MINIREVIEW

Vitamin B_{12} Sources and Bioavailability

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The usual dietary sources of vitamin B_{12} are animal foods, meat, milk, egg, fish, and shellfish. As the intrinsic factor-mediated intestinal absorption system is estimated to be saturated at about 1.5–2.0 μg per meal under physiologic conditions, vitamin B_{12} bioavailability significantly decreases with increasing intake of vitamin B_{12} per meal. The bioavailability of vitamin B_{12} in healthy humans from fish meat, sheep meat, and chicken meat averaged 42%, 56%–89%, and 61%–66%, respectively. Vitamin B_{12} in eggs seems to be poorly absorbed (<9%) relative to other animal food products. In the Dietary Reference Intakes in the United States and Japan, it is assumed that 50% of dietary vitamin B_{12} is absorbed by healthy adults with normal gastro-intestinal function. Some plant foods, dried green and purple lavers (nori) contain substantial amounts of vitamin B_{12}, although other edible algae contained none or only traces of vitamin B_{12}. Most of the edible blue-green algae (cyanobacteria) used for human supplements predominately contain pseudovitamin B_{12}, which is inactive in humans. The edible cyanobacteria are not suitable for use as vitamin B_{12} sources, especially in vegans. Fortified breakfast cereals are a particularly valuable source of vitamin B_{12} for vegans and elderly people. Production of some vitamin B_{12}-enriched vegetables is also being devised. Exp Biol Med 232:1266–1274, 2007

Key words: vitamin B_{12}; cobalamin; food source; bioavailability; deficiency; human

Vitamin B_{12} is the largest (molecular weight = 1355.4) and most complex of all the vitamins. Although the scientific use of the term "vitamin B_{12}" is usually restricted to cyanocobalamin, vitamin B_{12} represents all potentially biologically active cobalamins in this review. Cobalamin is the term used to refer to a group of cobalt-containing compounds (corrinoids) that have a lower axial ligand that contains the cobalt-coordinated nucleotide (5, 6-dimethylbenzimidazole as a base; Fig. 1). Cyanocobalamin, which is used in most supplements, is readily converted to the coenzyme forms of cobalamin (methylcobalamin and 5′-deoxyadenosylcobalamin) in the human body (1).

Vitamin B_{12} is synthesized only in certain bacteria (2). The vitamin B_{12} synthesized by bacteria is concentrated mainly in the bodies of higher predatory organisms in the natural food chain system. Animal foods (i.e., meat, milk, egg, fish, and shellfish) but not plant foods are considered to be the major dietary sources of vitamin B_{12} (1). Some plant foods, such as edible algae or blue-green algae (cyanobacteria), however, contain large amounts of vitamin B_{12}. Vitamin B_{12} compounds in algae appear to be inactive in mammals (3). Foods contain various vitamin B_{12} compounds with different upper ligands; methylcobalamin and 5′-deoxyadenosylcobalamin function, respectively, as coenzymes of methionine synthase (EC 2.1.1.13), which is involved in methionine biosynthesis and of methylmolonyl-CoA mutase (EC 5.4.99.2), which is involved in amino acid and odd-chain fatty acid metabolism in mammalian cells (4, 5).

Humans have a complex process for gastrointestinal absorption of dietary vitamin B_{12} (6). Vitamin B_{12} released from food protein is first bound to haptocorrin (salivary vitamin B_{12}–binding protein) in the stomach. After proteolysis of haptocorrin–vitamin B_{12} complex by pancreatic proteases in the duodenum, the released vitamin B_{12} binds to intrinsic factor (IF, gastric vitamin B_{12}-binding protein) in the proximal ileum. The IF–vitamin B_{12} complex can enter mucosal cells in the distal ileum by receptor-mediated endocytosis. Bioavailability of dietary vitamin B_{12} is significantly dependent on this gastrointestinal absorption

