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Iodine intake among children and adolescents in Norway: Estimates from the national dietary survey Ungkost 3 (2015-2016)

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ABSTRACT

Background: Iodine is crucial for normal growth and neurodevelopment. Before 1950, goitre caused by iodine deficiency was widespread in Norway, but decreased significantly after mandatory fortification of animal fodder. Recent dietary changes in milk consumption and fish intake may again have increased the risk of inadequate intakes in some population groups in Norway. The situation for children and adolescents is unclear, and data from nationally representative studies are highly needed. We aimed to describe the iodine intake in Norwegian children and adolescents and estimate the proportion of individuals with an increased risk of suboptimal, adequate and excessive usual iodine intake. In addition, we aimed to investigate whether individuals' characteristics were associated with iodine intake, and to identify the major iodine contributing foods in the diet of this population.

Methods: Data from 1722 individuals (4-, 9- and 13-year-olds) from a national dietary survey in Norway from 2015-2016 was used. Both descriptive and inferential statistics were conducted. Usual iodine intakes were estimated, stratified by age group and sex and compared to dietary reference intake cut-offs. Linear regression models were used to assess the association between iodine intake and participants' characteristics. The contribution of iodine from different foods was described for all and across different participant groups.

Results: We estimated that the proportion of participants with an increased risk of a suboptimal usual intake of iodine varied from 3-36%. A significant increased risk was observed for older children and girls compared to younger children and boys. Excessive usual intakes were not observed in any age group. Iodine intake was associated with sex, maternal educational level and area of residence. A lower intake was observed for girls and those with a mother with a low educational level. Moreover, those living in the western part and Mid-Norway had statistically significantly higher intakes compared to those living in the capital city and surroundings. Milk, milk products, cheese, fish and shellfish were the main contributors to iodine intake. Supplements contributed with very little of the total iodine intake.

Conclusions: We have shown that the estimated risk of suboptimal usual iodine intakes among children and adolescents in Norway varies according to age, sex, maternal educational level and area of residence. Those with a limited intake of the main dietary contributors to iodine intake may be at risk, and adolescent girls seem to be especially vulnerable.

1. Background

Iodine is especially critical for normal neurodevelopment and growth; consequently, iodine deficiency in children and adolescents can result in impaired mental functions in addition to delayed physical development [1]. Although most individuals tolerate high intakes of iodine [2], excess iodine intakes may also cause adverse effects [3].

Endemic goitre was a severe problem in Norway before 1950 [4], as for several other European countries [5,6]. Through voluntary, low levels of iodization of table salt (5 µg/day) and mandatory fortification programs of cow fodder, which resulted in an increased iodine content of milk and dairy products, the problem seemed to be resolved in

Abbreviations: AR, Average requirement; BMR, Basal metabolic rate; EAR, Estimated average requirement; IOM, The American Institute of Medicine; MSM, The Multiple Source Method; NNR2012, Nordic Nutrition Recommendation 2012; PAL, Physical activity level; RDA, Recommended dietary allowance; RI, Recommended intake; UIC, Urinary iodine concentration; UL, Tolerable upper intake level; WHO, World Health Organisation

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Norway [6]. However, dietary habits change and there is now a concern that mild iodine deficiency may have re-emerged in some groups. A few very recent, smaller studies indicate that a large proportion of children and adolescents in Norway seems to have an adequate status [7–9]. Yet, studies show that young women in Norway have an inadequate intake of iodine [10].

The World Health Organisation (WHO) recommends the use of median urinary iodine concentration (UIC) from spot urine samples to assess if the iodine status in a population is adequate [11]. Biological samples are not always available or possible to collect. Dietary assessment methods aimed to estimate dietary iodine intake could therefore provide a feasible alternative as lack of dietary iodine leads to iodine deficiency in humans [12].

The aim of this study was to describe the iodine intake in Norwegian 4-year-olds, 9-year-olds and 13-year-olds, and to estimate the proportion of individuals at risk of suboptimal, adequate and excessive usual iodine intakes, using the latest national dietary survey data from 2015-2016. Furthermore, we aimed to investigate whether participants' characteristics were associated with iodine intake and identify the major iodine contributing foods in the diet of this population.

2. Methods

2.1. Study population, recruitment and design of study

All data used in the current paper were collected during the latest nationally dietary survey among children and adolescents, conducted between 2015-2016 (UNGKOST 3) [13,14]. The Norwegian Tax Administration, administered by EVRY [15], drew a random sample of 4-year-olds, who were invited via a letter sent directly to their parents/guardians, followed by a phone call. The 9- and 13-year-olds were recruited from selected schools in 50 randomly selected municipalities. A total of 1987 4-year-olds, 1164 9-year-olds and 1290 13-year-olds were invited, out of which 399 (20%), 636 (55%) and 687 (53%), respectively, completed three or four dietary recording days, including one weekend day. The recording was done using a web-based food recording system (WebFR).

