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Micronutrient intake and status in rural Democratic Republic of Congo

D.V. Barclay[a,*], J. Mauron[a], A. Blondel[a], C. Cavadini[a], A.M. Verwilghen[b], C. Van Geert[b], H. Dirren[a]

[a]*Nestec Ltd., Nestlé Research Center, Lausanne, Switzerland*
[b]*Yasa-Bonga Hospital, City, Congo*

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Abstract

Vitamin, mineral and trace element intakes were assessed in a rural African population using a novel dietary survey method, and compared with status measurements. In addition to the previously described protein deficiency, multiple micronutrient deficiencies were observed. Although vitamin A intakes were generally satisfactory, some low plasma retinol concentrations were observed in adults, due perhaps to the very low protein intakes or infectious diseases. Vitamin B1, B2 and niacin intakes were clearly inadequate, and for the two former were confirmed by status measurements. Whilst B6 intake was low, B6 status was adequate, probably resulting from lower requirements because of low protein intakes. B12 intake was low in some age groups, whereas that of folate was satisfactory. Fe, Cu and Mg intakes appeared to be adequate. Intakes of phosphorus and iodine were low for children and adolescents; those of Zn and Ca were clearly inadequate, except for Zn in women. Dietary interventions to prevent or treat malnutrition in this region should address several micronutrients in addition to protein. © 2003 Elsevier Inc. All rights reserved.

Keywords: Africa; Congo; Vitamin; Mineral; Trace element; Micronutrient; Intake; Deficiency; Nutritional status

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1. Introduction

Malnutrition is widespread in many poor rural regions of Africa. In the Rural Health Zone of Yasa-Bonga of the Democratic Republic of Congo, severe malnutrition in the form of

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* Corresponding author. Tel.: +4121-785-9551; fax: +4121-785-8556.
E-mail address: denis.barclay@rdls.nestle.com (D. Barclay).

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kwashiorkor or marasmic kwashiorkor is frequent and generally affects children and women of child-bearing age [1,2]. In general, villagers in this region live from subsistence farming and food gathering. Malnutrition increases in the dry season from July to October when the food supply becomes scarce, up to the groundnut harvest beginning in February. Maternal nutritional status was previously shown to strongly influence lactation and infant growth in these villages [3]. The most recent published data available showed that one-quarter of children under 5 years presented clinical signs of protein-energy malnutrition and 40% had a weight-for-height less than the 5th percentile of the WHO reference values [4]. Biochemical studies of malnutrition in this region have pointed to dietary protein inadequacy as being a major nutritional deficiency [5–7], confirmed by our study on macronutrient intakes [8,9]. Given the economic decline in the country since these observations were made, the nutritional status of the rural population has certainly not improved, as witnessed by continued admission of patients with various manifestations of malnutrition. Since no information on food and nutrient intakes was available for this region, we carried out dietary surveys in villages surrounding the hospital. In general, the villagers consume two meals daily, each comprising a bulky cassava dough ball, sometimes with maize, and a spicy vegetable stew or sauce. The latter contains salt and hot red peppers, and one or more other ingredients such as cassava leaves or wild vegetables, mushrooms, groundnuts or melon seeds, palm oil, fish and extremely seldom, meat. We previously reported macronutrient intakes [8,9] showing that protein and fat provided less than 5% and 10% respectively, of energy intake across all age groups, mainly as a result of the very high intake of cassava (Manihot esculenta). Indeed, cassava provided a mean of 82%, 27%, 12% and 92% respectively, of dietary energy, protein, fat and carbohydrate. Thus the dietary pattern in this region, widespread in equatorial Africa, with overwhelming reliance on cassava as a source of energy, needs to be documented in order to better understand the underlying causes of malnutrition. We report here micronutrient intakes and status.

2. Subjects and methods

2.1. Study location

The study was conducted in the Rural Health Zone of Yasa-Bonga, some 450 km east of Kinshasa, in the Democratic Republic of Congo. Surveys were carried out on five different occasions between 1981 and 1987 in five villages (Mikula, Kinabamba, Kinzamba-Kasai, Mbanza Muluma, Mbanza Nganda) within a 15 km radius of the Yasa-Bonga hospital.

