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## RESEARCH ARTICLE

# Evidence for the Necessity to Systematically Assess Micronutrient Status Prior to Bariatric Surgery

Barbara Ernst · Martin Thurnheer ·  
Sebastian M. Schmid · Bernd Schultes

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## Abstract

**Background** Bariatric surgery has been proven the most effective treatment of morbid obesity, but micronutrient deficiency following bariatric surgery is a major concern. Increasing evidence points to a generally poor micronutrient status in obese subjects.

**Methods** We assessed micronutrient status in 232 morbidly obese subjects ( $\text{BMI} \geq 35 \text{ kg/m}^2$ ) prior to bariatric surgery. Serum albumin, calcium, phosphate, magnesium, ferritin, hemoglobin, zinc, folate, vitamin B<sub>12</sub>, 25-OH vitamin D<sub>3</sub>, and intact parathormone (iPTH) were determined. In a sub-sample of 89 subjects, we additionally assessed copper, selenium, vitamin B<sub>1</sub>, B<sub>3</sub>, B<sub>6</sub>, A, and E levels.

**Results** Deficiencies were found in 12.5% of the subjects for albumin, 8.0% for phosphate, 4.7% for magnesium, 6.9% for ferritin, 6.9% for hemoglobin, 24.6% for zinc, 3.4% for folate, and 18.1% for vitamin B<sub>12</sub>. In addition, 25.4% showed a severe 25-OH vitamin D<sub>3</sub> deficiency, which was accompanied by a secondary hyperparathyroidism in 36.6% cases. Prevalence of albumin deficiency ( $p < 0.007$ ) and of anemia ( $p < 0.003$ ; in women only) significantly increased with BMI. Of note, 48.7% of the subjects showed at least one of the most prevalent deficiencies, i.e., vitamin B<sub>12</sub>,

zinc and severe 25-OH vitamin D<sub>3</sub> deficiency. In the sub-sample, 32.6% showed a selenium, 5.6% a vitamin B<sub>3</sub>, 2.2% a vitamin B<sub>6</sub>, and 2.2% a vitamin E deficiency. Copper, vitamin B<sub>1</sub>, and vitamin A deficiency was found in none of the subjects.

**Conclusion** Data indicate a high prevalence of micronutrient deficiencies in morbidly obese subjects. Based on these results, we strongly recommend a systematic assessment of the micronutrient status in all candidates for bariatric surgery.

**Keywords** Morbid obesity · Micronutrient deficiencies · Preoperative assessment

## Introduction

Bariatric surgery has been proven the most effective treatment of morbid obesity leading not only to a long-term weight reduction [1, 2] but also to a significant improvement of health-related quality of life [3] and a reduction of overall mortality [4, 5]. However, micronutrient deficiency after bariatric procedures is a major concern [6, 7], which may prevent a physician recommending morbid obese patients for this effective treatment.

Positive energy balance deriving from excessive food intake in relation to energy expenditure is the pathophysiological basis of obesity in most cases, but the quality of ingested foods might be poor [8]. Here, the question arises as to whether in obese subjects micronutrient supply from consumed foods is sufficient to cover their organism's demands. Surprisingly, a quite low number of studies, most of which are summarized in Table 1, have been carried out to address this question. Data from the NHANES III including 3,831 obese subjects indicated a higher likelihood

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B. Ernst · M. Thurnheer · B. Schultes (✉)  
Interdisciplinary Obesity Center, Kantonsspital St. Gallen,  
CH-9400 Rorschach, Switzerland  
e-mail: bernd.schultes@kssg.ch

S. M. Schmid · B. Schultes  
Department of Internal Medicine I, University of Luebeck,  
23538 Luebeck, Germany

**Table 1** Published studies providing data on at least two nutritional components, including more than 50 obese subjects without previous bariatric surgery

