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Optimal growth and development: are teenagers getting enough micronutrients from their diet?

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The teenage years represent a crucial period of physical and cognitive growth and development with sufficient micronutrient intakes necessary to meet high nutritional requirements. This review examines current micronutrient intakes in teenagers in the Western world in the context of public health implications including the prevalence of inadequate intakes and risk of excessive intakes. Intakes of vitamins A, D, E and C, folate, calcium, iron, magnesium, zinc and potassium in teenagers are low when compared to generally accepted recommendations, while there is little risk of excessive micronutrient intakes based on current dietary patterns. Therefore, strategies should focus on increasing micronutrient intakes in order to decrease the risk of negative impacts resulting from these low intakes. These strategies should be mindful of guidance towards an environmentally sustainable diet whilst ensuring that nutrient intakes in teenagers are not further negatively impacted. In order to identify, implement and monitor the effectiveness of such strategies, intakes of micronutrients should be continually monitored in nationally representative samples of the population for all age groups including this vulnerable cohort of teenagers.

Key words: Micronutrients: Teenagers: Adequacy: Excess: Bone health: Cognitive health

The teenage years are a crucial time for physical and cognitive development; thus, sufficient intakes of nutrients are essential to meet high nutritional needs. Micronutrients play an important role in achieving optimal health during the teenage years by contributing to a wide range of critical functions in the body. Vitamin D, calcium, magnesium and phosphorus are of particular importance to bone health in this population group in order to optimise peak bone mass and to reduce the risk of osteoporosis and fractures in later life[1–4]. Vitamins A and C are necessary during the teenage years for the development of cells, cell integrity and tissue repair, while insufficient intakes of B vitamins, such as vitamin B_{12} and folate, might impair growth as a result of impaired DNA synthesis and cell division[4]. Iron is essential for the transport of oxygen, with increased requirements during the teenage years as a result of increased total blood volume, lean body mass and the advent of menstruation in girls[5]. Zinc plays a role in numerous physiological functions, such as gene expression and regulating intracellular signalling[6] while iodine is vital for the development of neurological and cognitive skills, which are of particular importance during the teenage years[4]. While sufficient intakes of micronutrients are essential for optimal health, it is important to note that for some micronutrients, intakes above recommended

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Table 1. Summary of national dietary surveys in Europe, the US, Canada, Australia and New Zealand, which provide data on intakes and sources of nutrients in teenagers

Country	Study name	Study year(s)	Age (years)	n*	Dietary assessment method	Dietary source	Reference
Austria	Austrian nutrition report (Österreichischer Ernährungsbericht 2012)	2010–12	13–14	44	3-d food record	Not specified	(9)
Belgium	Belgium national food consumption survey	2014–15	15–17	NR	2 × 24 h recall	All sources	(10)
Cyprus	Dietary intake of cypriot children and adolescents	2009–10	14–18	569	3-d food record	Food only	(11)
Denmark	Danish national survey of dietary habits and physical activity	2011–13	10–17	509	7-d food record	Not specified	(12)
Ireland	National teens' food survey II	2019–20	13–18	428	4-d food record	All sources	(13,14)
Italy	Third Italian national food consumption survey INRAN-SCAI 2005–06	2005–06	10–17·9	247	3-d food record	All sources	(15,16)
Portugal	National food, nutrition and physical activity survey of the portuguese general population, IAN-AF 2015–2016	2015–16	10–17	NR	2-d food record	All sources	(17)
Spain	ANIBES study	2013	13–17	NR	3-d food record, 24 h recall	Not specified	(18–21)
The Netherlands	Dutch national food consumption survey	2012–16	12–18	769	Diet history	All sources	(22)
The UK	National diet and nutrition survey (NDNS) rolling programme	2008/09–2011/12 2014/15–2015/16 2016/17–2018/19	11–18	NR 542 683	4-d food record	All sources	(23,24)
Sweden	Riksmaten Adolescents	2016–2017	14·5–18	769	24 h recall	Not specified	(25)
US	What we eat in America, NHANES	2015–2018	14–18	1421	2 × 24 h recall	Food only	(26)
Canada	Canadian Community Health Survey (CCHS) - Nutrition	2015	14–18	1753	24 h recall	Food only	(27)
Australia	Australian Health Survey	2011–12	14–18	–	24 h recall	Food only	(28)
New Zealand	New Zealand Adult Nutrition Survey	2008–09	15–18	NR	24 h recall	Food only	(29)