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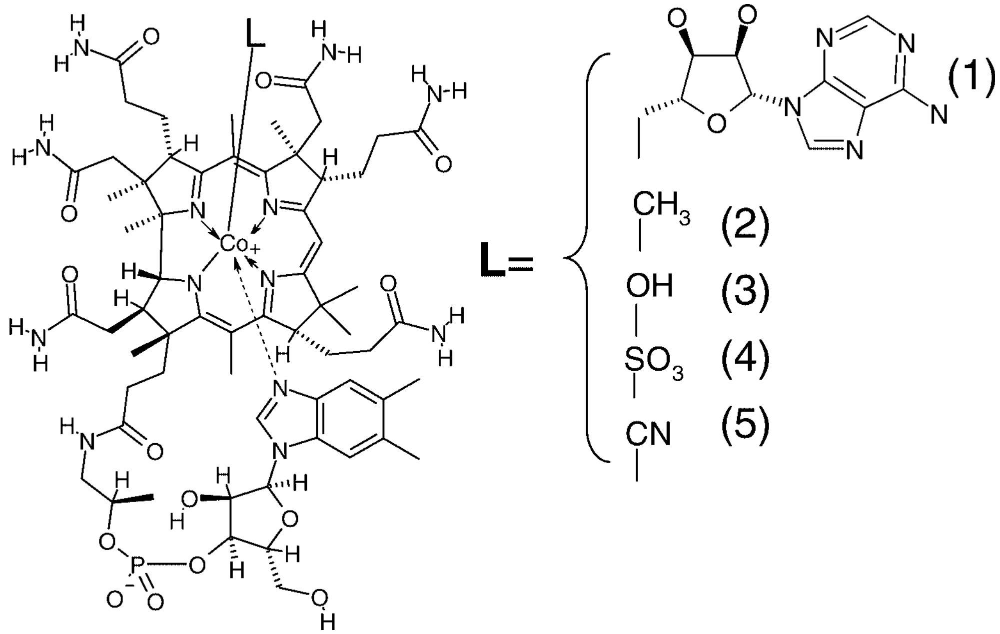


Figure 1. Structural formula of vitamin B_{12} and partial structures of vitamin B_{12} compounds. The partial structures of vitamin B_{12} compounds show only those portions of the molecule that differ from vitamin B_{12}. 1: 5′-deoxyadenosylcobalamin; 2, methylcobalamin; 3, hydroxocobalamin; 4, sulfitocobalamin; 5, cyanocobalamin or vitamin B_{12}.

system. In the Dietary Reference Intakes in the United States, it is assumed that 50% of dietary vitamin B_{12} is absorbed by healthy adults (7); however, there are few data on the bioavailability of vitamin B_{12} from foods. In this article presented here, up-to-date information is reviewed on vitamin B_{12} content and bioavailability in various foods in relation to the prevention of vitamin B_{12} deficiency.

Requirements of Vitamin B_{12} and Vitamin B_{12} Deficiency

The major signs of vitamin B_{12} deficiency are megaloblastic anemia and neuropathy (7). Strict vegetarians (vegans) have a greater risk of developing vitamin B_{12} deficiency relative to nonvegetarians (8) and must consume vitamin B_{12}–fortified foods or vitamin B_{12}–containing dietary supplements to prevent vitamin B_{12} deficiency. A considerable proportion of elderly subjects having low serum vitamin B_{12} levels without pernicious anemia have been reported to have malabsorption of protein-bound vitamin B_{12} (food-bound vitamin B_{12} malabsorption; Ref. 9). The food-bound vitamin B_{12} malabsorption is found in patients with certain gastric dysfunctions, such as atrophic gastritis with decreased stomach acid secretion (10). Because the bioavailability of crystalline vitamin B_{12} is not altered in patients with atrophic gastritis, the Institute of Medicine recommended that adults 51 years and older should obtain the majority of the recommended dietary allowance (RDA) of vitamin B_{12} through the consumption of foods fortified with crystalline vitamin B_{12} or vitamin B_{12}–containing supplements (7). Seal *et al*. (11) reported that a slightly higher dose (50 μg/day) of vitamin B_{12} supplementation significantly increases serum vitamin B_{12} concentrations in older patients with subnormal vitamin B_{12} status.

The RDA of vitamin B_{12} for adults is set at 2.4 μg/day in the United States (and Japan); however, daily body loss of the vitamin is estimated to be between 2 and 5 μg/day (7). Bor *et al*. (12) reported that a daily vitamin B_{12} intake of 6 μg appears to be sufficient to maintain a steady-state concentration of plasma vitamin B_{12} and vitamin B_{12}–related metabolic markers.

