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How is the adequacy of micronutrient intake assessed across Europe? A systematic literature review

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EURopean micronutrient RECommendations Aligned is a network of excellence funded by the European commission, and established to address the problem of differences between countries in micronutrient recommendations as well as to understand how nutritional information including requirements and adequacy of intake is processed among different population groups. The aims of the present paper were to review the methods used for the adequacy assessment of the intake of six micronutrients of public health concern (vitamin A, folate, vitamin B_{12}, Fe, Zn and iodine) in non-European and European nutrition surveys carried out on the apparently healthy population and to compare in particular the adequacy across surveys for folate intake. A systematic literature review was conducted to identify nutrition surveys that assessed micronutrient intake adequacy. The search yielded 9049 records, out of which 337 were eligible for the selected micronutrients. The majority (83·9 %) of the European surveys compared the adequacy of the nutrient intake against the Recommended Dietary Allowances (RDA); only a few surveys (8·0 %) used the estimated average requirement cut-point method, while none of them used the probability approach. The comparison of folate inadequacy across eight countries revealed that about 25 % of the adult female population had inadequate intakes when judged against the different recommendations used by the respective investigators, but nearly 75 % had inadequate intakes when compared against the estimated average requirement cut-point value of 320 μg/d. The present review showed that different methods were applied across Europe to estimate the adequacy of micronutrient intake, which led to different prevalence estimates of micronutrient inadequacy.

Dietary intake: Adequacy: Micronutrients: Folate: Adequacy assessment: Micronutrient intake

The dietary requirement for a micronutrient is defined as an intake level that meets specified criteria for adequacy, thereby minimising the risk of nutrient deficit or excess. These criteria cover a gradient of biological effects related to a range of nutrient intakes, which, at the extremes, include the intake required to prevent death associated with nutrient deficit or excess as well as other biological responses. The latter includes clinical disease as determined by signs and symptoms of nutrient deficiency, and subclinical conditions identified by specific biochemical and functional measures. Measures of nutrient stores or critical tissue pools may also be used to determine nutrient adequacy[(1)].

One of the aims of nutritional assessment both at the individual and at the population level is to evaluate to what extent food and nutrient intake is 'adequate'. Ideally, the comparison between the requirement and the intake for every nutrient of interest for a certain individual or population should allow one to conclude whether the diet of that individual/population was adequate. As neither the real intake nor the real requirement for one individual is known, the evaluation of nutrient intake adequacy of an individual or population is based on the probability of adequacy. The calculation of the probability of adequacy is based on the assumption that intake is independent of requirement; although this assumption

Abbreviations: EAR, estimated average requirement; IOM, Institute of Medicine.
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is not valid for energy intake, it is most likely applicable for vitamins and minerals[1,2].

There are different statistical approaches that can be used to estimate the prevalence of adequate usual intakes from the distribution of intakes and requirements. The method used depends on the subject (individual or population), on the nutrient under study and the type of distribution of the intakes. These methods include the ‘probability approach method’ and the ‘estimated average requirement (EAR) cut-point method’. The probability approach method requires the calculation of the probability of inadequacy of intake for each individual in a population subgroup, averaging the probabilities, and then using this average as an estimate of the prevalence of inadequacy. The EAR corresponds to the average daily nutrient intake level estimated to meet the requirement of half of the healthy individuals in a particular life stage and sex group. The EAR cut-point method is a short cut method of the probability approach and can be applied when the nutrient requirement is distributed symmetrically and the distribution of usual intakes is more variable than the distribution of requirements. If these conditions are met, the prevalence of inadequate intakes corresponds to the proportion of intakes that fall below the EAR. Other methods are the comparison to the cut-off values of the Recommended Dietary Allowances (RDA) or the comparison of the mean intake value of the population to the RDA, although they are inappropriate to define the population at risk of adequacy[1,3,4]. Other methods used are the scores of nutrient intake adequacy such as the nutrient adequacy ratio, which is calculated by dividing the estimated usual nutrient intake by the RDA, and the mean adequacy ratio, which is calculated by taking the sum of nutrient adequacy ratio of all micronutrients under study and then dividing it by the total number of nutrients. The percentage of the population with nutrient intakes below the Lowest Requirement Nutrient Intake is another calculation applied to estimate inadequacy.