*Total study sample (including energy under-reporters), NR = not reported; '-' Data not available, 'All sources' includes supplements and food sources.

upper levels (excessive intakes) can lead to negative health consequences[7].

In addition to high nutrient requirements, individuals begin to have more autonomy over their food choices during the teenage years, with increasing peer influence on their food choices and eating behaviours[8]. These food choices and eating behaviours can affect micronutrient intakes if foods consumed are of poor nutritional quality, thus placing teenagers at greater risk of inadequate intakes[8]. These behaviours may last into adulthood and continue to impact their micronutrient intake and related health outcomes throughout their adult lives[8].

The combination of the teenage years being a rapid growth phase and a time of change in terms of eating behaviours and food choices make teenagers a very vulnerable group, with nutrient intakes impacting their health during both the teenage years and into adulthood[1,8]. Thus, it is important to examine current micronutrient intakes in teenagers to identify whether intakes are sufficient and will promote optimal health across the life course but also to ensure that there is not a risk of excessive intakes. Therefore, the aim of this paper is to critically review current micronutrient intakes in teenagers in the Western world in the context of public health implications, including the prevalence of inadequate intakes and risk of excessive intakes. Tables 1–6 provide data on micronutrient intakes, and the prevalence of inadequate and excess micronutrient intakes in teenagers using data from the most recently published nationally representative dietary surveys in the Western world (Europe, Canada, the United States (US), Australia and New Zealand). Overall, intakes of vitamins A, D, E and C, folate, calcium, iron, magnesium, zinc and potassium are low in teenagers compared to generally accepted recommendations. The implications of these low intakes for public health, specifically in relation to bone health, cognitive function and immune health are discussed in detail in the following review.

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Table 2. Mean intakes of vitamins in teenagers from national dietary surveys in Europe, the US, Canada, Australia and New Zealand

	Vitamin A µg RE/d	Vitamin D µg/d	Vitamin E mg/d	Vitamin K µg/d	Vitamin C mg/d	Thiamine mg/MJ†	Riboflavin mg/d	Niacin mg NE/MJ†	Vitamin B6 mg/d	Vitamin B12 µg/d	Folate µg/d	Biotin µg/d	Pantothenic acid mg/d
Country/PRI	600–750[4]	15·0[4]*	11·0–13·0[4]*	45·0–70·0[4]*	70·0–110[4]	0·1[4]	1·4–1·6[4]	1·6[4]	1·4–1·7[4]	3·5–4·0[4]*	270–330 DFE[4]‡	35·0[4]*	5·0[4]*
Austria[9]	700	1·6	9·2	65·0	74·0	0·1	1·1	3·1	1·7	4·0	140‡	35·0	3·8
Belgium[10]	769	5·6	12·0	73·5	–	–	–	–	–	–	–	–	–
Cyprus[11]	918	–	–	–	93·8	0·2	1·9	–	1·6	–	–	–	–
Denmark[12]	967	2·9	7·0	–	90·5	0·1	1·6	3·1	1·4	5·2	277	–	–
Ireland[13]	635	3·7	8·5	–	78·0	0·2	1·8	4·9	1·9	5·5	287	29·3	6·5
Italy[16]	777	2·5	12·9	–	132	0·1	1·6	–	2·1	6·7	–	–	–
Portugal[17]	756	5·6	10·1	–	99·0	0·2	1·9	4·3	2·1	4·8	217	–	–
Spain[18–21]	570	3·7	7·5	–	61·6	–	–	–	–	3·9	155	–	–
The Netherlands[22]	671	3·3	13·3	64·8	111	0·2	1·8	2·0	1·7	4·7	238‡	–	–
The UK[23,24]	696	2·9	8·9	–	83·5	0·2	1·5	4·4	2·2	4·1	199	–	–
Sweden[25]	–	6·5	–	–	–	–	–	–	–	–	–	–	–
US[26]	560	4·4	7·9	74·7	62·6	0·2	1·9	2·9	1·9	4·8	519‡	–	–
Canada[27]	667	5·1	–	–	115	0·2	2·2	4·8	1·8	4·5	492‡	–	–
Australia[28]	690	–	9·7	–	103	0·2	1·9	4·3	1·3	4·4	658‡	–	–
New Zealand[29]	708	–	9·6	–	104	0·2	2·0	4·0	2·5	4·2	–	–	–

