nutrients were calculated using computer software (KBS 6.0; University of Oslo) based on data from the Norwegian food composition table (National Nutrition Council Norwegian Food Safety Authority, 1995).

Calculations and equations
To identify individuals underreporting their energy intake (EI), we calculated cutoff levels for acceptable reported EI according to Blacks equations and practical guidelines (Black, 2000a, b). Basal metabolic rate was estimated with the Mifflin–St Jeor equations (Mifflin *et al*., 1990), which is deemed to be the most reliable method for estimating basal metabolic rate in both non-obese and obese individuals (Frankenfield *et al*., 2005). We assumed a physical activity level 1.56 for women and 1.55 for men, in accordance with the Food and Agriculture Organization of the United Nations (FAO)/World Health Organization/United Nations University (UNU) 1985 values of low activity level for each gender. Men and women with EI:basal metabolic rate <1.10 and <1.11, respectively, were classified as underreporters.

Statistical analysis
Data are given as either mean (s.d.; normally distributed data), median (25th–75th percentile; non-normally distributed continuous data) or proportion (%) unless otherwise stated. Differences between groups were analyzed using independent samples *t*-test, Mann–Whitney *U*-test (continuous data) or Fisher's exact test (categorical data). Multiple logistic regression with predefined explanatory variables was used to assess the likelihood of insufficient vitamin D concentration (yes/no). Hosmer–Lemeshow test was used to assess the adequacy of the fit of the logistic regression models.

We fitted four separate logistic regression models. In model 1, gender was entered (women = reference) as the sole explanatory variable in a univariate (unadjusted) logistic regression analysis with insufficient vitamin D concentration (yes/no) as the dependent variable. In model 2, we adjusted for well-known confounding factors, such as season of blood sampling, age, current smoking (Brot *et al*., 1999) and vitamin D supplement. To address the possible modifying effects of overall obesity, in model 3, we further adjusted for BMI. In model 4, a final adjustment was made for WC. Interaction terms between gender and the other explanatory variables were included and tested. A 5% statistical significance level was chosen. The analyses were implemented in SPSS 16.0 (SPSS, Chicago, IL, USA).

Results

Characteristics
The characteristics of the 2026 morbidly obese patients (66% women) are shown in Table 1. Men were on average 2.8 years older, 21 kg heavier and had 13 cm wider WC than women ($P<0.001$ for all). The prevalence of type 2 diabetes and coronary artery disease was higher among men than women, whereas ethnicity, season of blood sampling, BMI and physical activity did not differ significantly between genders. Mean 25(OH)D concentrations were approximately 4 nmol/l lower in men than in women ($P=0.001$).

Vitamin D deficiency—gender differences
Overall, about half of the patients had vitamin D deficiency. In addition, vitamin D deficiency was more prevalent in men than in women, 56% versus 47% ($P<0.001$). This gender difference seemed to be most pronounced in the winter season, but the difference was also statistically significant in the summer season (Figure 1).

Gender differences in 25(OH)D concentrations according to season
Men had significantly lower 25(OH)D concentrations than women during the winter season, mean (s.d.) 45.3 (17.8) nmol/l versus 51.6 (22.4) nmol/l ($P<0.001$), whereas there was no difference in the summer season, mean 53.0 (23.9) nmol/l versus 54.8 (22.3) nmol/l, respectively ($P=0.21$). Both men ($P<0.001$) and women ($P=0.009$) had higher 25(OH)D concentrations during the summer season than the winter season. Figure 2 shows the mean vitamin D concentrations in men and women month by month.

