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Revised D-A-CH-reference values for the intake of zinc

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ABSTRACT

Background: The Nutrition Societies of Germany, Austria and Switzerland as the joint editors of the 'D-A-CH reference values for nutrient intake' have revised the reference values for zinc in July 2019.

Methods: For infants aged 0 to under 4 months, an estimated value was set based on the zinc intake via breast feeding. For all other age groups, the reference values were calculated using the factorial method considering endogenous zinc losses via intestinal losses, urine, faeces, skin and sweat, semen in men and the additional zinc requirements to build up body weight in children and adolescents as well as in pregnant women. Due to the strong influence of phytate intake on zinc absorption, the recommendations for the intake of zinc for adults are derived depending on low (0.5 mmol/day, corresponding to 330 mg/day), moderate (1.0 mmol/day, corresponding to 660 mg/day) and high (1.5 mmol/day, corresponding to 990 mg/day) phytate intake. The reference values for lactating women take into account the zinc loss via breast milk.

Results and conclusion: For adults, pregnant and lactating women, the recommended intake values for zinc range from 7 mg/day to 16 mg/day, depending on sex and dietary phytate intake.

1. Introduction

The D-A-CH 'reference values for nutrient intake' [1] are jointly issued by the Nutrition Societies of Germany, Austria and Switzerland (the abbreviation D-A-CH arises from the initial letters of the common country identification for the countries Germany [D], Austria [A] and Switzerland [CH]). Reference value is a collective term for recommended intake (RI), estimated values, and guiding values. A RI value, according to its definition, meets the requirement of nearly any person (approximately 98 %) of sex and age stratified population groups. Estimated values are given when human requirements cannot be determined with desirable accuracy. Guiding values are stated in terms of aids for orientation [1].

Reference values for nutrient intake are amounts that are assumed to

- protect nearly all healthy individuals in a population from deficiency-related conditions.
- ensure optimal physiological and psychological performance, and
- create a certain body reserve [1].

Reference values should be revised regularly. Since 2012, the D-A-CH nutrition societies have published revised reference values for the intake of several nutrients [2–12]. The last update of the reference value for zinc given by the D-A-CH nutrition societies dates to a 2000 report [13]. In summer 2019, the revised reference values for zinc intake were published in German. This paper provides a summary of this work.

The human body contains 2–3 g of zinc, which is mostly located in the muscles (50 %) and the skeleton (37 %) [14]. Zinc is always present as divalent cation (Zn^{2+}); the major proportion is bound to proteins [15]. The human body excretes only about 0.1 % of the zinc pool daily [16]. As a specific storage organ for zinc is lacking, regular zinc intake is required to prevent deficiency [17,18].

The biological functions of zinc are manifold and can be divided into catalytic, structural and regulatory ones. Overall, zinc influences

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cell growth, differentiation, apoptosis as well as immunity, cognition and reproduction [16]. Zinc exerts its catalytic or structure-stabilizing function as a component of numerous enzymes [19], while the stabilization of secondary structures in hundreds of transcription factors gives zinc a considerable role in the regulation of gene expression [20]. In addition, free zinc is of particular importance as an intracellular messenger for the immune system [21]. That a sufficient zinc supply is essential for the immune system was confirmed by the results of several studies, suggesting that zinc supplementation (in marginally zinc deficient subjects) has a positive influence on the defence against various infectious and autoimmune diseases [22]. Moreover, there are several associations between zinc deficiency and immunosenescence, which refers to the gradual deterioration of the immune system in elderly, and some symptoms of immuno-senescence are partially reversible by zinc supplementation [23].

Currently, there is no biomarker that adequately reflects the zinc status of an individual. Thus, the derivation of the currently valid reference values for zinc intake of various international nutrition societies is based on factorial calculations [24–30]. Basis therefore is the estimation of absorbed zinc needed to balance all obligatory zinc losses as well as additional requirements in growth periods, pregnancy or lactation [24]. The absorption of zinc is influenced by many factors [31]. Besides dietary protein, iron and calcium [32], the amount of zinc ingested and the phytate content of the diet are the most important factors affecting bioavailability [33]; together they account for 81 % of the variance in absorbed zinc [34]. A meta-analysis of 30 intervention studies indicates that a phytate:zinc molar ratio greater than 15:1 lowers zinc absorption significantly [31].

