

Prevalence of vitamin B₁₂ depletion and deficiency in Liechtenstein

Victoria Koenig^{1,†}, Zeno Stanga^{2,†}, Manfred Zerlauth³, Luca Bernasconi^{1,4}, Martin Risch³, Andreas Huber¹ and Lorenz Risch^{3,5,*}

¹Center of Laboratory Medicine, Kantonsspital Aarau, Switzerland: ²Division of Endocrinology, Diabetes and Clinical Nutrition and Department of General Internal Medicine, University Hospital and University of Bern, Bern, Switzerland: ³LMZ Risch Laboratories, Labormedizinisches Zentrum Dr Risch, Landstrasse 157, 9494 Schaan, Liechtenstein: ⁴LMZ Risch Laboratories, Pregassona, Switzerland: ⁵Private University of the Principality of Liechtenstein, Triesen, Liechtenstein

Submitted 9 July 2012: Final revision received 31 October 2012: Accepted 7 November 2012: First published online 14 December 2012

Abstract

Objective: Data about vitamin B₁₂ (B₁₂) deficiency in the general population are scarce. The present study was performed to determine the prevalence of B₁₂ deficiency in the general population of the Principality of Liechtenstein, as well as to identify sub-populations potentially at high risk.

Design: Retrospective study.

Setting: Ambulatory setting, population of the Principality of Liechtenstein.

Subjects: Seven thousand four hundred and twenty-four patients seeking medical attention whose serum samples were referred for routine work-up in an ambulatory setting were consecutively enrolled. Serum total B₁₂ was determined in all patients in this cohort. In addition, for a subgroup of 1328 patients, serum holotranscobalamin was also measured. Prevalence of B₁₂ deficiency was calculated. Further, multivariate logistical regression models were applied to identify covariates independently associated with B₁₂ deficiency and depletion.

Results: Nearly 8% of the general population was suffering from either B₁₂ depletion or deficiency. The ratio between B₁₂ depletion and deficiency was 2:1 for all age ranges. Pathological changes were detected predominantly in older people. Female gender was a significant predictor of B₁₂ depletion. In the cohort, nearly 40% exhibited either depletion or deficiency of B₁₂.

Conclusions: B₁₂ depletion and deficiency are common in Liechtenstein, a Central European country. The measurement of biochemical markers represents a cost-efficient and valid assessment of the B₁₂ state. When a deficiency of B₁₂ is diagnosed at an early stage, many cases can be treated or prevented, with beneficial effects on individual outcomes and subsequent potential reductions in health-care costs.

Keywords

Vitamin B₁₂
Vitamin B₁₂ deficiency
Prevalence
Serum total vitamin B₁₂
Holotranscobalamin

Vitamin B₁₂ (B₁₂, cobalamin) is a water-soluble vitamin and an essential nutrient that normally must be obtained from the diet. Metabolically, it is essential for two reactions catalysed by the enzymes methionine synthase and L-methyl-malonyl-coenzyme A mutase. The daily recommended daily intake of B₁₂ for adults is 2 µg⁽¹⁾. In healthy individuals, nutritional B₁₂ deficiency is unusual because total body stores in adults are about 2500 µg and daily turnover is slow⁽²⁾, meaning that reserves generally remain for up to 10 years⁽³⁾. B₁₂ deficiency can have many causes, such as nutritional habits (strict vegetarian and vegan diets: practice of abstaining from use of animal products), intestinal malabsorption (i.e. gastritis, state after total

gastrectomy), use of proton pump inhibitors and elevated requirements (hyperthyroidism)⁽²⁾.

Severe and persistent B₁₂ deficiency has relevant adverse effects on clinical condition, namely haematological, neurological, neuropsychiatric and metabolic dysfunctions (i.e. methyl-malonyl-coenzyme A acidosis, hyperhomocysteinaemia)^(3–5). Mild B₁₂ deficiency normally does not provoke clinical symptoms, but can be diagnosed by measurement of blood markers. The clinical laboratory parameters available to diagnose B₁₂ deficiency are serum total B₁₂, transcobalamin-bound B₁₂ (holotranscobalamin, HoloTC: active fraction of B₁₂), plasma homocysteine (Hcy) and methylmalonic acid (MMA)⁽⁶⁾. The metabolites Hcy and MMA can be used as indicators of B₁₂ deficiency, but many factors other than

† Contributed equally to this manuscript.