Characteristics of participants in the dietary survey
A subgroup of 154 subjects (112 women) was included in the dietary survey. Compared with the remaining 1872 patients in the full study population, fewer women in the dietary survey group had serum 25(OH)D measurements performed during the summer season: 49% versus 64% ($P=0.001$). There were no significant differences between

Table 1 Characteristics of morbidly obese men and women

	Total (n = *2026*)	*Men* (n = *690*)	*Women* (n = *1336*)	P[a]
Age (years)	43.1 (12.2)[b]	45.0 (12.1)	42.2 (12.2)	<0.001
Caucasian	1960 (97%)[c]	672 (98%)	1288 (97%)	0.660
Current smoker	535 (26%)	140 (20%)	395 (30%)	<0.001
Vitamin D supplement	231 (11%)	65 (9%)	166 (12%)	0.046
Winter season (November through till February)	762 (38%)	267 (39%)	495 (37%)	0.468
Anthropometric measures				
Weight (kg)	131 (22)	145 (22)	124 (18)	<0.001
Height (cm)	172 (9)	180 (7)	167 (7)	<0.001
BMI (kg/m^2)	44.4 (5.9)	44.6 (6.0)	44.3 (5.9)	0.302
Waist (cm)	131 (14)	140 (13)	127 (13)	<0.001
Hip (cm)	133 (12)	130 (12)	135 (12)	<0.001
Waist-to-hip ratio	0.99 (0.1)	1.08 (0.08)	0.94 (0.08)	<0.001
Physically active[d]	458 (32%)	165 (32%)	293 (31%)	0.723
Co-morbidity				
Type 2 diabetes	499 (25%)	233 (34%)	266 (20%)	<0.001
Coronary artery disease	91 (5%)	69 (10%)	22 (2%)	<0.001
Biomarkers				
25-hydroxyvitamin D (nmol/l)	52.4 (22.3)	50.0 (22.0)	53.6 (22.4)	0.001
Vitamin D deficiency	1019 (50%)	386 (56%)	633 (47%)	<0.001
PTH (pmol/l)	6.7 (3.8)	7.1 (4.8)	6.5 (3.2)	0.003
Secondary hyperparathyroidism	691 (34%)	255 (37%)	436 (33%)	0.054
Insulin, fasting (pmol/l)	127.1 (112.6)	144.0 (99.6)	118.4 (117.9)	<0.001
CRP (pg/ml)	10.7 (11)	9.3 (12.9)	11.5 (9.8)	<0.001
CRP$\geqslant$7 (pg/ml)	1308 (65%)	378 (55%)	930 (70%)	<0.001

Abbreviations: BMI, body mass index; CRP, C-reactive protein; PTH, parathyroid hormone.
[a]Independent samples *t*-test or Fisher's exact test where appropriate.
[b]Data given as mean (s.d.; all such values).
[c]Number (%; all such values).
[d]$\geqslant$60 min of vigorous intensity aerobic physical activity/week (n = 1451).

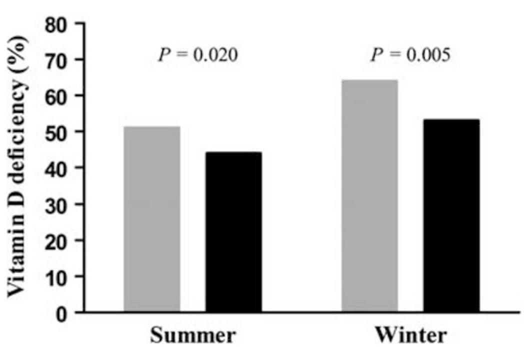

Figure 1 Gender differences in the prevalence of vitamin D deficiency (25(OH)D <50 nmol/l) according to season. Gray columns, men; black columns, women.

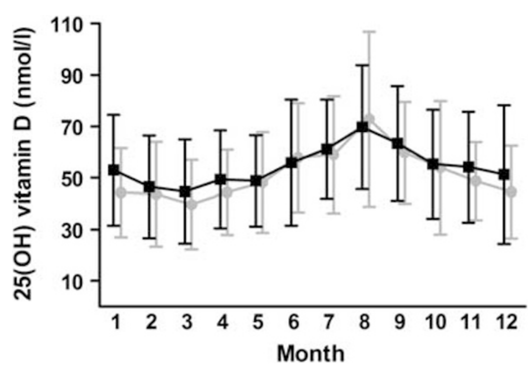

Figure 2 Mean (s.d.) vitamin D concentrations in morbidly obese men and women (*y*-axis) according to month of sampling (*x*-axis; 1 denotes January; 2, February; 3, March; 4, April and so on) Grey filled circles, men; black filled squares, women.

the two study populations with respect to age, BMI, WC, smoking habit or intake of vitamin D-containing supplements (data not shown).