In general, the bioavailability of zinc from foods of animal origin is higher than from plant-based foods, as the latter contain phytates and other inhibitors of zinc absorption [25]. For a mixed diet, an absorption rate of 31 % was determined. This value results from the weighted average absorption rates of the individual studies included in the review by Bel-Serrat et al. [31]; it is the absorption rate for a moderate dietary phytate content with a phytate:zinc molar ratio lower than 15:1, which is common in Central European diets [29,31].

2. Methods

2.1. Literature search

Structured literature searches across the database PubMed were performed for articles published between 1980 and September 2018 to identify eligible English and German articles reporting results of original human studies, meta-analyses and systematic reviews focusing on zinc requirements, bioavailability and existing dietary recommendations.

2.2. Derivation of the reference values for zinc intake

The reference values for the intake of zinc for infants aged 0 to under 4 months were derived based on the zinc content of breast milk, which is considered the optimal diet for infants [35–38]. For all other age groups, the reference values were calculated using the factorial method. The factorial method for deriving the reference values for infants 4 to under 12 months, children and adolescents considered an average absorption rate, average body weights, zinc losses (intestine, urine, skin, sweat and semen (boys > 10 years of age)), zinc requirement to build up body mass and the daily body weight gain. Because of the strong influence of dietary phytate on zinc absorption in adults, besides considering endogenous zinc losses and fractional zinc absorption, the deriving of reference values for the intake of zinc for adults takes into account three different phytate intake levels (low, moderate and high). Along with the abovementioned factors for adults, for the derivation of the reference values for pregnant women an additional requirement for zinc during pregnancy and the daily weight gain were considered, while for lactating women an additional requirement for zinc and the zinc loss via breast milk were considered. Based on the results of the structured literature searches, the derivation of the reference values for the different age groups is described more comprehensively in the following results sections.

3. Results

3.1. Adults

Due to the high impact of phytate intake on zinc absorption, the recommendations for intake of zinc for adults are derived depending on phytate intake: low (0.5 mmol/day, corresponding to 330 mg/day), moderate (1.0 mmol/day, corresponding to 660 mg/day) and high (1.5 mmol/day, corresponding to 990 mg/day); these values relate to typical Central European diets [29,39]. Considerably higher contents, such as in staple foods of some non-European countries or in certain vegetarian diets, were not considered here.

As a reliable marker for assessing the zinc status of individuals is not available [18,24,40], the recommended intake of zinc for adults is derived based on factorial calculations. In addition to non-absorbed zinc, endogenous zinc is lost via faeces, for example through enterocyte desquamation. Based upon calculations by Hambidge et al. [33], intestinal losses of 2.29 mg/day in men and 1.87 mg/day in women are considered for deriving the reference values for zinc intake.

At usual intake levels, non-intestinal zinc losses do not depend on zinc status [24]. These zinc losses can be quantified on the basis of the first balance study by Milne et al. (in 1983) [41] and several subsequent studies (summarized in different reviews, e.g. [18,31]). Thus, referring to the calculations of the International Zinc Nutrition Consultative Group (IZiNCG), the reference values for zinc were derived based on an urinary loss of 0.63 mg/day (men) or 0.44 mg/day (women), and on a loss through skin and sweat of 0.42 mg/day (men) or 0.36 mg/day (women) [26,33].

The average daily loss of zinc through semen in different studies ranged from 114 μg to 301 μg [42–45]. For deriving the reference values for zinc intake, an average daily loss of zinc through semen of 0.2 mg is assumed. Thus, the total non-intestinal loss of zinc in men is 1.25 mg/day. Adding to this amount the intestinal loss, the resulting zinc requirement in men is 3.54 mg/day.