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To the authors’ knowledge, a review of these methods has not been carried out yet. The aims of the present paper were to review the methods that have been used for the adequacy assessment of the intake of six micronutrients of public health concern – vitamin A, Fe, iodine, folate, vitamin B_{12} and Zn – in non-European and European nutrition surveys carried out on representative samples of an apparently healthy population. As an illustration, the estimated adequacy of folate intake found across surveys in adult women was compared.

Vitamin A deficiency, Fe deficiency anaemia and iodine deficiency disorders represent the three major micronutrients deficiencies in the world. Vitamin A deficiency is common in preschool-aged children throughout the world, but hardly any data were available in 1995 for the countries of the WHO European Region[6]. Anaemia currently affects 22 % of the preschool-aged children and 25 % of the pregnant women in the WHO European Region[7]. Insufficient iodine intake was found in 57 and 60 % of the general population and school-aged children, respectively[8]. While the global prevalence of folate deficiency is still uncertain, data suggest that low folate status is apparent among teenage girls in some European countries such as the United Kingdom (about 40 % of 15–18 year olds were found to have marginal folate status), and common among elderly people[9]. Furthermore, it is known that folate deficiency in women in childbearing age is associated with a higher risk of giving birth to infants with neural tube defects and other birth defects. A deficiency of folate in adults is in general associated with an increased risk of cardiovascular disease (CVD), cancer and impaired cognitive functions[1]. In the United Kingdom 31 % of the elderly and in Germany 15 % of the women of reproductive age are reported to be vitamin B_{12} deficient[9]. About 20 % of the world’s population is at risk of Zn deficiency[3] and in Europe Zn intake among elderly is generally low[10].

Methods

Search strategy and eligibility criteria

The present paper focuses on six micronutrients that represent public-health challenges and concerns[3]: vitamin A, Fe, iodine, folate, vitamin B_{12} and Zn. The search for surveys on the intake adequacy of micronutrients was carried out at the global level. European surveys included those conducted in one of the twenty-seven European Union countries (Austria, Belgium, Bulgaria, the Czech Republic, Cyprus, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden and the United Kingdom) or the four European Free Trade Association countries (Iceland, Liechtenstein, Norway and Switzerland).

A systematic literature search was performed in the PubMed database[11] (1990 to 30 March 2008; human studies only) on combinations of both medical subject headings and free-text keywords. It involved the use of each individual micronutrient key terms combined with searches about the concept of nutrient adequacy (e.g. (in)adequacy, (in)adequate intakes, threshold intake, cut point) and dietary intake (e.g. nutrition requirements, dietary intake, RDA). No language restrictions were applied at the search of studies in the PubMed database. Owing to limited translation possibilities, however, the final eligibility evaluation of full-text documents was restricted to publications in Dutch, English, French, German, Italian, Portuguese or Spanish only.

The first review stage involved the screening of titles, keywords and abstracts of the identified articles, to determine their appropriateness for inclusion. The reviewers were not blinded to the names of the authors, institutions or journal of publication. Observational (cross-sectional or cohort) studies carried out in apparently healthy population groups (children, adolescents, adults, elderly, pregnant and lactating women) and methodological papers on dietary intake and adequacy measurement were considered. Articles were excluded, when the information given in the title or available abstract suggested that the intake of micronutrients was not measured, the macronutrient intake adequacy was estimated only or that the survey was carried out in sick or institutionalised populations. Citations without an abstract or articles published in a language other than Dutch, English, French, German, Italian, Portuguese or Spanish were also excluded. The second screening stage involved the exclusion of articles, whose abstract did not provide descriptive information on the method used for the estimation of nutrient intake adequacy.