B₁₂ deficiency (e.g. renal failure) can increase Hcy and MMA. Furthermore, measuring MMA is complicated and expensive, requiring HPLC or GC-MS⁽⁷⁾. Thus algorithms for laboratory diagnosis of a B₁₂-deficient status recommend the initial measurement of B₁₂ and HoloTC. Clarke *et al.* state that HoloTC has better diagnostic accuracy than B₁₂ (77% *v.* 73%) and that the diagnostic utility is superior in the overall population as well as in patients with renal impairment⁽⁸⁾.

B₁₂ deficiency is characterized by low serum concentrations of total B₁₂ (<148 pmol/l) and HoloTC (<35 pg/l), whereas depletion shows total B₁₂ within the grey zone (148–221 pmol/l) and HoloTC lower than the cut-off^(4,8,9). To date, an internationally valid consensus as to the definition of B₁₂ deficiency has not been established, since different thresholds have been used⁽⁹⁾. The transition from B₁₂ depletion to deficiency is fluid. The early diagnosis of a deficient status is essential because simple B₁₂ supplementation may reverse clinical symptoms.

B₁₂ deficiency is prevalent primarily in elderly people, children and women of reproductive age, with prevalences ranging from 10 to 40%^(4,8,10–13). In general, no relationship between B₁₂ status and geographic distribution of the population can be claimed⁽¹⁰⁾. The condition has the potential to be a worldwide public health problem.

The aim of the present study was to investigate the prevalence of B₁₂ depletion and deficiency based on serum total B₁₂ and HoloTC concentrations in a representative population of Liechtenstein. Our secondary aim was to determine factors associated with depletion and deficiency.

Materials and methods

Study population

The current retrospective study was carried out in the resident population of the Principality of Liechtenstein, without age restrictions. The study period ranged from January 2000 until December 2007. Within the study period, the population of Liechtenstein averaged 35 168 permanent residents of nearly exclusively Caucasian origin, as described elsewhere⁽¹⁴⁾. Corrected for migration and deaths, the reference population totals 38 839.

Serum samples of 7424 consecutive patients from child age to advanced age seeking medical attention by their physicians, referred for routine laboratory work-up in an ambulatory setting, were included in the study. Out of them, a subgroup of 1328 patients was also evaluated.

Hospitalized patients were excluded from the study. In the case of multiple determinations in the same individual, only the lowest value was kept in the database and used for further analysis.

Laboratory methods

Venous blood samples were drawn from all individuals in fasting or non-fasting state into Vacutainer tubes (BD

Systems, Basel, Switzerland) or Sarstedt Monovette tubes (Sarstedt, Sevelen, Switzerland). The samples were referred to the Liechtenstein central laboratory. Serum total B₁₂ was measured within 24 h after venepuncture. For measurement of total B₁₂ concentrations, a competitive-binding immunoenzymatic assay employing chemiluminescence was used (Access Vitamin B₁₂, run on two different analysers, Access2 and Unicel DxI800 instruments (Beckman Coulter, Nyon, Switzerland), whose agreement was previously compared).

In a subgroup of 1328 patients investigated during 2007, also HoloTC levels were measured on the Abbott AxSYM[®] immunochemical automated analyser (Abbott Diagnostics, Baar, Switzerland). The between-day CV, as evaluated by commercially available control materials, were 4.5% (at 242 pmol/l), 5.5% (at 360 pmol/l) and 6.3% (at 911 pmol/l) for total B₁₂ and 8.7% (at 21 pmol/l) and 9.7% (at 52 pmol/l) for HoloTC.

According to the country's validated laboratory reference values, the cut-off point for B₁₂ deficiency was defined as serum level of total B₁₂ <125 pmol/l⁽¹⁵⁾. The cut-off point for B₁₂ depletion was defined as a serum level of 125–300 pmol/l for total B₁₂ and a serum level of <35 pg/l for HoloTC⁽⁹⁾.