2.2. Subjects

78 subjects from 12 families participated in the study, resulting in a total of 132 individual observations of 5 to 10 days each

- 33 in children, 4-8 years (14 girls, 19 boys)
- 15 in children, 9-13 years (8 girls, 7 boys)

- 19 in adolescents, 14-18 years (7 girls, 12 boys)
- 65 in adults, (34 women, 31 men)

The study was approved by the Director of the Yasa-Bonga hospital. The subjects gave their informed verbal consent after explanation of the goals and methods of the study.

2.3. Dietary survey

Given the meal habits in this region (consumption from family bowls; i.e. no individual portions), a novel dietary assessment method was employed. This method was previously described in detail [8,9]. Briefly, all subjects were weighed immediately before and after each of the two daily meals. Mechanical balances (precision of 50g; Sauter BN and LGK125P, August Sauter GmbH, Albstadt, Germany) were used, and weight gains during meals were calculated by difference. The individual weight increments allowed the calculation, for each subject, of food consumption as a percentage of the global family consumption.

All foods consumed at the morning and evening meals over 5-10 study days and left-overs were accurately weighed using a mechanical balance (precision of 1g; Terraillon SA, Annemasse, France). For each family, composite samples of all sauce ingredients (i.e. except cassava and maize staples) were frozen and shipped to the Nestlé Research Center in Switzerland where they were homogenized and freeze-dried and stored in Teflon-lined cans under nitrogen for analysis of vitamins and minerals. A total of 27 freeze-dried sauce samples were thus obtained, one per family per study period. Separate samples of cassava and maize were taken regularly for analysis and were treated as the sauce samples. One composite sample of cassava flour and one of maize flour, each one comprising 10 individual flour samples, were then analyzed.

2.4. Food analyses

Aliquots of all samples were sent to the TNO, Zeist, The Netherlands for analysis of vitamins. Vitamin A and carotenoids were determined by liquid chromatography [10]. Vitamin A content was calculated as retinol equivalents (RE), using conversion factors of 12ug for β-carotene and 24μg for other provitamin A carotenoids. Vitamins B1 and B2 were determined by liquid chromatography [11]. Vitamin B6, niacin and folate were measured using microbiological assays [12,13] and vitamin B12 using a competitive protein binding radioassay [14]. Ca, Cu, Fe, Mg and Zn were measured by atomic absorption spectrometry [15]. Phosphorus was determined using the molybdenum blue colorimetric method [16], and iodine by gas chromatography [17].

2.5. Micronutrient intakes

Individual vitamin and mineral intakes were calculated using global family food consumption, individual weight gains and the composition of the respective sauce, cassava and maize samples. The adequacy of vitamin and mineral intakes were evaluated by comparison with the Dietary Reference Intakes (DRIs), 1997-2001 [18–20].

Table 1
Subject description

		Age (years)		Weight (kg)	
	n	range	mean ± SD	range	mean ± SD
Males	19	4–8	5.6 ± 1.3	6.4–17.0	11.7 ± 2.6
	7	9–13	11.3 ± 1.6	12.2–25.0	18.2 ± 4.6
	12	14–18	15.8 ± 1.3	21.0–28.0	25.2 ± 2.6
	31	19–66	39.8 ± 14.3	28.0–54.5	44.9 ± 6.0
Females	14	4–8	6.6 ± 1.3	10.4–16.5	13.5 ± 1.8
	8	9–13	10.6 ± 1.6	16.0–24.0	19.0 ± 2.9
	7	14–17	14.9 ± 1.2	22.0–30.0	25.6 ± 2.8
	34	20–48	30.8 ± 8.8	32.6–42.0	40.4 ± 3.9

2.6. Micronutrient status

During the dietary surveys, fasting blood samples were drawn from adult subjects in order to measure nutritional status parameters with respect to certain vitamins and minerals. Serum retinol was determined by fluorimetry [21]. Thiamin status was assessed enzymatically by determination of the activation coefficient of erythrocyte transketolase (αETK; [22]) and riboflavin status by determination of the activation coefficient of erythrocyte glutathione reductase (αEGR; [23]). Vitamin B6 status was determined according to two different methods: the activation coefficient of erythrocyte aspartic transaminase (αEAST; [24]), and plasma pyridoxal 5'-phosphate (PLP; [25]). Plasma vitamin C was determined by microfluorimetry [26]. Blood hemoglobin levels were determined using the cyanmethemoglobin method. Micronutrient status was defined as normal, low or deficient according to commonly used cutoffs.