Surveys that fulfilled the first- and second-stage inclusion criteria were nevertheless excluded if they did not estimate the adequacy for any of the six selected micronutrients. The full text of the surveys identified to be potentially eligible was obtained and further evaluated during the last stage of the review. If more than one article was found for the same study, the article that provided the most relevant information was kept in the review.

Data analysis

All identified citations were downloaded into Reference Manager Version 10.0[12] and assigned a unique identification number and subsequently transferred into a database created with Microsoft Office Access 2003[13], which was used for the screening and analysis. Extracted data were additionally entered into this database.

For each of the six micronutrients, the data of the surveys found eligible were tabulated by study design, population group and method used to assess intake adequacy. A distinction was made between the surveys that used the recommended methods as the EAR cut point or the probability approach method and the surveys that used the comparison against the cut-off value of the RDA. Other methods were also evaluated, such as the nutrient intake adequacy scores or the use of the percentage of the population with nutrient intakes below the lowest requirement nutrient intake.

For the comparison of the estimated folate intake adequacy across European surveys, the mean prevalence of folate inadequacy in European adult women was estimated with the use of the statistical software ‘R’, version 2.7.1[14]. Surveys with information on mean folate intake and standard deviation were selected and the proportion of the population with an intake below the recommended national level was compared to the proportion of the population below the recommended EAR of 320 μg/d, which is recommended by WHO and the FAO[1].

Results

The search of the PubMed database yielded an initial 9049 records, out of which 8215 did not meet the first-stage inclusion criteria and were thus excluded from the review.