Assay of Vitamin B_{12} in Foods

Historically, vitamin B_{12} content of foods has been determined by bioassay with certain vitamin B_{12}–requiring microorganisms, such as *Lactobacillus delbrueckii* subsp. *lactis* ATCC7830 (formerly *Lactobacillus leichmannii*; Ref. 13). Radioisotope dilution assay (RIDA) method with radiolabeled vitamin B_{12} and hog IF (the most specific vitamin B_{12}–binding protein) has also been used for the determination of vitamin B_{12} content in foods (14). Although it was reported that the values determined by the RIDA method were slightly higher in human serum than those determined by the microbiologic method (15), Casey *et al*. (14) demonstrated the excellent correlation between both methods in food vitamin B_{12} analysis.

A fully automated chemiluminescence vitamin B_{12} analyzer with the acridinium ester–labeled vitamin B_{12} derivative and IF has been commercialized. Currently, various types of similar vitamin B_{12} analyzers are being manufactured and clinically used for the routine assay of human serum vitamin B_{12} worldwide. About 10 years ago, my colleagues and I evaluated the applicability of this machine in food analysis, indicating the excellent correlation coefficient between both methods in most foods tested, although in some specific foods the values determined by the microbiologic method were about several-fold greater than the values determined by the chemiluminescence method (16). This difference may be due to the fact that *L. delbrueckii* used for the microbiologic assay of food vitamin B_{12} uses corrinoid compounds that are inactive for humans as well as vitamin B_{12}. Ball (1) stated that about 30% of the reported vitamin B_{12} in foods may be microbiologically active corrinoids rather than vitamin B_{12}. Furthermore, it is known that both deoxyribosides and deoxynucleotides (known as the alkali-resistant factor) can substitute vitamin B_{12} in this lactic bacterium (17).

Vitamin B_{12} in Animal Food

Meat. In the United States Department of Agriculture database, vitamin B_{12} contents of cooked beef liver, lean meat, and turkey are estimated to be 83, 3, and 33 μg/100 g, respectively (18). Appreciable losses (~33%) of vitamin B_{12} in meats by cooking have been reported (19, 20).

Bioavailability of vitamin B_{12} from 100 g (0.9 μg vitamin B_{12}), 200 g (3.0 μg), and 300 g (5.1 μg) of ground patties cooked from mutton (labeled with radioactive vitamin B_{12}) in normal human subjects averaged 56%–77%, 76%–89%, and 40%–63%, respectively (21). An average absorption of vitamin B_{12} from liver pâté (38 μg vitamin B_{12}) is approximately 10%. Since the IF-mediated intestinal absorption system is estimated to be saturated at about 1.5–2.0 μg per meal under the physiologic conditions (22), vitamin B_{12} bioavailability should decrease significantly with increases in the intake of vitamin B_{12} per meal.

Absorption of vitamin B_{12}, assessed by measuring fecal excretion of radioactivity, after consuming 100 g (0.4–0.6 μg vitamin B_{12}), 200 g (0.8–1.3 μg), and 300 g (1.3–1.9 μg) of chicken meat (labeled with radioactive vitamin B_{12}) in healthy human subjects averaged 65%, 63%, and 61%, respectively (23).

Milk. Although vitamin B_{12} content (0.3–0.4 μg/100 g) of various types of milk is not high (18), milk and dairy products are significant contributors of vitamin B_{12} intakes, since the intake of dairy products is high in the general population (7). In bovine milk, all naturally occurring vitamin B_{12} is bound to the transcobalamin, one of the mammalian vitamin B_{12}–binding proteins (24). When radioactive vitamin B_{12} (0.25 μg) mixed in water or milk was administered to human subjects, the mean absorption, as assessed by a whole-body counting of radioactivity, was 55% or 65%, respectively (25).

Appreciable losses of vitamin B_{12} have been reported during the processing of milk; boiling for 2–5 min and 30 min resulted in 30% and 50% loss, respectively (1, 20). The 5-min microwave cooking led to 50% loss and 5%–10% lost by pasteurization (1, 20). When various milk samples were exposed to fluorescent light for 24 hrs at 4°C, the vitamin B_{12} concentration decreased considerably, depending on the type of milk tested (26). On the other hand, when the pasteurized milk was refrigerated for 9 days under retail-simulating or domestic handling conditions, there was no appreciable decline in the concentration of milk vitamin B_{12} (27).