*Adequate intake (AI) used where PRIs (Population reference intake) not assigned(4).
†Calculated crudely from the population mean of the nutrient and energy value.
‡1ug DFE (1ug natural food folate + 1.7 x synthetic folate i.e. folic acid); '-' Data not reported.

Table 3. Mean intakes of minerals in teenagers from national dietary surveys in Europe, the US, Canada, Australia and New Zealand

	Calcium mg/d	Iron mg/d	Magnesium mg/d	Zinc mg/d	Iodine µg/d	Potassium mg/d	Phosphorou mg/d	Selenium µg/d	Copper mg/d
Country/PRI	1000–1150[4]	11·0–16·0[4]	250-300[4]*	10·7–16·3[4]	120–150[4]*	2700-3500[4]*	550–640[4]*	55·0–70·0[4]*	1·1–1·6[4]*
Austria[9]	677	9·4	239	9·0	90·5	2039	–	–	–
Cyprus[11]	944	11·7	237	–	–	2337	1341	–	–
Denmark[12]	1051	9·6	306	11·0	229	2800	1427	43·5	–
Ireland[13]	812	11·0	236	8·4	–	2404	1180	–	–
Italy[16]	831	11·3	269	12·1	–	2930	1366	–	–
Portugal[17]	859	11·4	271	11·1	–	2992	1319	–	–
Spain[18,20,21]	817	11·4	216	8·6	–	–	1261	80·0	–
The Netherlands[22]	868	9·7	287	9·6	176	2684	1307	41·0	1·3
The UK[24]	784	9·9	209	7·5	127	2307	–	40·0	0·9
US[26]	965	14·4	247	10·4	–	2154	1295	107	1·0
Canada[27]	983	13·7	305	11·3	–	2672	1422	–	–
Australia[28]	833	10·8	291	10·8	181	2649	1429	81·4	–
New Zealand[29]	880	11·7	–	11·4	–	2799	–	53·9	–

*Adequate intake (AI) used where PRIs (Population reference intake) not assigned(4), '-' Data not reported.

Table 4. Prevalence of inadequate intakes (%<EAR) of fat-soluble vitamins in teenagers from national dietary surveys in Europe, the US, Canada, Australia and New Zealand

	Vitamin A		Vitamin D		Vitamin E	
Country	EAR µg/d*	%<EAR	EAR µg/d*	%<EAR	EAR mg/d*	%<EAR
Belgium[10]	490–570	30·0	–	–	–	–
Cyprus[11]	485–630	30·6	–	–	–	–
Ireland[13]	480–580	31·1	10·0	94·0	–	–
Portugal[17]	490–580	23·9	–	–	–	–
Spain[18–21]	490–580	46·0	15·0	93·0	11·0–13·0	61·0
The Netherlands[22]	–	43·5	–	–	–	–
Sweden[25]	–	–	7·5	70·3	–	–
US[26]	485–630	56·0	5·0	96·0	12·0	91·5
Canada[27]	485–630	39·4	10·0	94·4	–	–
Australia[28]	485–630	32·5	–	–	–	–

Note: No country reported data on the prevalence of inadequate intakes of vitamin K, '-' Data not reported.
*EAR (estimated average requirement) used within individual studies.