Reference	Study population	Deficiencies (%)													
		No. patients	Sex	BMI kg/m <sup>2</sup>	Country	Albumin	Ferritin	Hemoglobin	Zinc	Selenium	Vitamin B <sub>1</sub>	Folate	Vitamin B <sub>12</sub>	Vitamin A	Vitamin E
Kimmons et al. [9]	16191 (obese: 3831)	Premenopausal: 1320 Postmenopausal: 1267 m: 1244	–	≥30	USA	–	–	–	–	6.1	31.6	17.0	1.7	25.8	19.0
Madan et al. [29]	100	–	–	≥35	USA	–	–	–	–	2.8	25.2	14.2	0.4	21.2	7.2
Skroubis et al. [30]	Morbidly obese: 79 (BMI < 50 kg/m <sup>2</sup> ) super obese: 95 (BMI > 50 kg/m <sup>2</sup> )	m: 15, f: 64 m: 24, f: 71	–	45.6±4.9 (mean±SD) 57.2±6.1 (mean±SD)	Greece	0	8.3	–	–	–	–	16.4	–	–	–
Brolin et al. [31]	56	Female	–	weight: 89–189 kg	USA	–	–	21.4	–	–	14.3	8.9	–	–	–
Flancabaum et al. [32]	379	m: 59, f: 320	–	51.8±10.6 (mean±SD)	USA	0	8.4	22.0	–	–	–	0	–	–	68.1

Kimmons et al. [9] cut-off values: ≤ 1.05 μmol/l for vitamin A; ≤ 36 nmol/l for 25-OH vitamin D<sub>3</sub>; ≤ 220.6 pmol/l for vitamin B<sub>12</sub>; < 6.8 nmol/l for serum folate; < 1.3 μmol/l for selenium. Madan et al. [33] did not provide cut-off values. Skroubis et al. [34] cut-off values: < 147.6 pmol/l for vitamin B<sub>12</sub>; < 16.4 pmol/l for ferritin. Brolin et al. [35] cut-off values: < 154.9 pmol/l for vitamin B<sub>12</sub>; < 9.1 nmol/l for folate. Flancabaum et al. [32] did not provide cut-off values.

of deficiencies in multiple micronutrient components in subjects with a BMI above 30 kg/m<sup>2</sup> as compared with normal-weight subjects [9]. However, data from that study do not clarify the question whether the likelihood of micronutrient deficiencies increases with the severity of obesity, i.e., with increasing BMI classes. Also, the majority of studies focusing on morbid obesity (BMI ≥ 35 kg/m<sup>2</sup>) only assessed a limited number of micronutrient components prior to bariatric procedures. For instance, concentrations of vitamin B<sub>3</sub>, B<sub>6</sub>, and copper, deficiencies of which have in part been attributed to bariatric operations [10–22], have not yet been systematically studied in candidates for bariatric surgery prior to the operation.

From the clinical point of view, knowing the prevalence of micronutrient deficiencies in morbidly obese patients appears to be of utmost importance. Otherwise, deficiencies detected after bariatric surgery cannot unequivocally be attributed to the surgical intervention. Here, we report results of a comprehensive micronutrient assessment in 232 morbidly obese subjects (BMI ≥ 35 kg/m<sup>2</sup>) who were evaluated for bariatric surgery in our Interdisciplinary Obesity Center.

## Methods

In this prospective study, we assessed a comprehensive micronutrient status in all patients with a BMI of 35 kg/m<sup>2</sup> or higher who were referred by their general practitioner or by themselves to our Interdisciplinary Obesity Center for evaluation for bariatric surgery between November 2005 and December 2007. Patients who had undergone a bariatric procedure, e.g., gastric banding, prior to the present assessment were excluded from the study. Also, patients with overt renal function impairment (serum creatinine concentration >120 μmol/l for men, >100 μmol/l for women) were excluded from the study, since impaired renal function is well known to significantly affect vitamin D metabolism and thereby, PTH levels and calcium homeostasis. All the patients underwent an extensive endocrinological examination in order to detect endocrine disorders potentially responsible for their obesity, e.g., untreated hypothyroidism. However, such an endocrine disorder was detected in none of the subjects. The final sample included 232 patients. Informed consent was obtained from all the patients.

Height and weight were measured with patients wearing light clothing but no shoes. BMI was defined as weight (kg) divided by height squared (m<sup>2</sup>). In all the patients, blood samples were drawn in the morning (8:00–11:00) after an overnight fast. Micronutrient deficiency was defined as follows: serum albumin <536.0 μmol/l, serum calcium <2.0 mmol/l, serum phosphate <0.8 mmol/l, serum magne-