Vitamin B_{12} concentrations in fermented milk decreased significantly during storage at 4°C for 14 days relative to the original milk. About 20%–60% of vitamin B_{12} that is originally presented in milk is recovered in cottage cheese, hard cheese, and blue cheese (28). Sato *et al.* (29) demonstrated that the content of vitamin B_{12} in the whey is reduced considerably during lactic acid fermentation. This decrease in vitamin B_{12} content in whey is due to the production of vitamin B_{12} compounds that are not easily extracted for detection by conventional extraction method. Although the vitamin B_{12} compounds could be extracted by sonication and treatment by proteases, such as pepsin and papain, no information is available on any chemical properties of these compounds (29).

Egg. Vitamin B_{12} content in the whole egg is about 0.9–1.4 μg/100 g (18, 30), and most of the vitamin B_{12} is found in the egg yolk (31). Vitamin B_{12} intakes from the egg are generally large, because it is a popular food item (7). Bioavailability of vitamin B_{12} from scrambled egg yolks, scrambled whole eggs, boiled eggs, and fried eggs (1.1–1.4 μg vitamin B_{12} per 100 g) averaged 8.2%, 3.7%, 8.9%, and 9.2%, respectively (30). Vitamin B_{12} in eggs is generally poorly absorbed relative to other animal food products (32).

Shellfish. Various shellfish are consumed widely. The shellfish that siphon large quantities of vitamin B_{12}–synthesizing microorganisms in the sea are known to be excellent sources of vitamin B_{12}, of which concentrations can exceed sometimes 10 μg/100 g (33). The vitamin B_{12}–synthesizing microorganisms can also synthesize various corrinoids (including corrinoid compounds inactive for humans) with different bases in the lower ligand. When corrinoid compounds were isolated and characterized in popular shellfish, such as oysters, mussels, and short-necked clams, each corrinoid compound was identified as vitamin B_{12} (34). The higher values in the determination of vitamin B_{12} by the microbiologic method compared with the chemiluminesence method may be due to occurrence of certain vitamin B_{12}–substitutive compounds, of which chemical properties have not been characterized.

Fish. Fish (or shellfish) contribute greatly to vitamin B_{12} intake among Asians, particularly Japanese people, and this trend is spreading throughout the world (35). In the USDA database, vitamin B_{12} contents of certain fish (salmon, sardine, trout, tuna, etc.) are 3.0 to 8.9 μg/100 g (18). Based on our studies, the dark muscle of skipjack contains a substantial amount (159 μg/100 g) of vitamin B_{12} compared with the light muscle (dorsal portion 10 μg/100 g;

ventral portion 8 μg/100 g; Ref. 36). When a corrinoid compound was isolated and characterized in the dark muscle, it was identified as vitamin B_{12}. Similar results of high vitamin B_{12} content in dark muscle were found in the yellowfin tuna (37).

Various commercially available soup stocks, which are mainly made of dried bonito shavings and dried sardines, contain considerable amounts (0.2 to 1.2 μg/100 ml) of free vitamin B_{12}, indicating that these may be excellent free vitamin B_{12} sources.[1] The loss of vitamin B_{12} from fish meat by various cooking methods (boiling, steaming, sautéing, frying, and microwaving) was not high, with a range of 2.3%–14.8% (36).

Doscherholmen *et al*. (38) measured the bioavailability of radioactive vitamin B_{12} that was injected into the rainbow trout. A few weeks after this injection, the bioavailability of vitamin B_{12} from the fish meat was evaluated. The bioavailabilities of labeled vitamin B_{12} in 50 g (equivalent to 2.1 μg vitamin B_{12}), 100 g (4.1 μg), 200 g (9.2 μg), and 300 g (13.3 μg) of fish meat were 42%, 38%, 42%, and 30%, respectively.

Salted and Fermented Fish. The highest amount of vitamin B_{12} among foods described in the Japanese Standard Tables of Food Composition is 328 μg/100 g in salted and fermented salmon kidney that is called "Mefun" (39). Eating only 0.8 g Mefun can supply the total RDA (2.4 μg/day) for the adult population. Although this item has a delicate flavor, it has an extremely limited application, since it is popular only in Japan. It might be interesting, however, to describe the characterization of vitamin B_{12} in this item, which may potentially have the highest vitamin B_{12} content in nature. The vitamin B_{12} found in Mefun is not derived from concomitant vitamin B_{12}–synthesizing bacteria, but is accumulated in the salmon kidney. The majority of vitamin B_{12} found in Mefun was recovered in the free vitamin B_{12} fractions (40). Mefun may be an excellent free vitamin B_{12} source for elderly subjects with food-bound vitamin B_{12} malabsorption.