3. Results

3.1. Subject description

The age (range, mean ± SD) and body weights (range, mean ± SD) of the subjects are given according to gender and age group in Table 1.

3.2. Micronutrient intakes

Daily intakes of vitamins, minerals and trace elements by age and gender are presented in Table 2 (mean ± SD), and in Figs. 1 and 2 as percentages of Dietary Reference Intakes [18–20]. Compared to DRIs, intakes of vitamins B1, B2, B6 and niacin were clearly low for all age groups; mean intakes were generally less than 60% of DRIs. Intakes of vitamin B12 were marginally low, whereas those of vitamin A and folate generally equaled or exceeded DRIs. For the minerals and trace elements, dietary intakes of Fe, Cu and Mg were generally satisfactory. Intakes of phosphorus and iodine were low for children and adolescents only, whereas those of Zn and Ca were clearly inadequate for all age groups, with the exception of zinc in adult women.

Table 2
Daily vitamin and mineral intakes (mean ± SD) by age group and sex

		M4-8	F4-8	M9-13	F9-13	M14-18	F14-18	M19+	F19+
	n	19	14	7	8	12	7	31	34
Vitamin A	μgRE	489 ± 293	363 ± 213	840 ± 332	613 ± 284	726 ± 418	703 ± 280	987 ± 459	1127 ± 646
Vitamin B1	mg	0.17 ± 0.11	0.19 ± 0.12	0.26 ± 0.13	0.25 ± 0.13	0.41 ± 0.21	0.38 ± 0.25	0.42 ± 0.26	0.48 ± 0.29
Vitamin B2	mg	0.26 ± 0.13	0.21 ± 0.11	0.37 ± 0.13	0.44 ± 0.18	0.41 ± 0.10	0.39 ± 0.15	0.57 ± 0.26	0.58 ± 0.20
Vitamin B6	mg	0.32 ± 0.13	0.31 ± 0.13	0.54 ± 0.12	0.47 ± 0.09	0.65 ± 0.17	0.63 ± 0.21	0.75 ± 0.28	0.83 ± 0.28
Niacin	mg	4.9 ± 2.0	4.3 ± 1.6	8.5 ± 2.0	7.7 ± 1.7	8.6 ± 1.9	8.1 ± 2.0	10.7 ± 3.5	11.9 ± 3.9
Vitamin B12	μg	1.00 ± 0.69	0.94 ± 0.53	1.45 ± 0.76	1.75 ± 0.78	1.81 ± 0.73	1.25 ± 0.86	2.15 ± 1.12	2.48 ± 1.48
Folates	μg	224 ± 81	196 ± 110	304 ± 86	303 ± 68	353 ± 115	404 ± 130	465 ± 186	536 ± 214
Iron	mg	8.5 ± 4.4	7.3 ± 3.2	12.8 ± 3.6	14.4 ± 5.6	13.3 ± 4.1	12.1 ± 4.1	18.2 ± 7.6	20.0 ± 8.5
Zinc	mg	3.2 ± 1.5	3.0 ± 1.4	4.7 ± 1.2	5.3 ± 2.0	5.6 ± 1.8	5.1 ± 1.5	6.9 ± 2.6	7.7 ± 3.3
Copper	μg	584 ± 285	514 ± 211	929 ± 206	875 ± 276	967 ± 239	1000 ± 408	1274 ± 499	1415 ± 532
Calcium	mg	222 ± 129	240 ± 111	333 ± 171	410 ± 150	459 ± 191	323 ± 178	533 ± 225	615 ± 296
Magnesium	mg	153 ± 50	162 ± 54	273 ± 47	268 ± 112	362 ± 171	282 ± 72	380 ± 120	434 ± 147
Phosphorus	mg	342 ± 120	362 ± 143	562 ± 138	553 ± 111	687 ± 181	607 ± 173	803 ± 249	924 ± 319
Iodine	μg	53 ± 18	55 ± 19	99 ± 19	88 ± 11	112 ± 17	101 ± 30	133 ± 43	145 ± 35