Statistical analysis

The proportion of individuals with a B₁₂ measurement among the general population was assessed across different age strata by using the national census data controlled for cases of migration and deaths. The prevalence of individuals with B₁₂ depletion or deficiency was calculated within the cohort. Further, the prevalence of these individuals among the general population was determined by using the adjusted national census data. Differences between proportions were assessed with the χ^2 test. Finally, a logistic regression model was applied in order to detect associations between demographic factors such as age and gender and the presence of B₁₂ deficiency. A *P* value less than 0.05 was considered statistically significant.

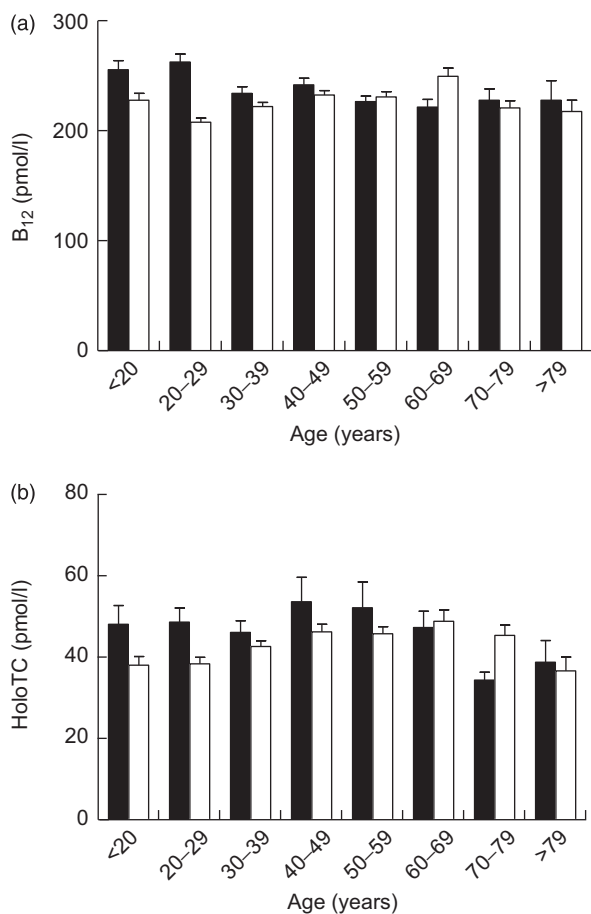
Results

A total of 7424 patients who sought medical attention were included in the study (ambulatory setting). This cohort comprised 19.1% of the country's entire population. The baseline characteristics of the study cohort are given in Table 1. Mean serum total B₁₂ levels fluctuated from 199 to 226 pmol/l between the different years.

Remarkably, only 12.4% of the cohort had a serum total B₁₂ level in a reference interval where B₁₂ deficiency is unlikely (>300 pmol/l); 74.2% of the cohort were within the grey zone (125–300 pmol/l), exhibiting B₁₂ depletion, while 13.4% of the cohort showed evidence of B₁₂ deficiency (<125 pmol/l). In the subgroup of participants with simultaneous total B₁₂ and HoloTC determination,

Table 1 Baseline characteristics of the study populations; ambulatory setting, Principality of Liechtenstein, January 2000–December 2007

Variable	Total cohort			Subgroup with HoloTC measurement		
	<i>n</i>	%		<i>n</i>	%	
No. of participants	7424	100		1328	100	
Gender						
Female	4915	66.2		884	66.6	
Male	2512	33.8		444	33.4	
	Mean	SD	Range	Mean	SD	Range
Age (years)	48	19	1–101	49	18	6–99
Mean serum total B ₁₂ (pmol/l)	230	130	11–1254	208	112	25–1144
Mean serum HoloTC (pmol/l)	Not measured	–	–	45	31	3–624

HoloTC, holotranscobalamin; B₁₂, vitamin B₁₂.**Fig. 1** Serum levels of (a) total vitamin B₁₂ (B₁₂) in the study cohort (*n* 7424) and (b) holotranscobalamin (HoloTC) in a subgroup of the cohort (*n* 1328), stratified according to age and gender (■, male; □, female); ambulatory setting, Principality of Liechtenstein, January 2000–December 2007. Values are means with their standard errors represented by vertical bars

B₁₂ depletion was seen in 26.4% (i.e. B₁₂ grey zone together with HoloTC <35 pmol/l). The mean total B₁₂ levels and the mean HoloTC levels across the different age/gender strata are shown in Fig. 1.