Information about the study was provided in writing to all the invited children and adolescents (9-and 13-year olds) and the parents/guardians of all three age groups. The parents/guardians of the invited children and adolescents, who agreed to participate, signed a consent form in which questions regarding the participant's characteristics were included. After completion of the study, a gift certificate worth 200 NOK (approximately 20 EUR) was sent to the participants. The Norwegian Centre for Research Data approved the study (Project numbers 43310 and 41946).

2.2. Dietary assessment

The WebFR used for dietary assessment has previously been described in detail, and has been validated in 9- and 13-year olds [16–18]. The WebFR is based around eating events and has images for portion size estimations. All participants were asked to record dietary intake for four consecutive days, including one weekend day. All entries in the WebFR were done at the end of each recording day.

The guardians/parents of the 4-year-olds completed the recordings on behalf of their children, with additional aid from kindergarten personnel. Specifically, kindergarten personnel were provided with a paper form to record the dietary intake during the time the child was attending kindergarten (if applicable), which the parents/guardians then used in the evening as an aid to complete the recordings. The 9-year-olds were asked to complete their recordings with assistance from parents/guardians, whereas the 13-year-olds were instructed to complete the recordings by themselves. Prior to the recordings, the 9- and 13-year-olds were given a practical demonstration on how to use the WebFR at school, conducted by researchers at the University of Oslo [13]. The parents/guardians of the 4-year-olds solely followed the built-in instructions in the WebFR, previously described in more detail [14].

The food composition database KBS (Version AE-18) from the University of Oslo was used to calculate iodine intake, energy intake, and the contribution of iodine from foods.

2.3. Assessment of participant's characteristics

Parents/guardians provided the data on the participants' age, sex, weight, height, area of residence (9-, and 13-year-olds only), and their own educational level in the consent form. Data on area of residence for the 4-year-olds was obtained from the Norwegian Tax Administration, administered by EVRY [15].

2.4. Dietary reference values for iodine

In the Nordic Nutrition Recommendation 2012 (NNR2012) [19], recommended intake (RI) for iodine is given for children and adolescents, but average requirement (AR), lower intake level or upper intake level are not specified. Hence, we have used the following dietary reference values for iodine in the current paper: estimated average requirement (EAR) and tolerable upper intake level (UL), from the American Institute of Medicine (IOM) for both children and adolescents [20], in addition to RI from NNR2012.

According to NNR2012, RI corresponds to the amount of the relevant nutrient that is sufficient to meet the need and maintain an adequate nutritional status in practically all healthy individuals in a specific age range [19]. For iodine this corresponds to 90 μg/day, for 4-year-olds, 120 μg/day for 9-year-olds and 150 μg/day for 13-year-olds (for both sexes). IOM defines EAR as the amount of a nutrient that is sufficient to meet the need and maintain an adequate nutritional status in half of all the healthy individuals in a specific age range [20]. For iodine, that is, 65 μg/day for 4-8-year-olds and 73 μg/day for 9-13-year-olds (for both sexes). Moreover, UL is defined by IOM as the highest average daily intake of a nutrient, that is likely not to lead to any negative health risk, for practically all individuals in the general population [20]. The UL is set to 300 and 600 μg iodine/day for 4-8-year-olds and 9-13-year-olds, respectively. An estimated usual iodine intake that corresponds to the RI or above, yet no higher than UL is defined as an adequate usual iodine intake in this paper. Additonally, an estimated usual iodine intake above UL is defined as excessive, whereas estimated usual iodine intakes lower than EAR is defined as suboptimal in this paper.

2.5. Statistics

IBM SPSS (version 25), was used for all statistical analyses. Mean total iodine intakes and SD were calculated, stratified by age groups and sex. Median and percentiles were also calculated, as iodine intakes were skewed. The intake distributions of usual iodine intakes were estimated using the statistical package in the MSM program, based on the Multiple Source Method (MSM) [21]. The first and last out of the consecutive recording days were used in the MSM program, to ensure a minimum of independency between the recording days. The percentage of individuals with a usual iodine intake below the EAR cut-off (suboptimal), at or above RI (adequate), and at or above UL (excessive) were estimated for the three age groups separately and stratified by sex. Subsequently, sensitivity analyses were run, only including acceptable reporters of energy. The established Goldberg cut-off approach [22] was used to determine if the reported dietary energy intake of the participants were plausible at the individual level. The acceptable reporters of energy were defined as individuals with a reported energy intake divided by their estimated basal metabolic rate (BMR), within the 95% CI of agreement of an age-specific physical activity level (PAL). Estimated BMR was obtained for each participant using age and weight specific equations from Henry [23]. The following PALs were assigned:

1.60 for the 4-year olds [24], 1.68 for the 9-year-olds [18], and 1.47 for the 13-year olds [18]. Chi-Square tests were used to investigate if there were statistically significant differences between the age groups and sexes, in the estimated proportion of individuals having a suboptimal usual iodine intake (below EAR).