Fish Sauce. Various kinds of fish sauces, traditional food supplements in the diet, are widely used as a seasoning worldwide. Fish sauce (Nam-pla) appears to constitute a major source of vitamin B_{12} in Thailand, since it contains considerable amounts of vitamin B_{12} (41). A considerable amount of vitamin B_{12} (range: 2.3 to 5.5 μg/100 g) was also found in "Ishiru" (a Japanese traditional fish sauce; Ref. 42). When two corrinoid compounds in the fish sauce were isolated and characterized, the main compound was identified as vitamin B_{12}, but the other minor compound could not be identified (42). Corrinoid compounds found in various fish sauces made in Japan could not be identified (43). Fish sauce may not be suitable for use as a source of vitamin B_{12}, considering the low daily intake of the sauce and occurrence of the unidentified corrinoid compounds.

[1]Nishioka M, Miyamoto E, and Watanabe F. Unpublished data.

Vitamin B_{12} in Plant Food

Vegetables. Many studies have been performed to measure vitamin B_{12} content in various vegetables. For decades, edible bamboo shoots have been believed to contain considerable amounts of vitamin B_{12}. However, it turned out that they do not contain appreciable amounts of vitamin B_{12}; however, certain compounds showing vitamin B_{12}–like activity (known as the alkali-resistant factor) were found in them (44). Similar results were found in cabbage, spinach, celery, garland chrysanthermum, lily bulb, and taro (44). Only trace amounts of vitamin B_{12} (<0.1 μg/100 g of wet weight edible portion), which was estimated by subtracting the alkali-resistant factor from total vitamin B_{12}, were found in broccoli, asparagus, Japanese butterbur, mung bean sprouts, tassa jute, and water shield (44). These vegetables may have the ability to take up vitamin B_{12} found in certain organic fertilizer.

Mozafar (45) demonstrated that the addition of an organic fertilizer, cow manure, significantly increases the vitamin B_{12} content in barley kernels and spinach leaves. Mozafar and Oeftli (46) investigated uptake of vitamin B_{12} by soybean roots under water culture conditions. Sato *et al*. (47) reported that a high level of vitamin B_{12} is incorporated into a vegetable, kaiware daikon (radish sprout), by soaking its seeds in vitamin B_{12} solutions before germination. The amount of vitamin B_{12} incorporated into kaiware daikon increases up to about 170 μg/100 g of wet sprout with 3-hr soaking of seeds in 200 μg/ml vitamin B_{12} solution. These vitamin B_{12}–enriched vegetables may be of special benefit to vegans or elderly persons with food-bound vitamin B_{12} malabsorption.

Tea Leaves and Tea Drinks. Considerable amounts of vitamin B_{12} are found in various types of tea leaves: green (0.1–0.5 μg vitamin B_{12} per 100 g dry weight), blue (about 0.5 μg), red (about 0.7 μg), and black (0.3–1.2 μg) tea leaves (48).

When a corrinoid compound was isolated from Japanese fermented black tea (Batabata-cha), the compound was identified as vitamin B_{12} (49). When vitamin B_{12}–deficient rats were fed this tea drink (50 ml/day, equivalent to a daily dose of 1 ng vitamin B_{12}) for 6 weeks, urinary methylmalonic acid excretion (an index of vitamin B_{12} deficiency) of the tea drink–supplemented rats decreased significantly compared with that of the deficient rats (49). These results indicate that the vitamin B_{12} found in the fermented black tea is bioavailable in rats. However, only 1–2 liters of consumption of fermented tea drink (typical regular consumption in Japan), which is equivalent to 20–40 ng vitamin B_{12}, is not sufficient to meet the RDA of 2.4 μg/day for adult humans.

Soybean. Vitamin B_{12} contents of soybean are low or undetectable. A soybean-fermented food, tempe, contains a large amount of vitamin B_{12} (0.7 to 8 μg/100 g; Ref. 50). Certain bacteria contamination during the process of tempe production may contribute to the vitamin B_{12} increase of tempe (51). Another fermented soybean, natto, contains a minute amount of vitamin B_{12} (0.1 to 1.5 μg/100 g; Ref. 52).