Table 2 Prevalence of B₁₂ depletion and deficiency in the cohort and the general population of Liechtenstein

	Cohort	Population
B ₁₂ depletion		
%	26.4	5.1
<i>n/n</i> _{cohort}	524/1328	
B ₁₂ deficiency		
%	13.4	2.6
<i>n/n</i> _{cohort} Or <i>n</i> _{population}	994/7424	994/38 839

B₁₂, vitamin B₁₂; HoloTC, holotranscobalamin. Serum total B₁₂ was determined in all individuals of the cohort (*n* 7424). B₁₂ depletion was measured by total B₁₂ and HoloTC assays; the cohort with concomitant HoloTC determination comprised 1328 individuals. The prevalence of B₁₂ depletion in the general population was extrapolated from the ratio between individuals with B₁₂ depletion and B₁₂ deficiency in the cohort (2:1).

The ratio between the prevalence of B₁₂ deficiency and depletion was investigated in both the general population and the study cohort (Table 2). Population prevalence of B₁₂ deficiency was obtained by calculating the ratio of individuals with B₁₂ deficiency among the reference population of 38 839. Population prevalence of B₁₂ depletion was extrapolated from the ratio between individuals with B₁₂ depletion and B₁₂ deficiency in the study cohort (2:1). Taking these findings into account allowed estimation of the prevalence of B₁₂ depletion and deficiency among the general population at nearly 8% (Table 2).

Stratifying the cohort with regard to gender and age showed that the prevalence of B₁₂ deficiency was significantly higher in females than in males (14.85% *v.* 10.51%, respectively, *P* < 0.001) and in persons aged 50 years and older than in those younger than 50 years (15.47% *v.* 11.79%, respectively, *P* < 0.001; Fig. 2). Interestingly, there was a bimodal distribution of the prevalence within females, with a first peak at childbearing age. The subgroup having both total B₁₂ and HoloTC measurements paralleled these findings, but demonstrated higher prevalence among all age groups (Fig. 3). Surprisingly, a remarkable B₁₂-deficient status was already seen in children.

Further calculating the prevalence of B₁₂ deficiency within the general population revealed characteristics

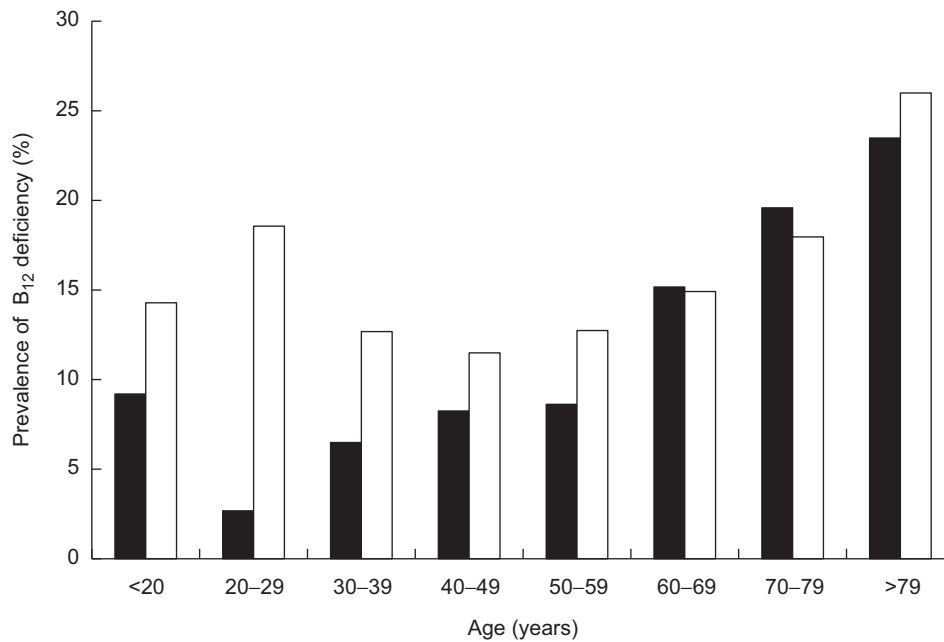


Fig. 2 Prevalence of vitamin B₁₂ (B₁₂) deficiency in the study cohort (*n* 7424), stratified according to age and gender (■, male; □, female); ambulatory setting, Principality of Liechtenstein, January 2000–December 2007