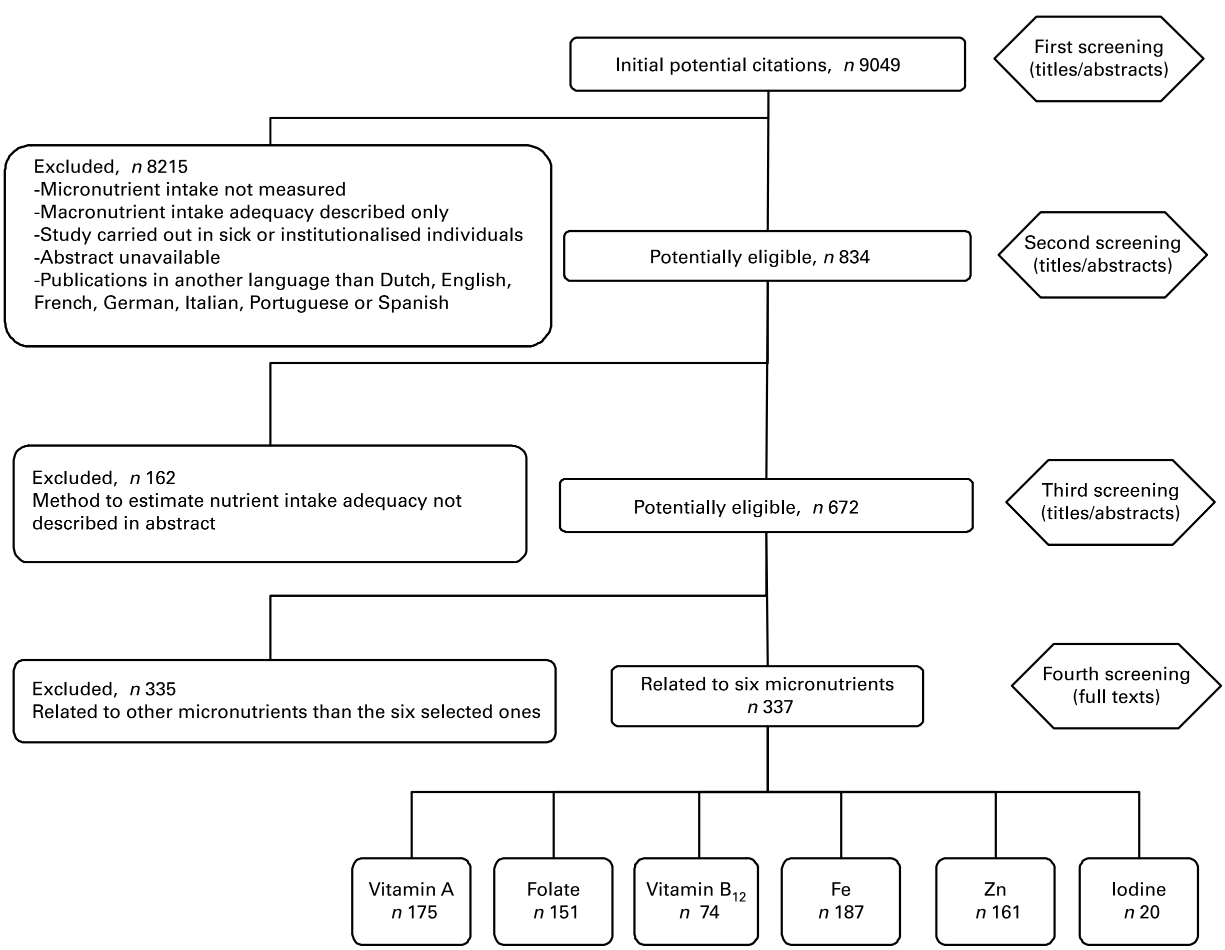

Fig. 1. Flow diagram of the process of identifying and including studies for the systematic literature review.

Table 1. Number of articles, by micronutrient, study design and by location

Micronutrient	Total number	Methodological reviews	Reviews with data	Original articles	European articles	Non-European articles	Articles focusing on only one micronutrient
Vitamin A	175	2	3	170	65	110	18
Folate	151	3	3	145	56	95	19
Vitamin B_{12}	74	1	2	71	30	44	2
Zn	161	7	4	150	49	112	20
Iodine	20	1	1	18	13	7	8
Fe	187	3	3	181	71	116	18
Total for six micronutrients	337	12	8	317	121	216	

During the second and third screening phase, another 162 and 335 studies were excluded respectively, which resulted in a total of 337 articles included in the review that were related to the six selected micronutrients (Fig. 1). The full list of these references can be provided upon request.

Global surveys

Table 1 shows the number of articles included in the review for each micronutrient, and distinguishes reviews from original articles, European and non-European surveys, and studies that focus on only one micronutrient.

The majority of the studies targeted adults, followed by children, adolescents, elderly, pregnant/lactating women and infants (Table 2).

Results on the specific method used for the estimation of the adequacy of intake of the selected micronutrients are given in Table 3. The main reference value used was the RDA, but some authors have also applied the EAR. The probability approach was used in five studies[15–21]. Some studies used other methods. For instance, four surveys applied the nutrient adequacy ratio and mean adequacy ratio[22–25] and three studies used the Lowest Requirement Nutrient Intake[26–28]. A study conducted in the United States on folate intake used the following other definition of 'adequacy': folate intake was defined as adequate when one consumed at least one folate-rich food at least 4–6 times/week, and as 'inadequate' when one folate-high/rich/excellent food was consumed fewer than 2–3 times/week[29].

European surveys

Out of the 121 European articles, nine methodological reviews were not considered in the present paper as they did not include original data, so that a total of 112 original articles were analysed.

The majority of studies (83·9 %) compared micronutrient intakes against the RDA for the estimation of adequacy. The probability approach method was never used. Only one study used another reference, the recommended values of the Caroline Walker Trust nutritional guidelines for primary schools[30]. Nine European studies (8·0 %) used the EAR/AR (average requirement) method, out of which two used it in combination with the RDA (Table 4); however, the EAR values applied differed across studies[40–48].