To date, zinc loss during menstrual bleeding has only been investigated in a single study, which observed an average daily zinc loss of 5 μg [46]. Compared to other losses, this amount is marginal, and therefore not included in the calculation of endogenous zinc losses. Hence, the total loss of zinc through urine, skin and sweat, together with the intestinal losses, result in a requirement in women of 2.67 mg/day.

In view of the above-mentioned results of the structured literature searches and thereby taking into account the data for endogenous zinc losses and three different phytate intake levels, the average zinc requirement was calculated based on fractional absorption of zinc determined according to the equation by Miller et al. [47] (see Eq. (1)), using the updated numerical values of the constants according to Hambidge et al. [48]. Considering a coefficient of variation of 10 % (addition of 20 %), the recommended intake in men with a low phytate intake level is 11 mg zinc/day, with a moderate phytate intake level 14 mg zinc/day and with a high phytate intake level 16 mg zinc/day, in women it is 7 mg zinc/day, 8 mg zinc/day and 10 mg zinc/day, respectively (see Tables 1 and 2). Due to the lack of sufficient data to calculate a specific zinc requirement for adults above 65 years of age, the recommendations for this age group are the same as for younger adults.

Table 1
Calculation of the recommended intake of zinc for adults.

	Phytate intake [mg/day]	Endogenous zinc losses [mg/day]	Average zinc requirement[a] [mg/day]	Considering a coefficient of variation of 10 % (addition of 20 %) [mg/day]	Recommended intake of zinc (rounded) [mg/day]
Men	330	3.54	9.0	10.8	11
	660	3.54	11.4	13.7	14
	990	3.54	13.7	16.4	16
Women	330	2.67	5.7	6.8	7
	660	2.67	7.0	8.4	8
	990	2.67	9.3	10.0	10

[a] Fractional absorption of zinc was calculated according to equation 12 by Miller et al. [47], using the updated numerical values of the constants according to Hambidge et al. [48].

Equation 1: Fractional absorption of zinc according to [38]

$$FAZ = \frac{0.5}{TDZ} \text{x} \left(A_{max} + \text{TDZ} + K_R \text{x} \left(1 + \frac{TDP}{K_P}\right) - \sqrt{\left(A_{max} + TDZ + K_R \text{x} \left(1 + \frac{TDP}{K_P}\right)\right)^2 - 4 \text{x} A_{max} \text{x} TDZ} \right) \quad (1)$$

Variables:

FAZ: Fractional absorption of zinc
TDZ: Total daily dietary zinc
TDP: Total daily dietary phytate

Constants:

A_{max}: Maximum absorption
K_R: Equilibrium dissociation constant of zinc-receptor binding reaction
K_P: Equilibrium dissociation constant of zinc-phytate binding reaction

Using the variables for TDZ and TDP, a matrix displaying the results can be calculated.

3.2. Infants, children and adolescents

3.2.1. Infants 0 to under 4 months

Because the reference values for infants were derived based on the zinc content of breast milk (see methods section), they are therefore estimated values.

Zinc content of breast milk is virtually independent of maternal zinc intake [49,50]. No effect of zinc supplementation on the zinc content of the breast milk is observed [51–53]. Zinc content of breast milk declines during the course of lactation. A calculation based on 33 studies revealed an average zinc content of breast milk of 4.11 mg/L during the first days after delivery which decreased up to 1.91 mg/L after one to two months [54].

Table 2
Recommended intake values for zinc.