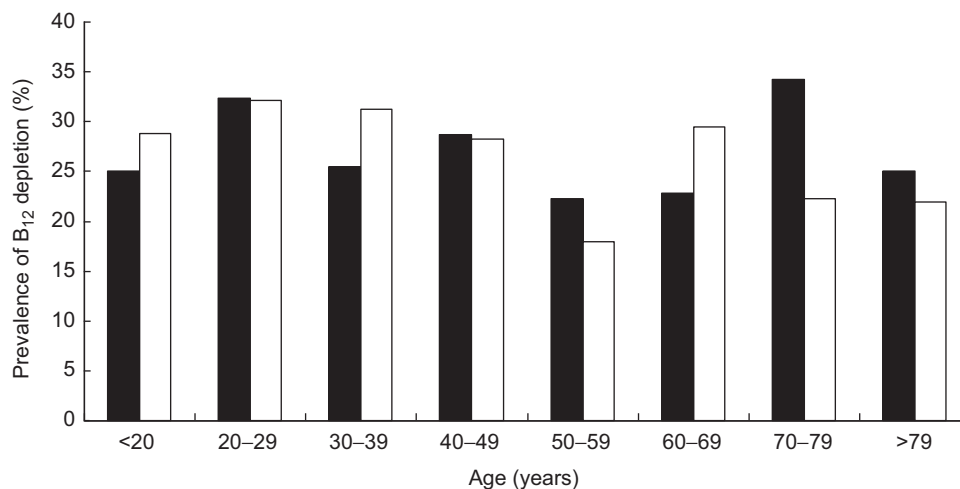


Fig. 3 Prevalence of vitamin B₁₂ (B₁₂) depletion (measured by total B₁₂ and holotranscobalamin assays) in a subgroup of the cohort (*n* 1328), stratified according to age and gender (■, male; □, female); ambulatory setting, Principality of Liechtenstein, January 2000–December 2007

similar to those within the cohort: older persons and females suffer more often from B₁₂ deficiency (Fig. 4).

Finally, a logistic regression model with age, gender and the interaction between age and gender as predictors of B₁₂ deficiency found that age (OR = 1.32; 95% CI 1.23, 1.43) and female gender (OR = 5.81; 95% CI 3.41, 9.89) were significant predictors of the presence of B₁₂-deficient status. Interestingly, the interaction between female gender and age was also significant (OR = 0.80; 95% CI 0.73, 0.87), indicating that the influence of age on the frequency of B₁₂ deficiency is stronger in women than in men.

Discussion

In the present retrospective study we found that nearly 20% of the population had a clinical suspicion of B₁₂ deficiency. About 40% of the cohort had biochemical evidence of impaired B₁₂ serum levels (26.4% depleted and 13.4% deficient). Within the general population of Liechtenstein, B₁₂ deficiency is encountered in 2.6%, whereas the prevalence of B₁₂ depletion can be estimated at 5.1%.

Comparing our data with other studies such as the Framingham Study⁽¹¹⁾, which described 12% of elderly