sium <0.7 mmol/l, serum ferritin <18.0 pmol/l, hemoglobin <8.7 mmol/l for men and <7.5 mmol/l for women, serum zinc <11.0 μmol/l, serum copper <13.0 μmol/l, serum selenium <0.9 μmol/l, serum vitamin B<sub>1</sub> <933.0 nmol/l, serum vitamin B<sub>3</sub> <65.0 μmol/l, serum vitamin B<sub>6</sub> <33.2 nmol/l, serum folate <4.5 nmol/l, serum vitamin B<sub>12</sub> <133.0 pmol/l, serum vitamin A <0.7 μmol/l, serum vitamin E <12.0 μmol/l, serum 25-OH vitamin D<sub>3</sub> <76.0 nmol/l (mild deficiency), <50.0 nmol/l (moderate deficiency), and <25.0 nmol/l (severe deficiency). Serum iPTH >6.5 pmol/l indicated hyperparathyroidism.

Serum copper, selenium, vitamin B<sub>1</sub>, B<sub>3</sub>, B<sub>6</sub>, A, and E were only assessed in a sub-sample of 89 patients. In all patients with vitamin B<sub>12</sub> deficiency, antibodies against parietal cells were measured to exclude atrophic gastritis. However, increased antibody titers could not be detected in any of the subjects tested.

Data were analyzed by using SPSS 12.1 for Windows (SPSS, Chicago, IL, USA). To assess the influence of the degree of obesity, the subjects were grouped according to their BMI in four groups, i.e., BMI 35–<40 kg/m<sup>2</sup>, BMI 40–<45 kg/m<sup>2</sup>, BMI 45–<50 kg/m<sup>2</sup> and BMI >50 kg/m<sup>2</sup>. Unless otherwise indicated, data are reported as mean ± SD. Variables were compared between different BMI groups by  $\chi^2$  test for discrete variables and ANOVA for continuous variables. For pairwise comparisons, Student's *t* test or  $\chi^2$  test was used. Associations between micronutrient levels and BMI were evaluated by Pearson's correlation coefficient. A *p* value <0.05 was considered significant.

## Results

The clinical characteristics of the study population are presented in Table 2. There were no significant differences in age and height across the four different BMI groups. Interestingly, the number of evaluated men was higher in the BMI >40 kg/m<sup>2</sup> groups than in the BMI 35–40 kg/m<sup>2</sup> group (all *p* < 0.05 for pairwise comparisons).

Table 3 provides data on micronutrients measured in the entire study population. Overall, below cut-off levels, i.e., deficiencies, were found in 12.5% of the subjects for albumin, 8.0% for phosphate, 4.7% for magnesium, 6.9% for ferritin, 6.9% for hemoglobin (<8.7 mmol/l in men and <7.5 mmol/l in women), 24.6% for zinc, 3.4% for folate, 18.1% for vitamin B<sub>12</sub>, and 89.7% for 25-OH vitamin D<sub>3</sub> (<76 nmol/l). In addition, 61.2% of the patients not only showed a mild but a moderate (<50 nmol/l) and 25.4% even a severe (<25 nmol/l) 25-OH vitamin D<sub>3</sub> deficiency. According to the high prevalence of 25-OH vitamin D<sub>3</sub> deficiency, 36.6% of the patients showed a secondary hyperparathyroidism with iPTH levels above 6.5 pmol/l. A primary hyperparathyroidism could be excluded in all the

**Table 2** Clinical characteristics of the study population

	Total (n=232)	BMI (kg/m <sup>2</sup> )				P (trend)
		35–<40 (n=47)	40–<45 (n=87)	45–<50 (n=56)	>50 (n=42)	
Women (%)	71.1	85.1	67.8*	67.9*	66.7*	0.131
Age (y)	40.5±11.6	40.0±11.3	38.9±11.3	42.0±11.3	42.1±12.8	0.344
Height (cm)	166.2±8.7	166.0±7.3	166.6±8.8	166.3±9.2	165.7±9.3	0.952
Weight (kg)	124.3±20.7	104.5±9.1	117.5±13.1	131.6±14.8	150.9±18.1	<0.001
BMI (kg/m <sup>2</sup> )	44.9±6.2	37.9±1.4	42.2±1.4	47.5±1.5	54.9±4.6	<0.001

Data are the mean±SD, or percentage. P values derive from  $\chi^2$  test or ANOVA as appropriate.

\*P<0.05 vs. BMI group 35–<40 by  $\chi^2$  test.

patients since none of them showed an increased serum calcium level.