Edible Algae. Various types of edible algae are used for human consumption the world over. Dried green (*Enteromorpha* sp.) and purple (*Porphyra* sp.) lavers (nori) are the most widely consumed among the edible algae and contain substantial amounts of vitamin B_{12} (32 to 78 μg/100 g dry weight; Ref. 39). In Japanese cooking, several sheets of nori (9 × 3 cm; about 0.3 g each) are often served for breakfast. A large amount of nori (<6 g) can be consumed from certain sushi, vinegared rice rolled in nori. However, edible algae other than these two species contain none or only traces of vitamin B_{12} (39). Dagnelie *et al*. (53) reported the effect of edible algae on the hematologic status of vitamin B_{12}–deficient children, suggesting that algal vitamin B_{12} appears to be nonbioavailable. As bioavailability of the algal vitamin B_{12} is not clear in humans, my colleagues and I characterized corrinoid compounds to determine whether the dried purple and green lavers and eukaryotic microalgae (*Chlorella* sp. and *Pleurochrysis carterae*) used for human food supplements contain vitamin B_{12} or inactive corrinoids. My colleagues and I found that these edible algae contain a large amount of vitamin B_{12} without the presence of inactive corrinoids (54–57).

To measure the bioavailability of vitamin B_{12} in the lyophilized purple laver (*Porphyra yezoensis*), the effects of feeding the laver on various parameters of vitamin B_{12} were investigated in vitamin B_{12}–deficient rats (58). Within 20 days after vitamin B_{12}–deficient rats were fed a diet supplemented with dried purple laver (10 μg vitamin B_{12}/kg diet), urinary methylmalonic acid excretion became undetectable and hepatic vitamin B_{12} (especially coenzyme vitamin B_{12}) levels significantly increased. These results indicate that vitamin B_{12} from the purple lavers is bioavailable in rats.

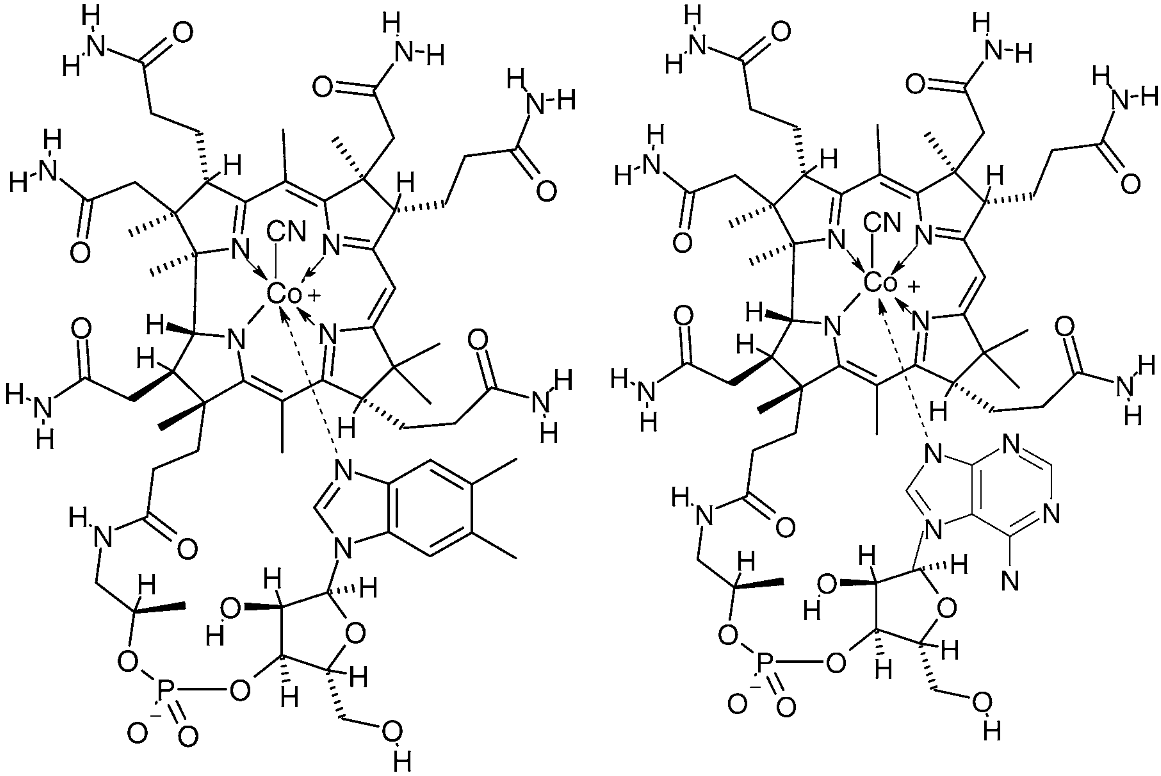
A nutritional analysis for the dietary food intake and serum vitamin B_{12} level of a group of six vegan children aged 7 to 14 who had been living on a vegan diet including brown rice for 4 to 10 years suggests that consumption of nori may keep vegans from suffering vitamin B_{12} deficiency (59). Rauma *et al*. (60) also reported that vegans consuming nori and/or chlorella had a serum vitamin B_{12} concentration twice as high as those not consuming these algae.