Macronutrient composition and gender differences

Men tended to report higher EI than women (P = 0.056), but the percentage energy distribution of macronutrients did not differ significantly between genders (Table 2). Except for protein and alcohol, where men had a significantly higher absolute intake than women, 17 g higher protein (P = 0.003) and 1 g higher (P = 0.018) alcohol intake, there were no significant gender differences in terms of the absolute intake of macronutrients.

Both men and women had a higher median percentage EI from total and saturated fat, and lower median percentage

Table 2 Macronutrient and vitamin D intake in morbidly obese men and women

Nutrient	*RDI* [a]	*Total* (n = 154)	*Men* (n = 42)	*Women* (n = 112)	P[b]
Energy (MJ)	9.2–11.8[c]	11.1 (8.5–13.9)[d]	11.9 (9–16.7)	10.9 (8.4–13.6)	0.056
Energy (kcal)		2647 (2043–3316)	2854 (2158–3982)	2603 (2011–3258)	0.056
Protein E%	10–20	16 (15–18)	16 (14–20)	16 (15–18)	0.897
Fat E%	<30	37 (34–41)	37 (32–42)	37 (35–41)	0.609
SFA E%	<10	15 (13–16)	14 (12–16)	15 (3–16)	0.370
MUFA E%	10–15	12 (11–14)	13 (11–14)	12 (11–14)	0.942
PUFA E%	5–10	7 (6–9)	7 (6–9)	7 (6–9)	0.727
Carbohydrate E%	50–60	45 (41–49)	45 (41–49)	45 (42–48)	0.897
Fibre (g)	25–35	27.3 (22–35)	30 (24–37)	26 (22–34)	0.207
Sugar E%	<10	6 (3–10)	5 (2–10)	6 (3–10)	0.670
Alcohol E%	<5[e]	0.3 (0–1)	0.4 (0.1–1)	0.2 (0–1)	0.062
Vitamin D (μg)	7.5	8.4 (5–12)	9.7 (5.3–15.8)	8.2 (4.7–11.3)	0.073

Abbreviations: E%, energy percentage; MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids; RDI, recommended dietary intake; SFA, saturated fatty acids.
[a]Nordic Nutrition Recommendations: NNR 2004 (Nordic Council of Ministers, 2004).
[b]Difference between men and women, Mann–Whitney *U*-test.
[c]Individual mean energy intake depends on several variables, such as gender, age and physical activity level. For normal weight individuals (body mass index 18.5–25) and sedentary men and women aged 31–60 years, energy intake reference is 11.8 MJ/day and 9.2 MJ/day, respectively. Exact reference value for energy intake is not possible to determine.
[d]Median; 25 and 75th percentile in parantheses (all such values).
[e]<10 g alcohol/day for women and <20 g/day for men.

Table 3 Odds of morbidly obese patients having 25-hydoxyvitamin D deficiency

Explanatory variables	*Model 1*		*Model 2*		*Model 3*		*Model 4*	
	OR (95% CI)	P	*OR (95% CI)*	P	*OR (95% CI)*	P	*OR (95% CI)*	P
Gender	1.41 (1.17–1.70)	<0.001	1.52 (1.26–1.84)	<0.001	1.52 (1.25–1.84)	<0.001	1.39 (1.10–1.76)	0.006
Season			1.52 (1.27–1.83)	<0.001	1.54 (1.27–1.85)	<0.001	1.50 (1.24–1.81)	<0.001
Age			0.98 (0.98–0.99)	<0.001	0.99 (0.98–0.99)	<0.001	0.99 (0.98–0.99)	<0.001
Current smoking			1.34 (1.09–1.64)	0.005	1.45 (1.17–1.78)	0.001	1.42 (1.15–1.75)	0.001
Vitamin D supplement			0.79 (0.60–1.05)	0.110	0.82 (0.61–1.10)	0.164	0.80 (0.60–1.08)	0.142
BMI					1.07 (1.06–1.09)	<0.001	1.06 (1.04–1.09)	<0.001
Waist							1.01 (1.00–1.02)	0.186