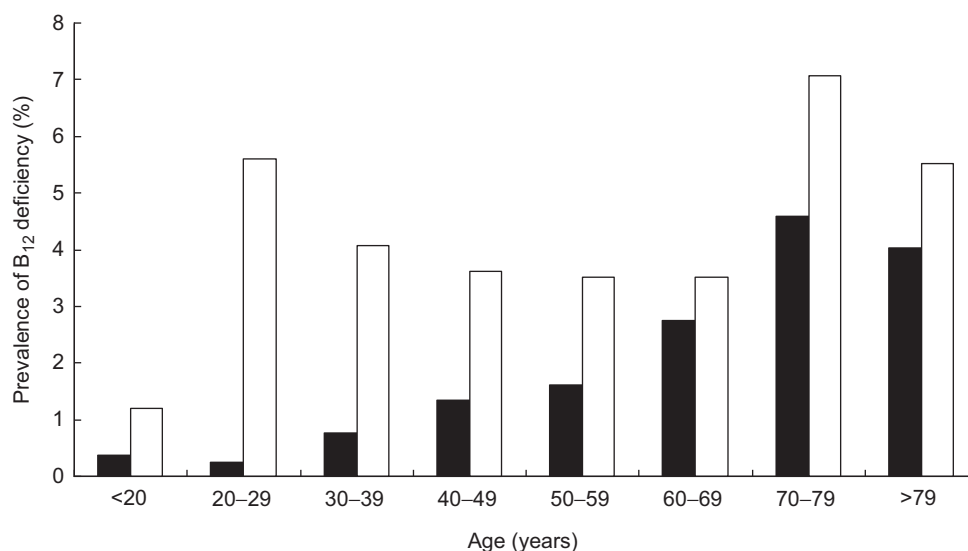


Fig. 4 Prevalence of vitamin B₁₂ (B₁₂) deficiency in the general population of Liechtenstein, stratified according to age and gender (■, male; □, female)

people as suffering from B₁₂ deficiency, we have to keep in mind that we were able to consecutively determine B₁₂ status in persons with clinical suspicion of B₁₂ deficiency within one entire country. Other studies have examined B₁₂ status in individuals randomly selected from the population^(10,16,17). Allen showed in a US sub-population of individuals aged ≥ 60 years that the prevalence of B₁₂ deficiency was 6% and the prevalence of B₁₂ depletion (marginal B₁₂ status, HoloTC not assessed) was about 20%⁽⁴⁾. According to Clarke *et al.*, in approximately 5–20% of elderly people a B₁₂ deficiency remains undiagnosed⁽⁸⁾. The prevalence of subclinical functional B₁₂ deficiency in the general population is higher than expected⁽⁷⁾.

There are hardly any population-wide studies about B₁₂ depletion or deficiency. The sub-populations examined mainly are elderly people (as mentioned above), children and women of reproductive age. Children are of special interest as early B₁₂ deficiency leads to impaired brain development and a higher risk of depression as an adult⁽¹⁸⁾. Our study shows that B₁₂-deficient status occurs at all ages, showing one peak in the third decade and another in advanced age (from age 70 years onwards). On the one hand, the capacity to absorb B₁₂ from food decreases in older people (i.e. atrophic gastritis, intestinal dysfunction), consequently leading to a malabsorption syndrome^(19,20). On the other hand, the principal reason for B₁₂ malabsorption is the pharmacological decrease in acid secretion in the stomach, causing an impairment of protein-bound B₁₂ absorption⁽²⁾. Drugs that decrease acid secretion comprise 3.9% of all administered drugs in Liechtenstein (Mag. Stefan Tomaselli, Liechtenstein Office of Public Health, personal communication). However, in our database, a link between antacid use and serum total B₁₂ concentration in an individual cannot be drawn.

Accordingly, we cannot provide evidence on the epidemiological importance of antacid use as a cause of B₁₂ deficiency.

Among young people in Madrid, Gil *et al.* appraised 4.8% as being deficient, with males more likely to be deficient than females, whereas our data show a significantly higher prevalence among girls within a similar percentage of affected persons⁽²¹⁾. This fact could be explained by the fact that in Central European countries girls show a higher rate of unhealthy dietary habits than boys^(22–25).

Refsum *et al.* showed that total B₁₂ and HoloTC concentrations were lower in women than in men, and they increased with age⁽¹²⁾. Further analyses in that study revealed the age effect to be limited to women, and the gender differences were confined to those aged ≤ 45 years. In women ≤ 45 years of age, there was a complete shift of the HoloTC distribution towards lower concentrations of $\sim 20\%$ ⁽¹²⁾. Would that suggest gender as a significant predictor for B₁₂ deficiency? In our study about 5% of the females of this age showed a B₁₂-deficient status. B₁₂ deficiency among females of reproductive age has an important impact, as it can cause infertility and abortion. Additionally, the fetus may suffer neural tube defects and prematurity⁽²⁶⁾.

Data about B₁₂ deficiency and/or depletion in men are scarce. We could not identify a single study concentrating on male individuals. In general they are mentioned among either the elderly or subgroups (i.e. alcoholics, post-gastrectomy state). In our trial men less often demonstrated a deficient B₁₂ status, but in association with age they had a more pronounced risk of being affected (OR = 0.8). In our cohort, males over the age of 80 years suffered even more often from B₁₂ impairment than women.