Edible Cyanobacteria. Some species of the cyanobacteria, including *Spirulina*, *Aphanizomenon*, and *Nostoc,* are produced at annual rates of 500-3000 tons for food and pharmaceutical industries worldwide (61). Tablets containing *Spirulina* sp. are sold as a health food fad, since it is known to contain a large amount of vitamin B_{12} (62). We found that commercially available spirulina tablets contained 127–244 μg vitamin B_{12} per 100 g weight (63). When two corrinoid compounds were characterized from the spirulina tablets, the major (83%) and minor (17%) compounds were identified as pseudovitamin B_{12} (adeninly cobamide) and vitamin B_{12}, respectively (Fig. 2). Several groups of investigators indicated that pseudovitamin B_{12} is hardly absorbed in mammalian intestine with a low affinity to IF (64, 65). Furthermore, researchers showed that spirulina vitamin B_{12} may not be bioavailable in mammals (63, 66). Herbert (67) reported that an extract of spirulina contains two vitamin B_{12} compounds that can block the metabolism of vitamin B_{12}. And van den Berg *et al*. (68) demonstrated that a spirulina-supplemented diet does not induce severe vitamin B_{12} deficiency in rats, implying that the feeding of spirulina may not interfere with the vitamin B_{12} metabolism. Further studies are needed to clarify bioavailability of spirulina vitamin B_{12} in humans.

Aphanizomenon flos-aquae, a fresh water cyanobacterium, grow naturally in Upper Klamath Lake, Oregon. Kay (69) described that the bacterial cells contain some corrinoid compounds that can be used as vitamin B_{12} in humans. In contrast, my colleagues and I found that the corrinoid compound purified from *Aphanizomenon* cells was identified as pseudovitamin B_{12}, which is inactive corrinoid for humans (70). We found that the dried bacterial cells contained 616 μg vitamin B_{12} per 100 g weight. *Escherichia coli* 215-bioautography of the *Aphanizomenon* extract indicated that the bacterial cells contained only pseudovitamin B_{12} (70).

Aphanothece sacrum (Suizenji-nori) is an edible cyanobacterium that is indigenous to Japan. The dried bacterial cells are used as an ordinary food item after soaking in water or a nutritional supplement. The nutrition labeling of this bacterial product shows that the dried cells contain a large amount of vitamin B_{12} (94 μg/100 g); however, the corrinoid compound purified from the bacterial cells was identified as pseudovitamin B_{12} (71). Therefore, its nutritional value is questionable. *Nostoc commune* (Ishikurage) contains considerable amounts (99 μg/100 g) of vitamin B_{12} in its dried cells as measured by the microbiologic method; however, only 12% of the vitamin may be active, since the main (88%) and minor (12%) compounds in the bacterial cells were identified as pseudovitamin B_{12} and vitamin B_{12}, respectively (72). In summary, the results reviewed above indicate that edible cyanobacteria often contain a large amount of pseudovitamin B_{12}, which is known to be biologically inactive in humans. Therefore, they are not suitable for use as a source of vitamin B_{12} for the prevention of vitamin B_{12} deficiency among the high-risk population, such as vegans and elderly subjects.