Age	Zinc[a] mg/day					
	m			f		
	Low phytate intake[b]	moderate phytate intake[c]	high phytate intake[d]	Low phytate intake[b]	moderate phytate intake[c]	high phytate intake[d]
Infants						
0 to under 4 months[e]	1.5					
4 to under 12 months	2.5					
Children and adolescents						
1 to under 4 years	3					
4 to under 7 years	4					
7 to under 10 years	6					
10 to under 13 years		9			8	
13 to under 15 years		12			10	
15 to under 19 years		14			11	
Adults						
19 to under 25 years	11	14	16	7	8	10
25 to under 51 years	11	14	16	7	8	10
51 to under 65 years	11	14	16	7	8	10
65 years and older	11	14	16	7	8	10
Pregnant women						
1st trimester				7	9	11
2nd and 3rd trimester				9	11	13
Lactating women				11	13	14

[a] As zinc absorption in adults is influenced by the phytate content in the diet, the recommended intake of zinc is set depending on phytate intake.
[b] corresponds to a phytate intake of 330 mg/day (0.5 mmol/day); phytate intake is low and, thus, zinc absorption is high in diets with low intake of whole-grain products and legumes and mostly animal-based protein sources.
[c] corresponds to a phytate intake of 660 mg/day (1.0 mmol/day); phytate intake is moderate and, thus, zinc absorption is moderate, too, in diets that include protein sources of animal origin, including meat or fish, as well as whole-grain products and legumes (wholesome diet), or in vegetarian or vegan diets with mostly high extraction rate, sprouted or fermented cereal products.
[d] corresponds to a phytate intake of 990 mg/day (1.5 mmol/day); phytate intake is high and, thus, zinc absorption is low in diets with high intake of whole-grain products (mainly unsprouted or unfermented) and legumes and with mostly or exclusively plant-based protein sources (e.g. soy).
[e] Estimated value based on the zinc content of breast milk.

The average intake of breast milk of an exclusively breastfed infant is 750 mL/day [55]. Based on the results of the structured literature search showing a mean zinc content of breast milk of 1.91 mg/L [54] within the first 4 months, the estimated value for the intake of zinc for breastfed infants aged 0 to under 4 months is set at 1.5 mg/day (see Table 2).

3.2.2. Infants 4 to under 12 months, children and adolescents

In contrast to adults, an impact of phytate intake on zinc absorption was not found in children until the age of 50 months [56]. Due to the lack of conclusive data regarding the age up to which this applies, the derivation of the recommended intake of zinc for children and adolescents is not calculated depending on the phytate content of the diet, but rather assumes an average absorption rate of 31 % for a mixed diet [31].

For infants aged 4 to under 12 months and for children and adolescents, no data on the average zinc requirement are available. Therefore, zinc losses are calculated from the zinc losses of adults adjusted to the respective reference body weights [1]. Zinc losses through semen are not considered in boys under 10 years of age. For the additional zinc requirement to build up body mass, the average content of 2 mg zinc/100 g body weight, as determined by Widdowson and Spray [57], is taken into account. Daily body weight gain is determined with the WHO (World Health Organization) child growth standards [58] for infants aged 4 to under 12 months and for children and adolescents with the median body weight of each age group according to the national German Health Interview and Examination Survey for Children and Adolescents (KiGGS) survey [59]. Per gram body weight gain, an additional zinc requirement of 0.02 mg is estimated.

Considering an average absorption rate of 31 % and a coefficient of variation of 10 % (addition of 20 %), the recommended intake of zinc is 2.5 mg zinc/day for infants aged 4 to under 12 months, 3 mg/day for 1- to under 4-year-olds, 4 mg/day for 4- to under 7-year-olds, 6 mg/day for 7- to under 10-year-olds. For 10- to under 13-year-olds, the recommended intake of zinc is 9 mg/day for boys and 8 mg/day for girls of the same age; and 12 mg/day for 13- to under 15-year-old boys and 10 mg for girls of the same age, and 14 mg/day for 15- to under 19-year-old male adolescents and 11 mg for female adolescents of the same age (see Tables 2 and 3).