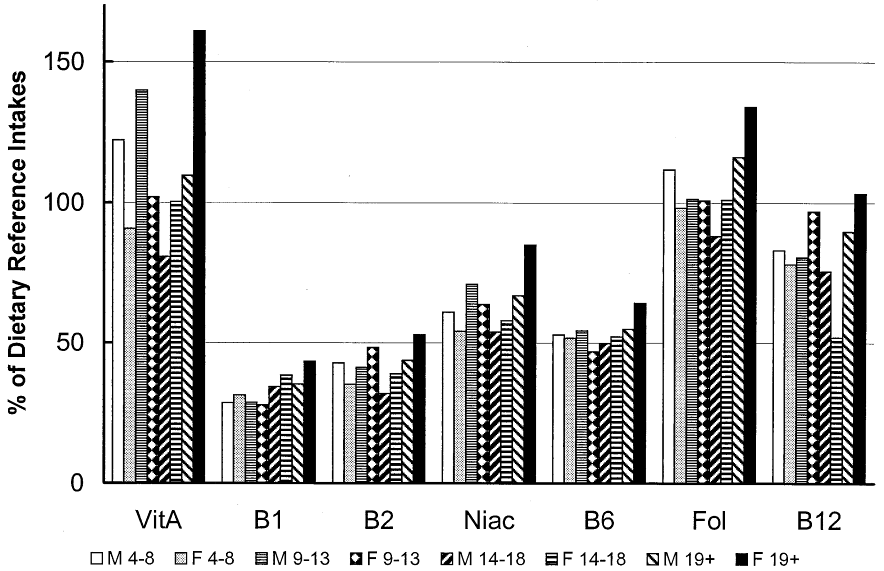

Fig. 1. Mean daily vitamin intakes, according to age and gender, as percentages of Dietary Reference Intakes, 1997–2001 [18–20].

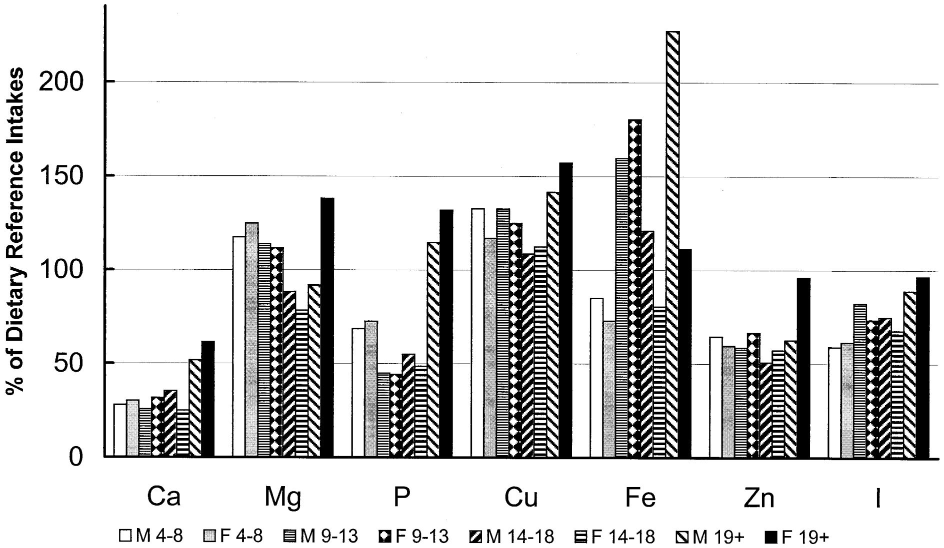

Fig. 2. Mean daily mineral and trace element intakes, according to age and gender, as percentages of Dietary Reference Intakes, 1997-2001 [18–20].