Analyzing data separately for BMI categories revealed a significant difference in the prevalence of albumin deficiency ( $p=0.007$ ) and hemoglobin deficiency ( $p=0.003$ ; in women) between groups with higher rates of deficiencies with increasing BMI.

Figure 1 illustrates the distribution of the three most prevalent deficiencies, i.e., 25-OH vitamin D<sub>3</sub> (<25 nmol/l), vitamin B<sub>12</sub>, and zinc deficiencies. Subnormal serum values of at least one parameter were found in 48.7% of the patients (Fig. 1a). When elevated iPTH levels instead of 25-OH vitamin D<sub>3</sub> (<25 nmol/l) were used as an indicator of 25-OH vitamin D<sub>3</sub> deficiency, the number of patients

**Table 3** Absolute values and rates of prevalence of deficiency in micronutrients

	Total (n=232)	BMI				P (trend)
		35–<40 (n=47)	40–<45 (n=87)	45–<50 (n=56)	>50 (n=42)	
<b>Absolute values</b>						
Albumin ( $\mu\text{mol/l}$ )	612.9±65.2	637.6±66.7	626.0±66.7	597.0±46.4	581.0±66.7	<0.001
Total calcium (mmol/l)	2.3±0.1	2.3±0.1	2.3±0.1	2.2±0.1	2.2±0.1	0.045
Phosphate (mmol/l) <sup>a</sup>	1.0±0.2	1.0±0.2	1.0±0.2	1.0±0.2	1.0±0.2	0.993
Magnesium (mmol/l) <sup>b</sup>	0.9±0.1	0.9±0.9	0.9±0.1	0.9±0.2	0.8±0.1	0.708
Ferritin (pmol/l)	165.2±163.8	132.5±122.0	171.1±169.4	200.5±193.4	142.4±143.1	0.145
Hemoglobin (mmol/l)	8.9±0.9	8.9±0.8	9.1±0.7	8.8±0.9	8.7±1.1	0.123
Zinc ( $\mu\text{mol/l}$ )	12.2±1.8	12.3±1.6	12.4±1.9	12.2±1.6	11.9±1.8	0.458
Folate (nmol/l)	13.1±8.4	11.3±4.8	13.6±8.6	14.7±11.3	12.0±6.8	0.170
Vitamin B <sub>12</sub> (pmol/l)	202.2±81.9	192.6±73.1	206.5±78.4	218.0±94.4	182.5±78.1	0.144
25-OH-D <sub>3</sub> (nmol/l)	47.0±36.4	50.3±28.2	51.1±49.3	44.5±24.5	38.2±23.1	0.241
IPTH (pmol/l)	6.2±2.9	5.4±2.1	5.9±2.5	6.7±3.9	6.9±2.8	0.046
<b>Deficiencies (%)</b>						
Albumin <536.0 $\mu\text{mol/l}$	12.5	8.5	9.2	8.9	28.6	0.007
Phosphate <0.8 mmol/l <sup>a</sup>	8.0	12.8	7.2	5.5	7.7	0.573
Magnesium <0.7 mmol/l <sup>b</sup>	4.7	4.5	0	10.0	7.5	0.052
Ferritin <18.0 pmol/l	6.9	10.6	4.6	5.4	9.5	0.494
Hemoglobin <8.7 mmol/l <sup>c</sup>	10.1	15.4	3.0	17.4	10.0	0.313
Hemoglobin <7.5 mmol/l <sup>d</sup>	5.9	2.0	1.4	8.0	18.8	0.003
Zinc <11.0 $\mu\text{mol/l}$	24.6	25.5	23.0	17.9	35.7	0.229
Folate <4.5 nmol/l	3.4	0	3.4	5.4	4.8	0.474
Vitamin B <sub>12</sub> <133.0 pmol/l	18.1	17.0	16.1	16.1	26.2	0.516
25-OH-D <76.0 nmol/l	89.7	85.1	89.7	89.3	95.2	0.481
25-OH-D <50.0 nmol/l	61.2	53.2	58.6	60.7	76.2	0.139
25-OH-D <25.0 nmol/l	25.4	23.4	20.7	26.8	35.7	0.317
IPTH>6.5 pmol/l	36.6	25.5	36.8	42.9	40.5	0.296