3.3. Pregnancy

For growth of the fetus, formation of the placenta and amniotic fluid, and for the increase of uterus, breast tissue and blood volume, the additional requirement for zinc during the entire pregnancy is 100 mg in total, of which about 60 % is required by the fetus and 40 % by maternal tissue [61]. There is some evidence that the additional requirement, at least partially, is compensated by an altered homeostasis, including an increased absorption rate. However, a marginal deficiency cannot be excluded [62]. To ensure sufficient zinc supply for the fetus [63,64], an additional requirement of 100 mg for the entire pregnancy is set. With regard to the daily weight gain during the three trimesters and a total weight gain of 12 kg [1], this corresponds to an additional requirement during pregnancy of 8 µg zinc per gram weight gain. Considering phytate-dependent zinc absorption (see Equation 1) and a coefficient of variation of 10 % (addition of 20 %), the recommended intake of zinc for pregnant women is 7 mg, 9 mg and 11 mg zinc/day with a low, moderate and high phytate intake in the first trimester, and 9 mg, 11 mg and 13 mg zinc/day, in the second and third trimester, respectively (see Table 2).

3.4. Lactation

Zinc is secreted with breast milk. During the first weeks of lactation, the zinc content of breast milk is considerably higher than in the further course (see “Infants 0 to under 4 months”). Zinc is released during the involution of the uterus [62]. This as well as an increased absorption partly compensated the losses [62]. Based on data of Brown et al. [54], a zinc secretion with breast milk of 1.43 mg/day was calculated, corresponding to the physiological additional daily requirement due to lactation (see derivation for “Infants 0 to under 4 months”). Considering an average absorption rate of 39 %, calculated as weighted average of five studies [65–69], and a coefficient of variation of 10 % (addition of 20 %; see derivation for adults), the additionally needed

Table 3
Recommended intake for zinc for infants (4 to under 12 month), children and adolescents taking into account differences in average body weight and growth factors.

Age [years]	Gen-der	Reference body weight[a] [kg] [1]	Endogenous zinc losses[b] [mg/day]	Weight gain[c] [g/day]	Zinc needed for growth[d] [mg/day]	Total amount from zinc losses and zinc needs for growth [mg/day]	Average zinc requirement considering absorption rate of 31 %)[e] [mg/day]	Considering a coefficient of variation of 10 % (addition of 20 %) [mg/day]	Recommended intake for zinc (rounded) [mg/day]
4 to under 12 month	male	8.6	0.41	10.1	0.20	0.61	1.96	2.35	2.5
	female	7.9	0.35	9.7	0.20	0.55	1.76	2.11	
1 to under 4	male	13.9	0.66	6.5	0.13	0.79	2.54	3.05	3
	female	13.2	0.59	6.6	0.13	0.72	2.32	2.79	
4 to under 7	male	20.2	0.95	6.8	0.14	1.09	3.52	4.22	4
	female	20.1	0.89	6.8	0.14	1.03	3.32	3.99	
7 to under 10	male	29.3	1.38	9.3	0.19	1.57	5.07	6.08	6
	female	28.7	1.28	9.7	0.19	1.47	4.75	5.69	
10 to under 13	male	41.0	2.05	12.8	0.26	2.31	7.45	8.94	9
	female	42.1	1.87	14.0	0.28	2.15	6.95	8.34	8
13 to under 15	male	55.5	2.78	17.6	0.35	3.13	10.1	12.12	12
	female	54.0	2.40	9.3	0.19	2.59	8.35	10.02	10
15 to under 19	male	69.2	3.46	8.9	0.18	3.64	11.75	14.10	14
	female	59.5	2.65	3.0	0.06	2.71	8.73	10.48	11

[a] The reference values for body weight for 4 to under 12 years old correspond to the median body weight of the WHO child growth standards [60] for the age of 8 months. The reference values for body weight for children aged one year and older correspond to the median body weight determined in the German Health Interview and Examination Survey for Children and Adolescents in Germany (KiGGS; 2003–2006) [59]. In each case, the values reflect the mid-point of the respective age range.

[b] Calculated from zinc losses for adults considering body weight; reference body weight (age group 25 to under 51 years): men 70.7 kg; women 60.0 kg [1]. For boys under 10 years of age, losses from semen were not considered.

[c] Calculated from the difference between the median weight of the age groups [58,59] and the number of days in each age group.

[d] 0.02 mg zinc per gram additional body weight [57].