Micronutrients for bone health

As over half of an individual's bone mass is laid down during the teenage years, sufficient intakes of calcium, vitamin D and magnesium are crucial to promote bone health due to the role of calcium and magnesium in bone mass accrual and the role that vitamin D plays in the absorption of calcium[2,30]. Intakes of vitamin D, calcium and magnesium are low amongst teenagers, with intakes substantially below recommended intakes. The prevalence of inadequate intakes among teenagers in the Western world ranges from 70–95 % for vitamin D, 45–73 % for calcium and 33–88 % for magnesium (Tables 4 and 6), which individually and combined may have negative implications for bone health. Typically a slightly lower prevalence of inadequate vitamin D intakes has been reported in the Nordic countries e.g. 70 % for teenagers in Sweden which is potentially due to fortification of fluid milk with vitamin D, in addition to different dietary patterns such as higher oily fish consumption, and the high population use of cod liver oil and vitamin D supplements[25,31] (Table 4). The low intakes of vitamin D globally are also reflected in biochemical status data (25-hydroxyvitamin D (25(OH)D) concentrations), with the prevalence of vitamin D deficiency ranging from 3 % in Australia to 21 and 22 % in the UK and Ireland, respectively, likely attributable to the higher dermal synthesis of vitamin D from ultraviolet B rays in Australia[23,32,33]. Furthermore, while inadequate intakes of vitamin D are high in all teenagers, the prevalence of inadequate intakes of calcium is higher amongst teenage girls (61–88 %) than teenage boys (30–58 %)[13,17,18,27,29], which may have implications further into adulthood with females more at risk of developing osteoporosis due to hormone changes during the menopause[34]. The combination of very low intakes of calcium, vitamin D and magnesium may raise concern for the future bone health of teenagers and may increase the risk of osteoporosis and fractures[2]. Key sources of calcium in teenagers include dairy products and additionally, cereals and cereal products are an important contributor to calcium intakes in the UK and Ireland due to the mandatory fortification of wheat flour with calcium in the UK[24,35]. Milk (including vitamin D fortified milk), meat products and cereals and cereal products, including fortified ready-to-eat breakfast cereals (RTEBC), are key sources of vitamin D and magnesium[10,15,17,18,22,23,28], highlighting the role of fortified foods such as RTEBC which are consumed by a high proportion of teenagers alongside natural sources of micronutrients[36,37]. While vitamin D supplementation is recommended in a number of countries, particularly during the winter months[10,34,38], data from nationally representative dietary surveys shows that nutritional supplements contributed just 6–18 % of vitamin D intakes in teenagers[10,22].

Cognitive function

Aside from bone health, the teenage years are a period of rapid cognitive growth with nutrients such as folate and iron playing important roles in cognitive health, yet intakes of these nutrients in teenagers are low with respect to recommendations. The prevalence of inadequate intakes of folate in teenagers ranges from 14–57 % and the prevalence of inadequate intakes of iron ranges from 7–44 % across countries in the Western world (Tables 5 and 6). In addition to the role of folate in cognitive health, the role of folate in pregnancy and infant health must also be considered in this cohort and during adulthood due to the possibility of pregnancy[39]. Supplemental folic acid intake of 400 µg/d is recommended for all women of childbearing age (irrespective of pregnancy intention) to reduce the risk of neural tube defects in infants. As about half of pregnancies are unplanned, particularly in teenagers[40], low intakes of folate among teenage girls may have negative implications in the case of pregnancy[40]. The high prevalence of inadequate intakes of folate among teenagers is of particular importance in this context with the prevalence of inadequate intakes of folate higher amongst girls (22–63 %) than boys (6–52 %)[13,17,26,27].