HoloTC is known to be a more sensitive and specific marker than total B₁₂, especially for subclinical functional

B₁₂ deficiency and depletion⁽²⁷⁾. In this context it should be kept in mind that, remarkably, B₁₂ depletion occurs twice as often as B₁₂ deficiency. To our knowledge there are no published studies discussing this issue. The problem in comparing different studies is that there are no internationally agreed-upon reference laboratory values for the stratification of B₁₂ deficiency and there is no widely accepted agreement about the therapeutic implications of B₁₂ depletion. Patients showing manifest B₁₂ deficiency have to be treated immediately after diagnosis, as some clinical symptoms can be reversed⁽⁵⁾.

The main limitation of our study concerns the lack of performance of additional laboratory tests such as Hcy or MMA. Both are comparably expensive and laboratory-intensive tests. On the other hand, MMA concentration is considered to be the most specific and sensitive parameter for diagnosis of B₁₂ deficiency⁽²⁷⁾. Furthermore, we did not randomly analyse the population of Liechtenstein, either with regard to subgroups like pregnant women or individuals affected by metabolic disease. In addition, we did not assess the health status and the illness for which medical attention was sought.

Conclusions

B₁₂ deficiency is a frequent finding in a Central European population (2.6%), and B₁₂ depletion is found twice as often. Female gender and age are independent, significant predictive factors of a B₁₂-deficient state, and regular monitoring of B₁₂ status is recommended for them. Current considerations for public health interventions to prevent B₁₂-associated pathologies in vulnerable sub-populations are still under debate⁽²⁸⁾.

The measurement of total B₁₂ and HoloTC concentrations are two valid and easily performed parameters for the detection of B₁₂ deficiency. Early recognition of subclinical depletion of B₁₂ is essential, and treatment of the deficiency is imperative, as symptoms can be reversed at an early phase and may also be preventable. Diagnosis of B₁₂ status is important, uncomplicated, and can lead to simple treatment, preventing major disabilities.

Acknowledgements

Sources of funding: This research received no specific grant from any funding agency in the public, commercial or not-for-profit sector. *Conflicts of interest:* The authors have no potential conflicts of interest to declare. *Ethics:* Ethical approval was not required. *Authors' contributions:* All authors have participated sufficiently, intellectually or practically, in the present study and take public responsibility for the content of the article, including the conception, design, conduct of the experiment, and data interpretation. *Acknowledgements:* The authors are indebted to J. Wurz for editing the manuscript.