[e] [31]

Table 4
Reference values for the intake of zinc from different nutrition societies.

	DGE, 2019			EFSA, 2014 [29]				NCM, 2014 [30]	NHMRC, 2006 [28]	WHO/FAO 2004 [27]			IOM, 2001 [25]
Infants	AI Zinc [µg/d]			AI Zinc [µg/d]				RI Zinc [µg/d]	AI Zinc [µg/d]	RNI Zinc [µg/d]			AI Zinc [µg/d]
	0–4 mths: 1.5			7–11 mths: 2.9				6 – 11 mths: 5 [35]	0–6 mths: 2	High BA	Mod. BA	Low BA	0–6 mths: 2
	4 – < 12 mths: 2.5								RDI Zinc [µg/d]	0–6 mths:			RDI Zinc [µg/d]
									7 – < 12 mths: 3	1.1[a]	2.8[b]	6.6[c]	7 – < 12 mths: 3
										7 – < 12 mths: 0.8[a], 2.5[d]	4.1	8.4	
Children and adolescents (male/female)	RI Zinc [µg/d]			PRI Zinc [µg/d]				RI Zinc [µg/d]	RDI Zinc [µg/d]	RNI Zinc [µg/d]			RDI Zinc [µg/d]
	1 – < 4 yrs: 3			1–3 yrs: 4.3				2–5 yrs: 6	1–3 yrs: 3	High BA	Mod. BA	Low BA	1–3 yrs: 3
	4 – < 7 yrs: 4			4–6 yrs: 5.5				6–9 yrs: 7	4–8 yrs: 4	1–3 yrs:			4–8 yrs: 5
	7 – < 10 yrs: 6			7–10 yrs: 7.4				10–13 yrs: 8/11	9–13 yrs: 6	2.4	4.1	8.3	9–13 yrs: 8
	10 – < 13 yrs: 9/8			11–14 yrs: 9.4				14 – 17 yrs: 12/9 [35]	14–18 yrs: 13/7	4–6 yrs:			14–18 yrs: 11/9
	13 – < 15 yrs: 12/10			15–17 yrs: 12.5/10.4						2.9	4.8	9.6	
	15 – < 19 yrs: 14/11									7–9 yrs:			
										3.3	5.6	5.6	
										10–18 yrs: 5.1/4.3	8.6/7.2	17.1/14.4	
Adults (male/female)	RI Zinc [µg/day] ≥ 19 years:			PRI Zinc [µg/day] ≥ 19 years:				RI Zinc [µg/day] ≥ 19 yrs: 9/7	RDI Zinc [µg/d] ≥ 19 yrs: 14/8	RDI Zinc [µg/d] ≥ 19 yrs:			RDI Zinc [µg/d] ≥ 19 yrs: 11/8
	Low phytate	Medium phytate	High phytate	Phytate [mg/d]						High BA	Mod. BA	Low BA	
	11/7	14/8	16/10	300	600	900	1200			4.2/3	7/4.9	14/9.8	
				9.4/7.5	11.7/9.3	14/11	16.3/12.7						
Pregnant women	RI Zinc [µg/day]			PRI Zinc [µg/day]				RI Zinc [µg/day]	RDI Zinc [µg/d]	RNI Zinc [µg/d]			RDI Zinc [µg/d]
	Low phytate	Medium phytate	High phytate	Phytate [mg/d]				9 [35]	14–18 yrs: 10	High BA	Mod. BA	low BA	14–18 yrs: 12
	1. tri: 7	1. tri: 9	1. tri: 11	300	600	900	1200		≥ 19 yrs: 11	1. tri.: 3.4	1. tri.: 5.5	1. tri.: 11	≥ 19 yrs: 11
	2. tri: 9	2. tri: 11	2. tri: 13	9.1	10.9	12.6	14.3			2. tri.: 4.2	2. tri.: 7	2. tri.: 14	
	3. tri: 9	3. tri: 11	3. tri: 13							3. tri.: 6	3. tri.: 10	3. tri.: 20	
Lactating women	RI Zinc [µg/day]			PRI Zinc [µg/day]				RI Zinc [µg/day]	RDI Zinc [µg/d]	RNI Zinc [µg/d]			RDI Zinc [µg/d]
	Low phytate	Medium phytate	High phytate	Phytate [mg/d]				11 [35]	14–18 yrs: 11	High BA	Mod. BA	low BA	14–18 yrs: 13
	11	13	14	300	600	900	1200		≥ 19 yrs: 12				≥ 19 yrs: 12
				10.4	12.2	13.9	15.6			0–4 mths: 5.8	9.5	19	
										3–6 mths: 5.3	8.8	17.5	
										6–12 mths: 4.3	7.2	14.4	