Abbreviations: BMI, body mass index; CI, confidence interval; OR, odds ratios.

intake of carbohydrates, than recommended in the Nordic Nutrition Recommendations: NNR 2004 (Nordic Council of Ministers, 2004). According to the lower cutoff level for plausible EI, 33 (30%) women and 16 (38%) men under-reported their EIs, with no significant difference between genders ($P = 0.41$). Mean (s.d.) physical activity level values for women and men were 1.39 (0.51) and 1.35 (0.53), respectively ($P = 0.64$).

Vitamin D intake
Men tended to have a higher total intake of vitamin D than women ($P = 0.073$; Table 2). Median (25–75th percentile) vitamin D intake tended to be higher during the winter in men 10.7 (7.0–16.9) μg versus 6.8 (4.5–15.4) μg ($P = 0.08$), but not in women: 9.3 (5.5–12.5) μg versus 7.0 (4.4–10.3) μg ($P = 0.45$). According to the Nordic Nutrition Recommendations: NNR 2004 (Nordic Council of Ministers, 2004), both genders had low median intakes of vitamin D during the summer, whereas their vitamin D intakes were adequate during the winter.

Odds of having vitamin D deficiency
In unadjusted logistic regression (model 1), obese men had significantly higher odds of vitamin D deficiency than women (odds ratio = 1.41; (95% confidence interval: 1.17–1.70; Table 3). The association between male gender and vitamin D deficiency was somewhat strengthened when adjusting for season, age, current smoking and vitamin D supplements (model 2). Further adjustment for BMI (model 3) did not influence the odds of vitamin D deficiency, whereas the addition of WC to the model slightly attenuated the relationship between male gender and vitamin D deficiency (odds ratio = 1.39; 95% confidence interval: 1.10–1.76). Although the difference between genders in prevalence of vitamin D deficiency seemed more pronounced during the winter than summer season, the interaction term between gender and season was not significant ($P = 0.45$). In addition, no significant interactions were found between gender and other explanatory variables: age ($P = 0.18$), current smoking ($P = 0.36$), vitamin D supplementation ($P = 0.24$), waist circumference ($P = 0.95$) and BMI ($P = 0.33$).

Discussion

The main finding in this cross-sectional study of 2026 morbidly obese patients is that obese men had approximately 40% higher adjusted odds of vitamin D deficiency than obese women.

It is well established that obesity is associated with vitamin D insufficiency. Our data confirm previous reports showing a high prevalence of vitamin D insufficiency in morbidly obese subjects (Carlin *et al*., 2006; Aasheim *et al*., 2008; Goldner *et al*., 2008; Lagunova *et al*., 2009). Our study has demonstrated that men had higher odds of vitamin D deficiency even after adjustment for the confounders season, age, current smoking and vitamin D supplements (model 2). The fact that further adjustment for BMI (model 3) did not change this relationship suggests that the association between male gender and vitamin D deficiency could not explained by the degree of overall obesity. Conversely, further adjustment for WC (model 4) slightly attenuated the relationship, indicating that gender differences in abdominal adiposity could potentially influence the association between male gender and vitamin D deficiency. Consistent with this, previous studies have indicated that vitamin D insufficiency in obese individuals is caused by decreased bioavailability secondary to deposition of vitamin D in body fat compartments (Wortsman *et al*., 2000), especially in visceral fat stores (Cheng *et al*., 2010).

Seasonal variation, vitamin D intake and gender

Our results confirm those from previous Nordic studies showing a significant drop in serum concentrations of 25(OH)D during the winter season in both genders (Vik *et al*., 1980; Jorde *et al*., 2010). Interestingly, men had significantly lower vitamin D concentrations than women in the winter season, but not in the summer. A recent Norwegian study of both lean and morbidly obese persons also found that men had larger seasonal variation of vitamin D concentration than women, in particular young non-obese men (Lagunova *et al*., 2009). Similar findings have been reported from New Zealand and Brazil, where middle aged and older men had a larger reduction in 25(OH)D during the winter season than women (Bolland *et al*., 2007; Maeda *et al*., 2010).