Vitamin B_{12}–Fortified Cereals. Ready-to-eat cereals fortified with vitamin B_{12} are known to constitute a great proportion of dietary vitamin B_{12} intake in the United States (7). Several groups of investigators suggested that eating a breakfast cereal fortified with folic acid, vitamin B_{12}, and vitamin B_6 increases blood concentrations of these vitamins and decreases plasma total homocysteine concentrations in elderly populations (73). Fortified breakfast cereals have become a particularly valuable source of vitamin B_{12} for vegetarians and elderly people.



Vitamin B_{12} Pseudovitamin B_{12}

Figure 2. Structural formula of vitamin B_{12} and pseudovitamin B_{12} (7-adeninyl cyanocobamide).

Conclusion

Vitamin B_{12} contents determined by the microbiologic assay method used widely in food analysis are incorrect in some specific foods, because this lactic bacterium can utilize inactive corrinoid compounds, such as pseudovitamin B_{12}, and substitute both deoxyribosides and deoxynucleotides (known as the alkali-resistant factor) for vitamin B_{12}. Thus, vitamin B_{12} contents should be calculated by subtracting the

Table 1. Bioavailability of Dietary Vitamin B_{12}[a]

Foods	Predominate corrinoid[b]	Bioavailability[c]	Content (μg/100 g)
Animal meats			
Mutton, cooked		56%–89% (21)	2.6 (18)
Chicken, cooked		61%–66% (23)	9.4 (18)
Cow's milk		65% (25)	0.4 (18)
Eggs			
Chicken, cooked		<9% (31)	1.3 (18)
Shellfish			
Oyster	Vitamin B_{12} (34)		46.3 (34), 28.1 (17)
Mussel	Vitamin B_{12} (34)		15.7 (34), 10.3 (17)
Short-necked clam	Vitamin B_{12} (34)		37.0 (34), 52.4 (17)
Fish meats			
Skipjack, dark muscle	Vitamin B_{12} (36)		158.5 (36)
Yellowfin tuna, dark muscle	Vitamin B_{12} (37)		52.9 (37)
Rainbow trout, cooked		42.0% (38)	4.9 (18)
Edible algae			
Purple laver	Vitamin B_{12} (54)		32.3 (54), 77.6 (17)
Green laver	Vitamin B_{12} (55)		63.6 (55), 31.8 (17)
Chlorella	Vitamin B_{12} (56)		200.9–211.6 (56)

[a] Numbers in parentheses are reference numbers.
[b] Isolated and identified.
[c] intake of <2 μg vitamin B_{12} per meal in healthy humans.

values of the alkali-resistant factor from the values of total (or apparent) vitamin B_{12} in all foods tested to prevent overestimating their vitamin B_{12} contents. Even if IF-based clinical assay kits or analyzers are used for measuring food vitamin B_{12} content, they may not represent only vitamin B_{12} because of the possibility that the binding of vitamin B_{12} to IF is interfered slightly by certain food ingredients or inactive corrinoid compounds, such as pseudovitamin B_{12}. The difficulty to evaluate whether certain foods contain vitamin B_{12} or inactive corrinoids may be easily resolved by the use of a simple technique, bioautography with vitamin B_{12}–dependent *E. coli* 215 after separation of the sample by silica gel 60 thin-layer chromatography (72, 74). The database of vitamin B_{12} content in foods should be revised in order to accurately assess dietary intakes of vitamin B_{12}.

Although food items that contribute to the vitamin B_{12} intake vary widely depending on food cultures or food habits throughout the world, animal products (meat, milk, egg, fish, and shellfish) are excellent sources of vitamin B_{12} (Table 1). Dried edible cyanobacteria as nutritional supplements may not be suitable for vitamin B_{12} sources, because the majority of the vitamin in the bacterial cells is pseudovitamin B_{12}. As technologies advance, various plant foods that contain an appreciable amount of naturally occurring vitamin B_{12} and are fortified with crystalline vitamin B_{12} may be available for human consumption to maintain adequate vitamin B_{12} status in the general population and to prevent vitamin B_{12} deficiency among vegans or elderly persons.

For the Dietary Reference Intakes in the United States and Japan, it is assumed that 50% of dietary vitamin B_{12} is absorbed and utilized by healthy adults with a normal gastrointestinal function. Further information on bioavailability of vitamin B_{12} from various food sources of vitamin B_{12} is needed to determine more precise RDA of the vitamin.

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