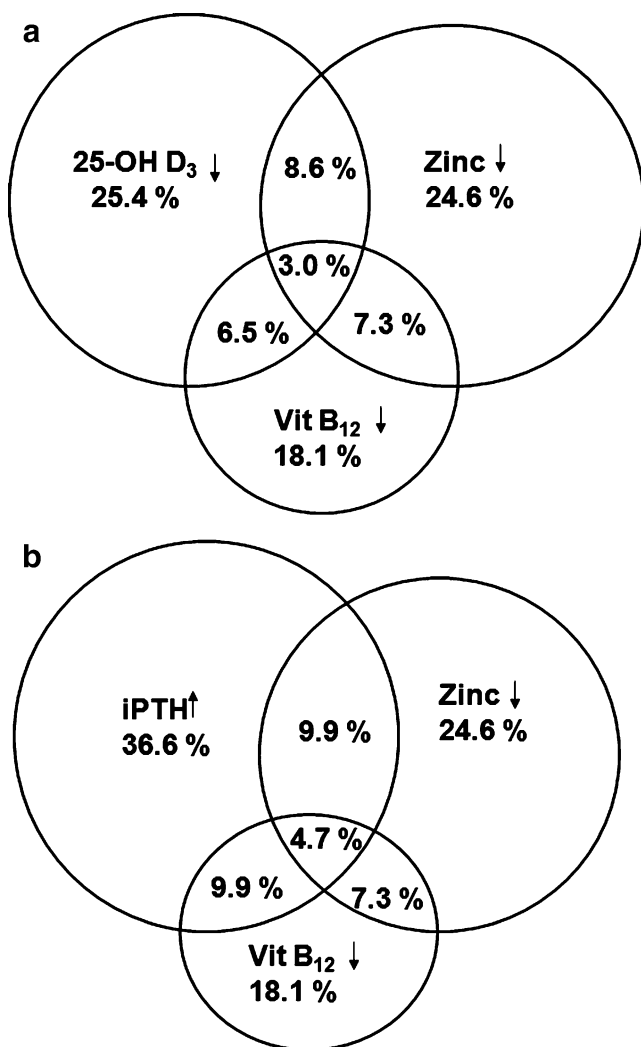
Data are the mean±SD, or percentage. P values derive from  $\chi^2$  test or ANOVA as appropriate.

<sup>a</sup> Measured in 224 patients.

<sup>b</sup> Measured in 213 patients.

<sup>c</sup> For men.

<sup>d</sup> For women.



**Fig. 1** Relationship between zinc, vitamin B<sub>12</sub>, and 25-OH vitamin D<sub>3</sub> deficiency (a) and between zinc deficiency, vitamin B<sub>12</sub> deficiency, and iPTH elevation (b)

showing at least one alteration in the three parameters was even higher reaching 56.9% (Fig. 1b). There was no significant difference in these prevalences across the four BMI groups ( $p=0.390$  for the analysis including 25-OH vitamin D<sub>3</sub> and  $p=0.801$  for analysis including iPTH).

Looking at absolute values, there was a clear-cut decrease in albumin levels with increasing BMI ( $p<0.001$ ). Total calcium levels were also reduced in the higher as compared to the lower BMI groups ( $p=0.045$ ), but this difference between groups disappeared when calcium levels were corrected for albumin levels ( $p=0.113$ ). Also, ferritin, hemoglobin, vitamin B<sub>12</sub>, and 25-OH vitamin D<sub>3</sub> levels appeared to decrease with increasing BMI but differences across BMI groups did not reach significance (all  $p>0.14$ ). However, iPTH levels clearly increase with BMI ( $p=0.046$ ) and correlation analysis confirmed the positive association between iPTH levels and BMI ( $r=0.191$ ;  $p=0.004$ ).

Comparison of data between men and women (Table 4) revealed that, as expected, men were significantly taller and heavier than women (both  $p<0.001$ ), but age and BMI was similar in both sexes (both  $p>0.34$ ). Women displayed significant lower albumin ( $P=0.001$ ), ferritin ( $p<0.001$ ), hemoglobin ( $p<0.001$ ), and zinc ( $p=0.003$ ) concentrations than men. Also, prevalence of ferritin deficiency was higher in women than in men ( $p<0.038$ ).