In the Nordic Nutrition Recommendations: NNR 2004 (Nordic Council of Ministers, 2004), a vitamin D intake of $\geqslant 7.5\,\mu g$/day is recommended. Little is known about the dietary vitamin D intake of morbidly obese men and women. The median vitamin D intake in our sub-population of $8.4\,\mu g$/day was normal according to current Nordic recommendations. A recent Spanish study also reported adequate vitamin D intake according to regional recommendations in overweight and moderately obese (BMI 24–35) women (Rodriguez-Rodriguez *et al*., 2009). Previous studies have shown that obese subjects tend to underreport EIs (Heitmann and Lissner, 1995; Johansson *et al*., 1998), especially women (Johansson *et al*., 1998). We estimated that 30% of women and 38% of men underreported their EIs. One British study found that women were more likely than men to report avoiding high-fat foods (Wardle *et al*., 2004). Despite an expected underreporting of fat, especially in women, the total percentage fat intake was higher than recommended (37% versus $<30\%$) for both genders. Probably as a consequence of the high fat intake, the dietary intake of the fat soluble vitamin D was adequate for both genders in our study according to Nordic recommended daily intake (Nordic Council of Ministers, 2004).

Somewhat surprisingly, no association was observed between vitamin D deficiency and supplement intake. This might have several explanations, including sequestration of vitamin D in body fat compartments. The latter notion is supported by a study showing that BMI was inversely correlated with peak serum vitamin D_2 concentrations after a high dose of oral intake of vitamin D_2 (50 000 IU, 1.25 mg; $r=-0.56$, $P=0.007$; Wortsman *et al*., 2000). Our results are therefore consistent with the hypothesis that vitamin D supplementation in obese persons yield smaller increases in vitamin D concentrations (Wortsman *et al*., 2000).

Sun exposure and physical activity

It has been speculated that the inadequate vitamin D status associated with obesity is mediated in part by less ultraviolet radiation from sun exposure (Harris and Dawson-Hughes, 2007). Solarium usage could be one possible explanation of the higher 25(OH)D concentrations in women during winter. However, morbidly obese women may find the usage of solarium difficult because of the narrow space often provided. Solarium usage was not registered in our study.

Physical activity has been identified as a contributor to adequate vitamin D concentration in some (Scragg and Camargo, 2008; Brock *et al*., 2010a; Brock *et al*., 2010b), but not all (Barake *et al*., 2010; Cheng *et al*., 2010), reports. The conflicting results may be explained by varying study conditions, including differences in latitudes, age and physical activity measurements. In our study, men and women reported similar physical activity levels and we found no association between low vitamin D status and physical activity.

Study limitations

Strengths of our study include the prospective collection of data in a large, homogenous population of morbidly obese individuals and adjustment for possible confounders including season of blood sampling, age, current smoking, use of vitamin D supplements, BMI and waist circumference. Cross-sectional studies are inherently limited in that they cannot establish cause and effect relationships, and our results may not necessarily be valid in non-white populations. Performing the biochemical analyses on a routine basis throughout the study period may have limited the internal validity of the study, as this increases the risk of drift of laboratory assays.

Conclusions

Morbidly obese Norwegian men had significantly higher odds of vitamin D deficiency than obese Norwegian women. Therefore, future guidelines for monitoring 25(OH)D concentrations should take into account not only obesity and seasonal variations, but also gender. Clinicians should be especially aware of the high prevalence of vitamin D deficiency in morbidly obese men.

Vitamin D intake was comparable between men and women and could therefore not explain the difference in prevalence of vitamin D deficiency between genders. Randomized controlled trials of obese men and women exploring the dose–response effect of vitamin D supplementation during different seasons are highly warranted.

Conflict of interest

The authors declare no conflict of interest.

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