Adequacy of folate intake

Eight European surveys were identified that estimated the prevalence of adequacy or 'inadequacy' of folate intake in European adult women and that provided a mean and SD intake (Table 5) [44,48–54]. Folate intake in Europe was inadequate in 25·1 % of the adult female population, according to the comparison with the different recommendations used by the authors of the studies (Table 6). If the authors would have used the corresponding respective national recommendations, the percentage obtained would have been slightly higher (34·6 %); when using the national EAR as a reference, the proportion of the population having inadequate folate intake would have been 17·1 %. Compared with the WHO/FAO recommendations of 400 μg/d and an EAR of 320 μg/d, 92·1 % and 74·8 % of the adult female population would have an inadequate intake of folate, respectively.

Discussion

For the assessment of the adequacy of micronutrient intake in Europe, it is important to consider that the methods used for

Table 2. Number and percentages of articles targeting different age groups/pregnant and lactating women by micronutrient

	Infants (<1 year)		Children (1–9 years)		Adolescents (10–19 years)		Adults (>19 years)		Elderly (>60 years)		Pregnant/ lactating women	
Micronutrient	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%
Vitamin A	10	5·7	58	33·1	42	24·0	62	35·4	33	18·9	13	7·4
Folate	4	2·6	29	19·2	32	21·2	54	35·8	28	18·5	15	9·9
Vitamin B_{12}	2	2·7	19	25·7	12	16·2	27	36·5	18	24·3	5	6·8
Zn	15	9·3	29	18·0	26	16·1	42	26·1	27	16·8	15	9·3
Iodine	2	10·0	6	30·0	6	30·0	10	50·0	5	25·0	0	0·0
Fe	14	7·5	54	28·9	47	25·1	54	28·9	31	16·6	17	9·1
Total for six micronutrients	28	8·3	86	25·5	76	22·5	114	33·8	63	18·7	32	9·5

Table 3. Number of articles indicating the reference used for estimating the intake adequacy, by micronutrient

	RDA				EAR			Combination of RDA and EAR				
Micronutrient	RDA	RNI	RI	RDI	EAR	AR	Probability approach	RDA + EAR	RNI + EAR	RDI + EAR	Others	Total
Vitamin A	104	14	3	9	26	4	3	4	2	1	5	175
Folate	81	17	3	5	30	4	2	2	2	0	5	151
Vitamin B_{12}	37	7	1	2	16	4	2	1	1	0	3	74
Zn	88	14	4	1	35	4	5	3	1	0	6	161
Iodine	11	6	0	0	2	0	0	0	1	0	0	20
Fe	108	13	7	9	28	4	5	3	1	0	9	187
Total for six micronutrients	251				66			9			11	337

RDA, Recommended Dietary Allowances; EAR, estimated average requirement; RNI, recommended nutrient intake; RI, recommended intake; RDI, recommended dietary intake; AR, average requirement.

data collection and analysis can vary throughout the different steps taken that lead to the estimation of adequacy. This can potentially result in an over- or underestimation of the usual intake and, as a consequence, of the adequate intake. The use of different methods for the collection of dietary intake data across surveys is an important source of variation in the estimate of micronutrient intake and thus in the estimate of micronutrient adequacy. In the second step, the food composition tables used to translate food intake into micronutrient intake might be another source of variation. Finally, the intake data analysed have to be compared against reference values. The main reference value used to assess adequacy was the RDA, both in non-European and in European studies. The latest dietary reference intakes published by the US Institute of Medicine (IOM) in 2000[4] were accompanied with new suggestions about how the proposed updated references to nutritional assessment should be applied, including the application of nutritional requirements to assess nutrient intake adequacy. Despite that, from 2000 onwards, many studies (163 out of 199) still used the RDA value as a reference for estimating intake adequacy. Consequently, the use of this approach will lead to an overestimation of the prevalence of inadequacy compared to the use of the EAR cut-point value.

A few studies compared the intake with the mean group intake, assuming that if that value is approximate to the RDA, only 2–3 % of the group members would have inadequate intakes. IOM does not recommend such an approach, as the RDA for a nutrient takes into account the individual variability of requirement and thus exceeds the requirement of almost all individuals. Comparing the mean intake of a group of individuals with the RDA underestimates the prevalence of individuals at risk of inadequate intake.