References

- Herbert V (1987) Recommended dietary intakes (RDI) of vitamin B-12 in humans. *Am J Clin Nutr* **45**, 671–678.
- Stover PJ (2010) Vitamin B₁₂ and older adults. *Curr Opin Clin Nutr Metab Care* **13**, 24–27.
- Aaron S, Kumar S, Vijayan J *et al.* (2005) Clinical and laboratory features and response to treatment in patients presenting with vitamin B₁₂ deficiency-related neurological syndromes. *Neurol India* **53**, 55–58.
- Allen LH (2009) How common is vitamin B-12 deficiency? *Am J Clin Nutr* **89**, issue 2, 693S–696S.
- Dali-Youcef N & Andrès E (2009) An update on cobalamin deficiency in adults. *Q J Med* **102**, 17–28.
- Hoey L, Strain JJ & McNulty H (2009) Studies of biomarker responses to intervention with vitamin B-12: a systematic review of randomized controlled trials. *Am J Clin Nutr* **89**, issue 6, 1981S–1986S.
- Herrmann W, Obeid R, Schorr H *et al.* (2003) Functional vitamin B₁₂ deficiency and determination of holotranscobalamin in populations at risk. *Clin Chem Lab Med* **41**, 1478–1488.
- Clarke R, Sherliker P, Hin H *et al.* (2007) Detection of vitamin B₁₂ deficiency in older people by measuring vitamin B₁₂ or the active fraction of vitamin B₁₂, holotranscobalamin. *Clin Chem* **53**, 963–970.
- Miller JW, Garrod MG, Rockwood AL *et al.* (2006) Measurement of total vitamin B₁₂ and holotranscobalamin, singly and in combination, in screening for metabolic vitamin B₁₂ deficiency. *Clin Chem* **52**, 278–285.
- McLean E, de Benoist B & Allen LH (2008) Review of the magnitude of folate and vitamin B₁₂ deficiencies worldwide. *Food Nutr Bull* **29**, 2 Suppl., S38–S51.
- Lindenbaum J, Rosenberg IH, Wilson PW *et al.* (1994) Prevalence of cobalamin deficiency in the Framingham elderly population. *Am J Clin Nutr* **60**, 2–11.
- Erfsum H, Johnston C, Guttormsen AB *et al.* (2006) Holotranscobalamin and total transcobalamin in human plasma: determination, determinants, and reference values in healthy adults. *Clin Chem* **52**, 129–137.
- Garcia-Casal MN, Osorio C, Landaeta M *et al.* (2005) High prevalence of folic acid and vitamin B₁₂ deficiencies in infants, children, adolescents and pregnant women in Venezuela. *Eur J Clin Nutr* **59**, 1064–1070.
- Amt für Volkswirtschaft des Fürstentums Liechtenstein (2005) *Abteilung Statistik, Statistisches Jahrbuch 2004*, 1st ed. Vaduz: Amt für Volkswirtschaft.
- Ray JG, Goodman J, O'Mahoney PRA *et al.* (2008) High rate of maternal vitamin B₁₂ deficiency nearly a decade after Canadian folic acid flour fortification. *Q J Med* **101**, 475–477.
- Miller JW, Garrod MG, Allen LH *et al.* (2009) Metabolic evidence of vitamin B₁₂ deficiency, including high homocysteine and methylmalonic acid and low holotranscobalamin, is more pronounced in older adults with elevated plasma folate. *Am J Clin Nutr* **90**, 1586–1592.
- Pflipsen MC, Oh RC, Saguil A *et al.* (2009) The prevalence of vitamin B₁₂ deficiency in patients with type 2 diabetes: a cross-sectional study. *J Am Board Fam Med* **22**, 528–534.
- Black MM (2008) Effects of vitamin B₁₂ and folate deficiency on brain development in children. *Food Nutr Bull* **29**, 2 Suppl., S126–S131.
- Carmel R (2008) Nutritional anemias and the elderly. *Semin Hematol* **45**, 225–234.
- Andres E, Frederici L, Serraj K *et al.* (2008) Update of nutrient-deficiency anemia in elderly patients. *Eur J Intern Med* **19**, 488–493.
- Gil PR, Esteban HJ, Hernandez BV *et al.* (2008) Serum vitamin B₁₂ levels in an adolescent population in Madrid. *An Pediatr (Barc)* **68**, 474–480.

22. Ryan YM (1997) Meat avoidance and body weight concerns: nutritional implications for teenage girls. *Proc Nutr Soc* **56**, 519–524.
23. Narring F, Tschumper A, Inderwildi Bonivento L *et al.* (2004) *Santé et styles de vie des adolescents âgés de 16 à 20 ans en Suisse (2002) (SMASH 2002 – Swiss multicenter adolescent survey on health 2002)*. *Raisons de Santé* 95b, pp. 5–20. Lausanne: Institute universitaire de médecine sociale et préventive.
24. Decarli B, Cavadini C, Grin J *et al.* (2000) Food and nutrient intakes in a group of 11 to 16 year old Swiss teenagers. *Int J Vitam Nutr Res* **70**, 139–147.
25. Chamay-Weber C, Narring F & Michaud PA (2005) Partial eating disorders among adolescents: a review. *J Adolesc Health* **37**, 417–427.
26. Molloy AM, Kirke PN, Troendle JF *et al.* (2009) Maternal vitamin B₁₂ status and risk of neural tube defects in a population with high neural tube defect prevalence and no folic acid fortification. *Pediatrics* **123**, 917–923.
27. Herrmann W, Obeid R, Schorr H *et al.* (2005) The usefulness of holotranscobalamin in predicting vitamin B₁₂ status in different clinical settings. *Curr Drug Metab* **6**, 47–53.
28. Green R (2009) Is it time for vitamin B-12 fortification? What are the questions? *Am J Clin Nutr* **89**, issue 2, 712S–716S.