Iron requirements increase significantly throughout the teenage years due to increased total blood volume and

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Table 5. Prevalence of inadequate intakes (%<EAR) of water-soluble vitamins in teenagers from national dietary surveys in Europe, the US, Canada, Australia and New Zealand

	Vitamin C		Thiamine		Riboflavin		Niacin		Vitamin B_6		Vitamin B_{12}		Folate	
Country	EAR mg/d*	%<EAR	EAR mg/d*	%<EAR	EAR mg/d*	%<EAR	EAR mg/d*	%<EAR	EAR mg/d*	%<EAR	EAR µg/d*	%<EAR	EAR µg/d*	%<EAR
Belgium[10]	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Cyprus[11]	56·0–63·0	34·3	0·9–1·0	12·6	0·9–1·1	8·2	–	–	1·0–1·1	16·9	–	–	–	–
Ireland[13]	60·0–90·0	47·8	0·072 mg/MJ	0·4	1·1–1·4	20·1	1·3 mg NE/MJ	0·0	1·2–1·5	14·3	1·0–1·25	0·3	210–250	31·1
Portugal[17]	–	–	–	–	1·4	17·3	–	–	1·2–1·3	13·0	–	–	250	57·2
Spain[18–21]	75·0–85·0	55·0	–	–	–	–	–	–	–	–	–	–	–	–
The Netherlands[22]	50·0–60·0	18·8	–	–	–	–	–	–	–	–	–	–	–	–
US[26]	56·0–63·0	55·0	0·9–1·1	7·0	0·9–1·1	5·0	11·0–12·0	3·0	1·0–1·1	10·0	2·0	9·0	330	14·0
Canada[27]	56·0–63·0	21·0	0·9–1·0	5·0	0·9–1·1	2·8	11·0–12·0	0·0	1·0–1·1	2·5	2·0	8·0	330	20·6
Australia[28]	28·0	2·0	0·9–1·0	24·3	0·9–1·1	2·9	11·0–12·0	0·0	1·0–1·1	9·5	2·0	5·0	–	–

*EAR (estimated average requirement) used within individual studies, '-' Data not reported.

Table 6. Prevalence of inadequate intakes (%<EAR) of minerals in teenagers from national dietary surveys in Europe, the US, Canada, Australia and New Zealand

	Calcium		Iron		Magnesium		Zinc		Iodine		Phosphorous		Selenium		Copper	
Country	EAR mg/d*	% <EAR	EAR mg/d*	% <EAR	EAR mg/d*	% <EAR	EAR mg/d*	% <EAR	EAR µg/d*	% <EAR	EAR mg/d*	% <EAR	EAR µg/d*	% <EAR	EAR mg/d*	% <EAR
Cyprus[11]	–	–	7·7–7·9	16·1	300–340	87·5	–	–	–	–	1055	0·0	–	–	–	–
Ireland[13]	860–960	50·5	6·0–8·0	6·7	230–250	32·6	8·9–11·8	48·3	–	–	–	–	–	–	–	–
Portugal[17]	960	63·5	7·0–8·0	17·9	–	–	–	–	–	–	–	–	–	–	–	–
Spain[18–21]	960	45·0	–	–	250–300	57·0	9·9–11·8	38·0	–	–	–	–	55·0–70·0	3·0	–	–
The Netherlands[22]	–	–	7·0–10·0	43·6	–	–	–	–	100	7·0	–	–	–	–	0·7	1·9
US[26]	1100	69·0	7·7†	10·0	300–340	86·0	7·3–8·5	26·0	–	–	1055	30·0	45·0	<3·0	–	13·5
Canada[27]	1100	66·5	7·7†	14·8	300–340	64·4	7·3–8·5	24·6	–	–	–	–	–	–	–	–
New Zealand[29]	1050	72·8	8·0	19·6	–	–	9·9–11·8	11·7	–	–	–	–	40·0	59·3	–	–

*EAR (estimated average requirement) used within individual studies.
†IOM method used to calculate risk of iron inadequacy in girls, '-' Data not available or reported.