Table 4. Selected European studies that applied the EAR/AR reference values

Reference value	First author	Publication years	Survey years	Country	Population group (age range)	Sample size	Sex	Selected micronutrients
EAR (IOM 2000[4])	Manios[40]	2008	2003–2004	Greece	Infants, children (1–5 years)	2374	NA	Folate, Fe, Zn
EAR and RNI (United Kingdom 1991[31])	Cowin[41]	2007	1994	United Kingdom	Children (18 months)	1026	NA	Vitamin A, folate, Zn, iodine, Fe
EAR (United Kingdom 1991[31] and United States 2001[32])	Pynaert[42]	2007	NA	Belgium	Young adult women (NA)	NA	NA	Fe
EAR (France 2001[33])	Touvier[43]	2006	2000	France	Children, adolescents, adults, elderly (4–92 years)	2373	NA	Vitamin A, folate, Fe
EAR (United States IOM 1997[34], 2002[35])	Schroder[44]	2004	1994–1996	Spain	Elderly (65–74 years)	1748	838 M, 910 F	Vitamin A, folate, vitamin B_{12}, Zn, Fe
EAR (United Kingdom 1991[31])	Emmett[45]	2002	1996	United Kingdom	Children (3 years)	863	NA	Fe
Basal requirement (WHO/FAO/IAEA 1992[36])	Michaelsen[46]	1994	1987–1988	Denmark	Infants (0–12 months)	91	NA	Zn
AR (EC 1993[37])	Kiely[47]	2001	1997–1999	Ireland	Adults (18–64 years)	1379	662 M, 717 F	vitamin A, folate, vitamin B_{12}, Fe, Zn
EAR and RDA (Dutch 1992–1993[3839])	Brussaard[48]	1997	NA	The Netherlands	Adults, elderly (20–79 years)	444	NA	Folate

AR, average requirement; EAR, estimated average requirement; NA, not available.

Table 5. Selected European studies on inadequacy of folate intake in adult women

First author	Publication year	Survey year	Country	Reference value for adequacy	Cut-off folate (μg)	Population inadequate (%)	Adult female population(*n*)	Mean intake (μg)	SD (μg)
Hatzis[49]	2006	NA	Greece	RNI (EC[37])	400	86·5	236	247	138
Sofi[50]	2005	2002–2003	Italy	RDA (IOM[4])	400	89·0	309	338	121
Planells[51]	2003	NA	Spain	RDA (Varela[55] and IOM[56])	2/3 of 200	23·5	1715	196	105
Aranceta[52]	2001	1990–1998	Spain	RDI (Varela[55] and EC[37])	2/3 of 200	10·0	5480	252	103
O'Brien[53]	2001	1997–1999	Ireland	AR (EC[37])	140	8·9	717	260	144
Schroder[44]	2004	1994–1996	Spain	EAR (US IOM[34,35])	320	70·0	662	285	66
Rasmussen[54]	2000	1998	Denmark	RI (NNR 1996[57])	300	64·8	258	276	90
Brussaard[48]	1997	NA	The Netherlands	EAR and RDA (source not provided)	400	95·0	300	270	79

RNI, recommended nutrient intake; RDA, Recommended Dietary Allowances; NA, not available; AR, average requirement; EAR, estimated AR; RI; recommended intake.

The EAR cut-point method was not frequently used. The probability approach method was only applied in seven non-European surveys, while it was not used at all in Europe. Other methods such as nutrient adequacy ratio and mean adequacy ratio were used in very few non-European studies.

Among the surveys that used the RDA as a reference, a wide range of reference values was used in Europe to assess nutrient intake adequacy. This means that the estimation of adequacy can also differ between countries.