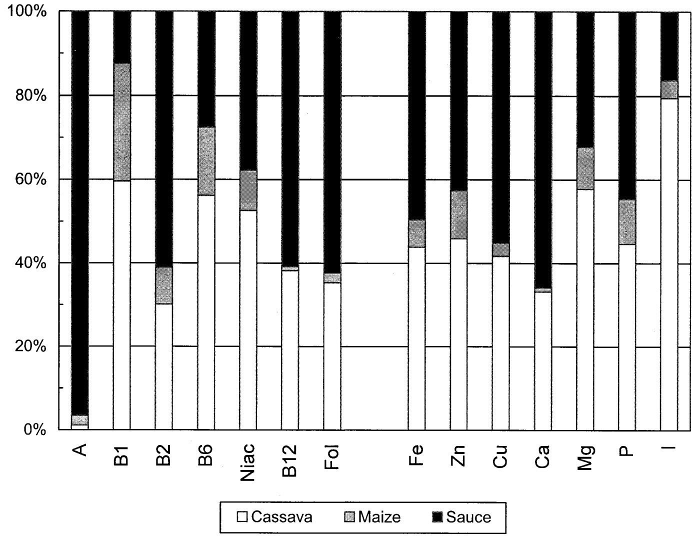

Fig. 3. Proportions of total micronutrient intakes from staple foods and sauces.

The contributions to micronutrient intakes of the dietary staples cassava and maize, as well as the vegetable sauces, are given in Fig. 3. Almost 100% of vitamin A intake came from the vegetable sauces. The sauces were also major contributors to vitamin B2, B12, folate, Ca and Cu intakes. For all other vitamins and minerals considered, large proportions (35-85%) of dietary intakes were derived from cassava and, to a lesser extent, from maize.

3.3. Micronutrient status

The biochemical indicators of micronutrient status of adults are shown in Table 3. For vitamin A, 27% of plasma retinol values were low, and 3% were in the deficient range. For thiamin and riboflavin status indicators, 38% and 25%, respectively, of values were low and 13% and 56%, respectively, indicated deficiency. All values for both markers of vitamin B6 status were in the normal ranges. For vitamin C, 15% of values were low, but none were in the deficient range.

4. Discussion

Deficiencies in micronutrients are associated with increased risks of morbidity and mortality. For example, vitamin A deficiency is associated with increased risk for xerophthalmia and blindness, severe infection, anemia, poor growth and mortality [27]; iron deficiency during infancy impairs cognitive development and immune function and is associated with increased morbidity [28]; iodine deficiency during pregnancy and childhood is the single most important preventable cause of brain damage worldwide [29]; zinc deficiency, even mild-to-moderate, increases the risk of poor growth and development,

Table 3
Micronutrient status of adults

Nutrient	Indicator	unit	n	Mean ± SD	Low	Deficient[*]
Vit. A	Plasma retinol	μmol/L	37	1.05 ± 0.54	27%	3%
Vit. B1	αETK	—	16	1.14 ± 0.07	38%	13%
Vit. B2	αEGR	—	16	1.36 ± 0.23	25%	56%
Vit. B6	αEAST	—	16	1.61 ± 0.15	0%	—
Vit. B6	PLP	nmol/L	16	80 ± 17	0%	—
Vit. C	Plasma Vit. C	μmol/L	27	37 ± 13	15%	0%
Fe	Hb (Females)	g/L	8	104 ± 30	50%	—
Fe	Hb (Males)	g/L	8	127 ± 27	25%	—

[*] Range of normal, low and deficient status:

Plasma retinol:	normal: >0.70;	low: 0.35–0.75;	deficient: <0.35 μmol/L
αETK:	normal: <1.15;	low: 1.15–1.25;	deficient: >1.25
αEGR:	normal: <1.20;	low: 1.20–1.29;	deficient: >1.29
αEAST:	normal: <2.00		
Plasma PLP	normal: >30 nmol/L		
Plasma Vit. C:	normal: >23;	low: 11.4–23;	deficient: <11.4 μmol/L
Hb (Females):		low: <120 g/L	
Hb (Males):		low: <130 g/L	

reduced immune function, increased infectious diseases and mortality [30]. Since there was no published information on the nutritional status of this poor rural population, we conducted studies in order to assess micronutrient intakes and status.

Given the heavy reliance on cassava, the dietary patterns and eating habits of this typical rural equatorial African population, as well as the lack of knowledge of the composition of several commonly consumed local foods, a novel method of measurement of nutrient intakes had to be developed. This was well accepted by the subjects and provided a relatively simple way of estimating food and nutrient intakes. Since individual portions are not served, the actual proportions of sauces and staples consumed by family members cannot be measured on an individual basis with this method; i.e. the average proportions and compositions for the family had to be used for all family members.