Table 7. Prevalence of excess intakes (%>UL) of micronutrients in teenagers from national dietary surveys in Europe, the US, Canada, Australia and New Zealand

Nutrient	Belgium[10]	Canada[27]	Cyprus[11]	Ireland[13]	Netherlands[22]	US[26]†
	%>UL*					
Vitamin A/retinol	0·0	–	1·0	0·0	–	–
Vitamin D	0·5	0·0	–	0·0	0·0	<3·0
Vitamin E	0·0	–	–	0·0	0·0	–
Vitamin K	0·0	–	–	–	–	–
Thiamine	–	–	0·0	–	–	–
Riboflavin	–	–	0·0	–	–	–
Niacin	–	–	–	0·0	–	–
Vitamin B_6	–	0·0	0·0	0·0	0·0	–
Vitamin C	–	0·0	0·0	0·0	–	<3·0
Folic acid	–	–	–	4·3	–	–
Calcium	–	0·0	–	0·0	0·0	<3·0
Iron	–	0·0	0·0	0·0	0·0	<3·0
Zinc	–	0·2	–	0·3	1·0	<3·0
Magnesium	–	–	4·0	–	0·0	–
Phosphorus	–	0·0	0·0	0·0	–	<3·0
Copper	–	–	–	0·5	0·0	<3·0
Iodine	–	–	–	–	0·0	–
Selenium	–	–	–	–	–	<3·0

*UL (Tolerable upper intake level) as indicated in individual studies.
†<3 % in the US indicates negligible amounts, '-' Data not available or reported.

lean body composition, and increased iron requirements for girls due to the onset of menstruation[5]. International bodies including the European Food Safety Authority and the US Institute of Medicine have acknowledged the difficulty in setting dietary reference values for iron due to large uncertainties in the rate and timing of pubertal growth and menarche, as well as substantial inter-individual variance in menstrual blood loss[41,42]. Notwithstanding this, iron intakes are generally low in teenagers with respect to recommendations, and there is a higher prevalence of inadequate intakes of iron amongst girls (9–34 %) than boys (5–16 %)[11,13,17,22,26,27,29]. A higher prevalence of inadequate intakes of iron in girls in the Netherlands (77 %) may be due to a higher cut-off used to determine inadequacy reflecting increased requirements due to menstruation[22]. In the UK, 9 % of girls and 1 % of boys are classified as having iron deficiency anaemia[23], although manifestations of low iron intakes such as difficulty concentrating and tiredness will likely have manifested before iron deficiency anaemia is present[43]. Key sources of iron and folate in teenagers are a combination of animal sources (i.e. milk and meat products) alongside cereal products, while vegetables are an important source of folate[15,17,19,20,22–24,28,29].

General health and immunity

Maintaining a healthy immune system and overall general health is important throughout the lifecycle and during the teenage years. Nutrients important for general health including vitamins A, C, E, zinc and potassium are low with respect to recommendations among teenagers and may result in increased risk of impaired immunity and susceptibility to infections[44,45] (Tables 2–6). Intakes of vitamin C in teenagers are generally below recommendations with the prevalence of inadequate intakes ranging from 21–49 % (Table 5). Although zinc intakes are generally in line with recommendations, it is of note that between 12–25 % of teenagers (and up to 68 % in Spain) have inadequate intakes of zinc (Table 6). Similar to other micronutrients, there is a higher prevalence of inadequate intakes of zinc in girls (7–57 %) compared to boys (16–36 %)[13,21,26,27,29]. As zinc is necessary for the synthesis of tissue, these low intakes may have implications for optimal growth[6]. Intakes of vitamin A are also low in the diets of teenagers with respect to recommendations which may impact functions such as normal vision, growth and development, gene expression and reproduction[4]. Although clinical signs of vitamin A deficiency are not common in developed countries[46], there is a high prevalence of inadequate intakes of vitamin A (24–56 %) in the teenage population (Table 4). Intakes of vitamin E and potassium are also generally below recommendations (Tables 2–4), which may impact functions such as cell metabolism and synthesis of protein and glycogen[4]. Meat products and milk are important sources of vitamin A and zinc which contribute to general health in teenagers while fruit, vegetables and potatoes are key sources of vitamin C intakes. Vegetables, cereal products, meat and dairy are key sources of potassium, and fats and oils are an important source of vitamin E[15,17,21,22,24,28,29].