AI: Adequate Intake; BA: bioavailability; DGE: Deutsche Gesellschaft für Ernährung; EFSA: European Food Safety Authority, IOM: Institute of Medicine; Mod.: moderate; mths: months; National Health and Medical Research Council; NCM: Nordic Council of Ministers; PRI: Population Reference Intake; RDI: Recommended Dietary Intake; RI; Recommended Intake; RNI: Reference Nutrient Intake; WHO/FAO: World Health Organization/Food and Agriculture Organization; yrs: years.

[a]Exclusively human-milk-fed infants. The bioavailability of zinc from human milk is assumed to be 80 %; assumed coefficient of variation, 12.5 %.

[b]Formula-fed infants. Applies to infants fed whey-adjusted milk formula and to infants partly human-milkfed or given low-phytate feeds supplemented with other liquid milks; assumed coefficient variation,12.5 %.

[c]Formula-fed infants. Applicable to infants fed a phytate-rich vegetable protein-based formula with or without whole-grain cereals; assumed coefficient of variation, 12.5 %.

[d]Not applicable to infants consuming human milk only.

intake is estimated to 4.3 mg zinc/day. Thus, the recommended zinc intake in total for lactating women is 11 mg, 13 mg and 14 mg/day with a low, moderate and high phytate intake, respectively (see Table 2).

4. Discussion and conclusion

By definition, the D-A-CH reference values for nutrients are the basis to plan health-maintaining diets and to evaluate actual nutrient intakes of healthy people aiming to minimize risks for nutrient deprivation or oversupply [1].

The present revision of the D-A-CH reference values lastly published in 2000 comprises some important changes: Firstly, considering the high impact of dietary phytate on zinc absorption, in the revised version the recommended intake of zinc for adults is stated in dependence of the level of phytate intake, while in 2000 it was derived independently. Secondly, for pregnant women, instead of a reference value from the 4th month of pregnancy (in 2000), the current reference values are given separately for the first trimester and the second plus third trimesters (in terms of daily weight gain during pregnancy); each depending on the phytate intake. As no significant influence of dietary phytate on zinc absorption was found in children and adolescents, the reference values for zinc for these age groups are still derived independently of its intake.

In view of the absence of adequate biomarkers reflecting the zinc status, the current reference values from various international expert panels (see Table 4) were all derived on the basis of factorial calculations (except for younger infants) [24]. However, the reference values slightly vary between the different expert panels and some of the reasons therefore are listed below. Sources of these variations include the usage of different data for reference body weights, the selection of diverse studies (e.g. to assess endogen zinc losses, additional requirements in growth or for lactating women) as well as varying classification of age-groups (especially children and adolescents). Furthermore, discrepancies exist concerning the derivation of reference values for infants, children and adolescents. Firstly, in line with the D-A-CH-panel, the Nordic Council of Ministers (NCM) [30], the National Health and Medical Research Council (NHMRC) [28], and the Institute of Medicine (IOM) [25] released adequate intakes for younger infants (< 4 or 6 months) based on the zinc content in breast milk, while the World Health Organization and Food and Agriculture Organization (WHO/FAO) [27] derived recommended intakes based on a factorial approach. Secondly, although all expert panels used the factorial approach to derive the physical zinc requirements for older infants (> 4 or 6 months) by extrapolating the zinc losses from data of adults or younger infants, the WHO/FAO [27] was the only expert panel adjusting the data to the metabolic rates and not the respective reference body weights.