The present paper presented the folate intake in European adult women as an example to illustrate how the use of different methods can lead to different prevalence estimates of nutrient inadequacy. Most health authorities recommend a daily intake of 200 μg dietary folate for women, while WHO/FAO[1] recommends a minimum intake of 400 μg/d. Few studies have shown that present dietary folate intake of adults in European countries meets the average RDA of 200 μg/d, but not the recommended WHO/FAO value of 400 μg/d[58,59]. One study showed that weighed mean intake for women was 247 μg/d with a range of 168–320, and median values lower than 200 mg/d were not frequently seen[58]. As reported in another study, the dietary folate intake in eight European countries ranged from 207 to 284 μg/d for women and from 218 to 352 μg/d for men; for these European countries the average intake of dietary folate for men was 283 (SD 39) μg/d and for women 238 (SD 26) μg/d[59].

The present results indicate that 25·1 % of the European adult female population would have an inadequate folate intake according to the reference intake values that were considered in the respective surveys. Compared against the EAR, the prevalence of folate inadequacy turned out to be lower: in particular, the use of the corresponding national EAR cut-point values resulted in 17·1 % of the population having inadequate intake of folate, whereas 74·8 % were estimated to have inadequate folate intake when the WHO/FAO recommended EAR cut-point value of 320 μg/d was used as the reference. These calculations were made under the assumption that the intake of the population that was found to be inadequate in folate was normally distributed and therefore needs to be interpreted with caution. Furthermore, no correction for other factors was made. Nevertheless, the results give an indication of the variation that can occur when different methods are applied to estimate intake adequacy.

Table 6. Percentages of folate intake inadequacy in European adult women compared against different reference values

Total adult female population (*n*)	According to survey results: Population inadequate (%)	According to survey results: Cut-off folate (μg)	Compared to national RDA: Population inadequate (%)	Compared to national RDA: Cut-off folate (μg)	Compared to national EAR: Population inadequate (%)	Compared to national EAR: Cut-off folate (μg)	Compared to WHO/FAO RNI[1]: Population inadequate (%)	Compared to WHO/FAO RNI[1]: Cut-off folate (μg)	Compared to WHO/FAO EAR[1]: Population inadequate (%)	Compared to WHO/FAO EAR[1]: Cut-off folate (μg)
236	86·5	400	36·7	200	21·9	140	86·5	400	70·2	320
309	89·0	400	12·7	200	5·1	140	89·0	400	44·1	320
1715	23·5	2/3 of 200	51·5	200	29·7	140	97·4	400	88·1	320
5480	10·0	2/3 of 200	30·7	200	13·8	140	92·5	400	74·5	320
717	8·9	140	33·8	200	20·2	140	83·5	400	66·2	320
662	70·0	320	9·9	200	1·4	140	95·9	400	70·0	320
258	64·8	300	60·5	300	30·5	230	91·6	400	68·8	320
300	95·0	400	64·8	300	30·6	230	95·0	400	73·7	320
9677	25·1		34·6		17·1		92·1		74·8	

RDA, Recommended Dietary Allowances; EAR, estimated average requirement; RNI, recommended nutrient intake.

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Conclusions

The present review showed that different methods have been applied across Europe to estimate the adequacy of micronutrient intake, which has led to different prevalence estimates of micronutrient inadequacy. The harmonisation of methods and the development of a software tool are important steps that can lead to a standardised way of estimating the adequacy of micronutrient intake in Europe. European micronutrient recommendations aligned has the potential to provide guidance to develop the proper tool that would enhance harmonisation of nutrient intake adequacy assessment across Europe.

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G. T. screened the literature, undertook analysis and wrote the first draft of the paper. T. M. A. W. supervised the work, developed the literature search strategy, screened part of the literature and wrote the final draft of the paper. F. B. managed the project and commented on drafts of the paper.

B. R.-V. contributed to the literature search strategy and commented on drafts of the paper. L. R.-B. contributed to the design of the review and commented on drafts of the paper. J. N. contributed to the literature search strategy and commented on drafts of the paper. A. G.-A. contributed to the design of the review and commented on drafts of the paper. L. S.-M. contributed to the design of the review and commented on drafts of the paper.

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