We previously reported macronutrient intakes in typical villages of this equatorial region of Africa, characterized by a hot, humid climate, poor soil, and with cassava as the main crop of the subsistence farmers [8,9]. The dietary intakes in this region provide sufficient energy for the adult, but not for child growth. The observed protein intakes are clearly inadequate for all age groups. This is in agreement with the documented high frequency of kwashiorkor and marasmic kwashiorkor in this population. In the present report, the intakes of several micronutrients were inadequate in comparison with DRIs. The highest micronutrient intakes were generally found for women followed by men, adolescents and children, reflecting differences in overall food and energy intakes.

4.1. Vitamin A

Nearly 100% of vitamin A intake came from the vegetable sauces in the form of carotenoids, since foods of animal origin were very rarely consumed. A large proportion of these carotenoids was provided by red palm oil, commonly consumed in this region.

Compared to DRIs, vitamin A intakes appeared to be generally satisfactory (Fig. 1). However plasma retinol levels showed quite wide variation between individuals, with approximately 27% and 3% respectively, of adult values in the low and deficient ranges. There are a number of possible explanations for this apparent contradiction. Firstly, the low protein and lipid intakes and deficiencies in other micronutrients may also influence vitamin A nutrition in our subjects. Carotenoid cleavage and synthesis of retinol transport proteins are reduced in protein deficiency, and dietary fat is necessary for efficient intestinal absorption of vitamin A and carotenoids [31]. In contrast however, vitamin A status was normal in malnourished Nigerian children consuming considerable amounts of provitamin A carotenoids [32]. Another factor potentially influencing vitamin A status is malaria which is endemic in this part of Africa. In a neighboring region of the Congo, low serum retinol levels were observed in children suffering from malaria [33,34].

4.2. B vitamins

Mean intakes of vitamins B1, B2, B6 and niacin were generally below 60% of DRIs, and result from the absence of grain products, meat and dairy foods in the diet. Intakes of vitamin B12 were marginally low; those of folate were generally satisfactory. The limited thiamin and riboflavin status data we report here tend to confirm the observed low intake data. Beri-beri, although infrequent, is regularly observed in the region as documented by hospital admissions, confirming to a certain degree the thiamin intake and status data. Clinical signs of niacin deficiency have not been documented in the region surrounding the hospital. However, outbreaks of pellagra were observed further to the east near Lubumbashi and responded rapidly to administration of niacin [35]. For vitamin B6, our status data are not in agreement with those on intake. Despite some uncertainties and limitations of the methods employed for status measurement, we can tentatively conclude that the vitamin B6 status of these subjects was satisfactory in contrast to intake which was clearly low (50-60%) compared to DRIs. The most obvious explanation for this is that pyridoxine requirements are related to protein intake, and may be expressed as 0.016 mg/g of protein [36]. Considering the average protein intakes we previously measured in this population of 23 g/day (men and women combined), the vitamin B6 requirement for an adult would amount to 0.37 mg/day, a figure well covered by the measured average intake of 0.8 mg/day.

4.3. Iron

Fe intakes appeared to be generally sufficient; mean intakes ranged from 73% in young girls to 110% in women and 230% in men compared to DRIs. However, we may have over-estimated the adequacy of the dietary Fe intake, given that the quasi-totality of Fe was derived from plant sources and that animal protein was virtually absent from the diet. Vitamin C is known to enhance food Fe bioavailability. Although we were unable to determine vitamin C intake directly, nutritional status with respect to vitamin C was generally satisfactory suggesting that intakes were also satisfactory. We have no direct information on the level of phytic acid, a potent inhibitor of Fe absorption, in the diet of our subjects. However, the technique of steeping peeled tubers in running water for several days prior to sun-drying and cooking, as carried out by our subjects, has been shown to almost completely destroy the phytic acid in cassava [37]. Therefore, our data seem to indicate that both the amount and bioavailability of dietary Fe may be adequate, or at least marginally so. Our very limited data on Fe status of our subjects do not allow us to draw firm conclusions on Fe nutrition in this region. Nevertheless, the high frequency of hookworm infestations and the endemic malaria may well contribute more to the frequently observed anemia, than do intake and bioavailability of dietary Fe. Although hospital records on anemia may not reflect population prevalences, those from the Yasa-Bonga hospital suggest that anemia is the most common micronutrient deficiency-related disorder in the region, the highest prevalences being in women and children. This lends support to the notion that adequate dietary Fe intakes do not prevent a high prevalence of anemia under these particular circumstances with high rates of infections and protein-energy malnutrition. For comparison, in urban areas of the country (Kinshasa), Fe deficiency affected more than 50% of mothers [38], and studies further to the east indicated that anemia was related to protein-energy malnutrition, perhaps mediated by selenium deficiency [39].