Risk of excessive micronutrient intakes in teenagers

Due to negative health consequences from high intakes for some micronutrients, it is important to consider the balance between the benefit of addressing low intakes with

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the risk of excessive intakes. Although few data are available for teenagers, there is little to no risk of excess intakes, with minimal excess intakes of zinc (0–1 %), vitamin D (0–0·5 %), vitamin A (0–1 %), folic acid (4 % Ireland only) and magnesium (0–4 %) (Table 7). As there is little risk of excess intakes based on current dietary patterns, strategies should focus on increasing micronutrient intakes in order to decrease the risk of negative impacts resulting from low intakes.

Considerations for the future

While the available evidence shows that intakes of vitamin B_6, vitamin B_{12}, vitamin K, thiamine, riboflavin, niacin, biotin, pantothenate, iodine, copper, phosphorus and selenium in teenagers are currently in line with generally accepted recommendations, ongoing monitoring of all micronutrient intakes at both the lower and upper ends of the distribution is important due to ongoing changes in the food supply, as well as potentially different food consumption patterns due to changing dietary recommendations. A sustainable, nutritious diet is a global objective, and it is well recognised that changes to dietary patterns may improve planetary health[47]. As a result, dietary guidelines are now recommending a more sustainable diet, with reduced consumption of animal foods including dairy products[48], while the recent EAT Lancet report suggests a need for a 50 % reduction in meat intake for environmental benefit[49]. Considering the importance of animal sources, particularly meat and dairy, to intakes of vitamins and minerals in all population groups but especially teenagers, adherence to these recommendations may have unintended effects on micronutrient intakes. A decline in red meat intake in teenagers has been shown in the UK[50], while a decrease in dairy consumption in teenagers has been reported in Ireland[51], the Netherlands[22] and the UK[23,24] over the last 15 years, with a concurrent decrease seen in calcium intakes in these countries. Additionally, due to the reduced bioavailability of iron from fortified foods and non-haem iron from plant-based foods, more research on the impact of these dietary changes on biochemical status of iron is warranted[42]. Although plant sources such as grains are good sources of zinc, it is important to consider that grains also contain phytates, which can reduce the absorption of a number of minerals including zinc[6]. While most recommendations account for this in a mixed diet, the efficiency of mineral absorption is likely to be lower in a predominantly plant-based diet[6].

Conclusion

Intakes of vitamins A, D, E and C, folate, calcium, iron, magnesium, zinc and potassium are low amongst teenagers in Europe, Canada, the US, Australia and New Zealand when compared to generally accepted recommendations. Sufficient micronutrient intakes are crucial during the teenage years to promote optimal health and growth during this life stage and into adulthood, with key dietary habits also forming which have been shown to track into later life. Teenage bone health may be affected by the low intakes of vitamin D, calcium and magnesium, resulting in an increased risk of fracture and osteoporosis in later life[2,52]. Low intakes of folate and iron in teenagers may have a negative impact on cognitive health and also on maternal and infant health in the case of pregnancy[4,39,42,53]. Low intakes of vitamins A, C, E, zinc and potassium in teenagers may have an impact on general health and result in impaired immunity[6,45,46]. Based on current dietary patterns, there is little risk of excessive micronutrient intakes in teenagers and therefore strategies should focus on increasing micronutrient intakes in order to decrease the risk of negative impacts resulting from these low intakes. These strategies should be mindful of guidance towards an environmentally sustainable diet whilst ensuring that nutrient intakes in teenagers are not further negatively impacted. In order to identify, implement and monitor the effectiveness of such strategies, intakes of micronutrients should be continually monitored in nationally representative samples of the population for all age groups including this vulnerable cohort of teenagers.

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Author contributions

N. M. W., L. K. and J. W. contributed to the scope of this review. N. M. W. contributed to the data extraction and wrote the first draft. All authors contributed to the writing of the final manuscript. All authors critically reviewed the manuscript and approved the final version submitted for publication.

Competing interests

There are no conflicts of interest.

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