Table 5 provides data on serum copper, selenium, vitamin B<sub>1</sub>, vitamin B<sub>3</sub>, vitamin B<sub>6</sub>, vitamin A, and vitamin E levels measured in a subgroup of 89 subjects. Here, 32.6% of the subjects showed a selenium deficiency, 5.6% a vitamin B<sub>3</sub> deficiency, 2.2% a vitamin B<sub>6</sub> deficiency, and 2.2% a vitamin E deficiency, while below cut-off levels were not found for copper, vitamin B<sub>1</sub>, and vitamin A in any of the subjects. Mean values for vitamin B<sub>1</sub> ( $p=0.011$ ) and vitamin A ( $p=0.033$ ) were significantly lower in women than in men, while that of copper were significantly higher in women ( $p<0.001$ ).

## Discussion

Present data indicate a high prevalence (>10%) of albumin, zinc, selenium, vitamin B<sub>12</sub>, and 25-OH vitamin D<sub>3</sub> deficiency as well as elevated iPTH levels in morbidly obese patients (BMI ≥ 35 kg/m<sup>2</sup>). In addition, moderate rates of deficiencies (prevalence 5 to 10%) were found for phosphate, ferritin, hemoglobin, and vitamin B<sub>3</sub>, and low prevalence rates (<5%) of deficiencies were found for magnesium, vitamin B<sub>6</sub>, folate, and vitamin E levels. None of our patients showed deficiencies in serum levels of copper, vitamin B<sub>1</sub>, and vitamin A. Rates of albumin deficiency and anemia (in women only) increased with BMI as did absolute iPTH levels. However, even a substantial number of the patients within the lowest BMI group (35–40 kg/m<sup>2</sup>) displayed a micronutrient deficiency that should not be neglected.

Beside its obvious clinical significance in regard of the management of bariatric candidates, the present finding of a high prevalence rate of deficiency in distinct micronutrient components may also provide broader implications. Here, it is tempting to speculate that at least some of the found micronutrient deficiencies contribute to the well-known health impairing effects of obesity. For instance, vitamin D deficiency has been found to be associated with an increased risk for diabetes, cardiovascular diseases, and several types of cancer [23, 24]. Also, zinc deficiency is currently suggested to critically promote acute and chronic liver diseases [25] as well as the development of several types of cancer [26, 27]. To sum up, the high rate of micronutrient deficiencies found here strongly calls for further investigations assessing its potential contribution to the genesis of diseases being associated with obesity.

**Table 4** Comparison of absolute values of and deficiencies in micronutrients between men and women

	Men (n=67)	Women (n=165)	P value
Age (year)	41.4±11.4	40.1±11.7	0.436
Height (cm)	174.6±7.3	162.8±6.7	<0.001
Weight (kg)	138.8±19.6	118.5±18.2	<0.001
BMI (kg/m <sup>2</sup> )	45.5±5.3	44.7±6.5	0.342
Albumin (μmol/l)	634.7±66.7	604.2±62.3	0.001
Albumin <536.0 μmol/l	6.0%	25.0%	0.055
Phosphate (mmol/l) <sup>a</sup>	1.0±0.2	1.0±0.2	0.666
Phosphate <0.8 mmol/l <sup>a</sup>	10.8%	6.9%	0.336
Magnesium (mmol/l) <sup>b</sup>	0.9±0.2	0.9±0.1	0.152
Magnesium <0.7 mmol/l <sup>b</sup>	4.9%	4.6%	0.922
Ferritin (pmol/l)	310.5±204.0	106.2±94.4	<0.001
Ferritin <18.0 pmol/l	1.5%	9.1%	0.038
Hemoglobin (mmol/l)	9.6±0.9	8.6±0.7	<0.001
Hemoglobin <8.7 mmol/l, <7.5 mmol/l <sup>c</sup>	10.1	5.9	0.140
Zinc (μmol/l)	12.8±2.0	12.0±1.7	0.003
Zinc <11.0 μmol/l	20.9%	26.1%	0.408
Folate (nmol/l)	12.9±7.0	13.1±9.1	0.893
Folate <4.5 nmol/l	4.5%	3.0%	0.584
Vitamin B <sub>12</sub> (pmol/l)	212.8±81.1	197.8±82.1	0.205
Vitamin B <sub>12</sub> <133.0 pmol/l	14.9%	19.4%	0.423
25-OH-D <sub>3</sub> (nmol/l)	44.3±25.2	48.1±40.1	0.391
25-OH-D <sub>3</sub> <76.0 nmol/l	88.1%	90.3%	0.611
25-OH-D <sub>3</sub> <50.0 nmol/l	62.7%	60.6%	0.768
25-OH-D <sub>3</sub> <25.0 nmol/l	28.4%	24.2%	0.514
iPTH (pmol/l)	6.1±2.3	6.3±3.2	0.514
iPTH>6.5 pmol/l	35.8%	37.0%	0.869

Data are the mean±SD, or percentage. *P* values derive from  $\chi^2$  or unpaired Student's *t* test as appropriate.