4.4. Zinc and copper

Compared to DRIs, Zn intakes appeared to be very low across all age groups, except for adult women. However, in evaluating the adequacy of Zn intake, we have to relate them to very low protein intakes in our subjects. Indeed, balance studies in adult men showed that Zn requirements were related in part to dietary phosphorus and protein [40]. The requirement for Zn is lowest when dietary phosphorus and protein are low, and highest when dietary phosphorus and protein are high. Since the protein and phosphorus intakes of our subjects were low, the observed mean Zn intakes of 7 to 8 mg/day in adults may not be as inadequate for men as they appear to be with respect with DRIs, whereas they are adequate for women. In comparison however, the Zn status of women in Kinshasa was poor [41]. For the younger age groups, Zn intakes were only 50-60% of DRIs, and may contribute to the high prevalence of stunting reported in the region [4]. Intakes of Cu appeared to be satisfactory across all age groups.

4.5. Calcium

Ca intakes were uniformly low and consistent with the total absence of dairy products in the diet. However, the apparently huge Ca deficit, especially in the younger age groups, may not be as big as it seems for a number of reasons. At low Ca intakes, intestinal absorption is increased and renal excretion is decreased. Moreover, Ca excretion in young adult men is diminished when protein intake is low and increased when phosphorus intake is low [42]. Increased protein intake caused Ca balance to change from positive to negative at lower phosphorus intake, but had no net effect at higher phosphorus intake; i.e. the effect of protein is most pronounced at low phosphorus intakes, which is the case for our subjects. It could therefore be argued that the observed Ca intakes of our subjects may in fact only be marginally low. On the other hand, the low breast milk Ca levels previously described provide indirect evidence of inadequate Ca nutrition in this region [43]. Although not specifically described in the Congo, Ca-deficiency rickets has been shown to occur in South

Africa and Nigeria [44,45]. Moreover, twelve months Ca supplementation of Gambian children with low habitual Ca intakes significantly increased bone mineral accretion [46]. In contrast to these observations, the prevalence of rickets is very low in the Yasa-Bonga region as documented by extremely low hospital admission rates, thus lending support to the notion that under the local conditions, Ca intake may in fact be only marginally inadequate. Compared to DRIs, intakes of phosphorus were low in the younger age groups but not in adults.

4.6. Iodine

Iodine intakes were moderately low, especially in younger age groups. Furthermore, the very high consumption of cassava, potentially containing goitrogenic substances, may increase the risk of iodine deficiency as already shown elsewhere in the region [47]. However the villagers we observed steep the peeled cassava tubers for several days in running water in order to remove cyanogenic glucosides. In spite of the inadequate protein intake which may aggravate the development of goiter as previously shown in Senegal [48], the hospital admission rate for goiter is low. This would suggest that the elimination of goitrogenic factors in cassava is performed efficiently by the villagers.

In this poor rural region of equatorial Africa with cassava as the main staple food, dietary interventions to prevent or treat malnutrition should pay special attention to several vitamins and minerals in addition to protein. In contrast to most developing countries, it is more the low intakes of vitamins B1, B2, Ca and Zn rather than those of Fe, vitamin A and iodine that appear to be most critical. Since salt is the only food item which is regularly purchased, it may constitute a vehicle for vitamin and mineral fortification. However, given the absence of centralized salt production and the current socio-economic situation in the region, this may be impractical at present. An alternative approach could be the distribution of multi-micronutrient supplements. Since protein deficiency is also a major problem in this region, a more relevant approach might be the diversification of agricultural practices to increase the production of leguminous seeds (Bambara groundnuts, groundnuts, beans) and grains (maize, millet) in order to complement the high energy yielding cassava. In addition to increased protein supply, such measures should also enable increases in the supply of several micronutrients. It should be borne in mind however that increasing protein intakes might simultaneously increase the requirements for certain micronutrients (vitamin B6, Zn, Ca).

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