Additionally, there are differences regarding subdivisions for the reference values for pregnant and lactating women: With regard to the daily weight gain during pregnancy, the revised D-A-CH- and the WHO/FAO-reference values [27] are given separately for the first trimester and the second plus third trimesters of pregnancy. Contrary, the NHMRC [28] and the IOM [25] subdivided between the ages < 19 or ≥ 19 years, while the European Food Safety Authority (EFSA) [29] and the NCM [30] made no subdivisions. For lactating women, the NHMRC and IOM distinguished between the ages < 19 and ≥ 19, the WHO/FAO [27] regarding the months of lactation (0–4, 3–6 and 6–12), while the D-A-CH-, EFSA- [29] and NCM-panel [30] made no subdivisions.

One important source for discrepancies between the current reference values, is the usage of different absorption efficiencies (15–50 %). In this context, a differently assumed zinc bioavailability in the habitual diets is of great importance. Thus, the current D-ACH- and the EFSA-reference values [29] for adults were derived dependent on dietary phytate, as being one of the most important factors affecting zinc bioavailability. The D-A-CH reference values set three categories of phytate (low = 330 mg/day, moderate = 660 mg/day) and high = 990 mg/day), while the EFSA set four different levels of dietary phytate: 300, 600, 900 and 1200 mg/day. These phytate intake levels between 300–900 mg/day cover the range of typical European populations, however unlike the EFSA, in the revised D-A-CH reference values considerably higher phytate contents (> 900 mg/day), as in staple foods of some non-European countries or in certain vegetarian diets, were not considered. In contrast, the NHMRC [28], NCM [30] and IOM [25] derived the reference values independently of the phytate intake, while the WHO/FAO [27] set the three categories "high, moderate, and low zinc bioavailability"; thereby considering the nature of the diet (i.e. its content of promoters and inhibitors of zinc absorption, including phytate) and three different absorption efficiencies (15, 30 and 50 %). Finally, another important factor is the application of different estimates of variation to meet the dietary zinc requirements of almost all persons (approximately 98 %): the coefficients of variation (CV) varied between 10 % (D-A-CH, IOM, NHMRC, EFSA (children, adolescents, pregnant and lactating women)), 15 % (NCM) and 25 % (WHO). The reference values for non-pregnant/non-lactating adults derived by the EFSA were based on the 97.5th percentiles for reference body weights, which are equivalent to CVs 10 and 14 % [29].

However, despite these variations, in comparison with the reference values for zinc derived by these various international expert panels (see Table 4), the current revised D-A-CH reference values lay within the range of the recommendations by the EFSA [29], IOM [25], NCM [30], WHO/FAO [27] and the NHMRC [28].

As mentioned above, the revised D-A-CH reference values for zinc intake are set depending on phytate intake, since high phytate contents in the diet can lower zinc absorption by up to 45 % in adults [31]. The phytate content of foods is also important for the evaluation of dietary sources for zinc. Whole-grain cereals and legumes are rich in both, zinc and phytate, which, however, impairs zinc bioavailability. Moreover, food preparation methods such as soaking, sprouting, fermentation or leaven can degrade phytate, thereby increasing the bioavailability of zinc [70].

According to the National Nutrition Survey II (NVS II), which only reports zinc intake, not considering its bioavailability, only a part of the general population meets the intake recommendations. For both sexes, younger adults (25 to < 65 years) have a higher zinc intake than the elderly (> 65 years) [71]. In particular, elderly people and patients with chronic inflammatory diseases were observed to be vulnerable for zinc deficiency [72]. In general, however, a sufficient zinc supply in Germany can be achieved through a balanced diet. Therefore, for meeting the revised D-A-CH recommendations zinc supplementation is not required for the general population, but there is a considerable fraction with insufficient intake of zinc, which might benefit from measures such as nutritional interventions or zinc supplementation.

Declaration of Competing Interest

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