<sup>a</sup> Measured in 224 patients.

<sup>b</sup> Measured in 213 patients.

<sup>c</sup> Hemoglobin <8.7 mmol/l for men and <7.5 mmol/l for women.

**Table 5** Absolute values and prevalence of deficiency in micronutrients measured only in a sub-sample of the study population

	Total (n=89)	Men (n=23)	Women (n=66)	P value
Age (year)	40.7±10.7	41.3±8.3	40.5±11.5	0.719
Height (cm)	166.3±8.1	174.1±7.8	163.6±6.4	<0.001
Weight (kg)	121.2±21.7	138.9±20.6	115.0±18.6	<0.001
BMI (kg/m <sup>2</sup> )	43.8±6.8	45.8±5.7	43.0±7.1	0.068
Copper (μmol/l)	20.0±4.8	17.3±2.3	21.0±5.0	<0.001
Copper <13.0 μmol/l	0%	0%	0%	–
Selenium (μmol/l)	1.1±0.2	1.0±0.2	1.1±0.2	0.286
Selenium <0.9 μmol/l	32.6%	39.1%	30.3%	0.437
Vitamin B <sub>1</sub> (nmol/l)	2740±516.7	2956.6±433.3	2663.3±523.3	0.011
Vitamin B <sub>1</sub> <933.0 nmol/l	0%	0%	0%	–
Vitamin B <sub>3</sub> (μmo/l)	155.1±78.8	138.1±53.6	160.8±85.3	0.139
Vitamin B <sub>3</sub> <65.0 μmo/l	5.6%	4.3%	6.1%	0.759
Vitamin B <sub>6</sub> (nmol/l)	74.1±37.0	80.2±45.4	72.1±34.0	0.458
Vitamin B <sub>6</sub> <33.2 nmol/l	2.2%	0%	3.0%	0.398
Vitamin A (μmol/l)	3.3±1.0	3.7±0.8	3.2±1.0	0.033
Vitamin A <0.7 μmol/l	0%	0%	0%	–
Vitamin E (μmo/l)	36.0±10.7	35.1±10.2	36.2±11.2	0.689
Vitamin E <12.0 μmo/l	2.2%	0%	3.0%	0.398

Data are the mean±SD, or percentage. *P* values derive from  $\chi^2$  or unpaired Student's *t* test as appropriate.

Several limitations of our study need to be pointed out. First, our study population was recruited from patients referred to our Interdisciplinary Obesity Center for obesity treatment. Therefore, results obtained here should not be generalized to a population-based level. Second, deficiency in micronutrient components may depend on cultural and geographical factors, and thus, our findings cannot be generalized to other cultures and geographical regions. For instance, vitamin D<sub>3</sub> production within the skin largely depends on the amount of sunlight exposure, making vitamin D<sub>3</sub> deficiency more likely to occur in countries with rare sunshine or cultural limitations to expose large areas of uncovered skin to the sun. Also, the high number of selenium deficiencies found in our study most likely results from the fact that in the region of the Alps, soils were washed out during the glacial period [28]. Lastly, since we did not systematically assess micronutrient intake in the present study, it remains unclear whether the observed micronutrient deficiencies result from an inadequate intake by nutritional habits or other factors that have not been assessed here.

In conclusion, the present results clearly point to a rather high prevalence of micronutrient deficiencies in morbidly obese patients seeking obesity treatment. Although the clinical significance of most of these deficiencies remains to be established, based on the present data, we strongly recommend performing a systematically assessment of micronutrient status including at a minimum the determination of albumin, phosphate, ferritin, zinc, selenium, vitamin B<sub>12</sub>, 25-OH vitamin D<sub>3</sub>, iPTH, and vitamin B<sub>3</sub> in candidates for bariatric surgery. Without such an assessment, it will be impossible to straightforwardly attribute micronutrient deficiencies that are detected after the operation to the bariatric procedure per se. Also, it can be assumed that starting a supplementation in regard of detected deficiencies prior to the bariatric operations yields beneficial effects.

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