We used linear regression to determine if participants' characteristics were associated with the mean total iodine intake. Age group, sex, maternal educational level and place of residence were all used as independent variables (IV) and run separately in univariate models. All IV that were statistically significant at the 0.1 level in the univariate models were included in a multivariate model. Sensitivity analyses were conducted for the linear regression models, by including acceptable reporters of energy intake only, as previously described. Additional sensitivity analyses were conducted on all the previous run models, using log transformed total iodine intake, to lessen the skewness in the data, and improve the assumptions of the models. We used complete case analysis to handle missing data.

The contribution of iodine from different food categories as a percentage of the total iodine intake was calculated for all participants, and all three age groups, separately, for all, and for consumers of the different food categories.

The median intake of iodine in μg/day from the top three iodine contributing food categories were calculated for all participants, and separately by age group, sex, maternal educational level and place of residence. Then, the non-parametric Mann-Whitney U tests and Kruskal-Wallis H tests were used to assess whether the intake differed across the different participant groups. A significance level of 0.05 was used in all test.

3. Results

The three age groups included in this paper represents all parts of Norway, and have been described extensively in former reports on the dietary survey (Ungkost 3) [13,14]. Both sexes were equally represented; a total of 49%, 54% and 52% out of the 4-, 9- and 13-year-olds, respectively, were girls. Mean (SD) bodyweights were 17.4 (2.2) kg, 32.9 (6.2) kg and 50.3 (9.6) kg, for the 4-, 9- and 13-year-olds, respectively.

Iodine intake, for the three age groups, stratified by sex, is shown in Table 1. Median intakes were in the range of 80-108 μg/day. Mean and median iodine intakes for the 4-year-olds were above the RI. Both the 9- and 13-year-olds had mean and median intakes below the RI values for their age groups. The proportion having an increased risk of a suboptimal usual iodine intake (below EAR) differed statistically between age groups ($p < 0.001$) and sex ($p < 0.001$), showing a larger proportion of older children and girls with an increased risk compared to younger children and boys. The highest percentage of individuals with suboptimal usual iodine intakes (below EAR) was observed for 13-year-old girls (36%), whereas the lowest was observed for 9-year-old boys (3%). After running a sensitivity analysis, including only acceptable reporters of energy, the proportion of individuals with suboptimal usual iodine intakes (below EAR) was reduced for all groups, except for the 4-year-old boys.

Table 1 shows that 75% of 4-year-olds boys and 8% of 13-year-old-girls had adequate usual intakes (over or equal to the RI). When we only included data from acceptable reporters of energy, the estimated proportion of individuals having adequate usual iodine intakes (above or equal to the RI), increased for all age groups and for both sexes, except for 4-year-old-boys (Table 1).

No individuals among the 4-, 9- or 13-year-olds had excessive usual iodine intakes (exceeding UL).

The total mean iodine intake did not differ across the age groups (Table 2). A significantly lower total mean iodine intake was observed for girls as compared to boys, this association was consistent across the three different models.

A low maternal educational level is associated with a significantly lower total mean iodine intake, compared to a higher educational level (Table 2).

The total mean iodine intake differed significantly across areas of residence (Table 2). Children living in the western part and Mid-Norway had significantly higher iodine intakes compared to those living in the capital city or its surroundings, in all models. Those living in the Eastern-inland area and Northern part of Norway also had significant higher total iodine intakes compared to capital city or its surroundings, but results were less consistent across models, and confidence intervals were wider.

The main sources of iodine in the current study are presented in Table 3. The three food categories contributing with the largest proportion of iodine were "milk, cream, ice cream and yogurt", "cheese", "fish and shellfish", in that order. Over 95% of the participants consumed milk, milk products and cheese. Fewer consumed whey cheese than standard cheese. Whey cheese contributed with a higher proportion of the total iodine intake than standard cheese, among consumers. Lean and fatty fish contributed with 39 % and 3% respectively of total

Table 1
Iodine intakes among children and adolescents in Norway, compared to dietary reference intakes (n = 1722).

	N	Total intake, μg/day			% of participants		% of acceptable reporters [d]		
		Median (25-75 p)	Mean (SD)	Mean usual (SD)[a]	IOM < EAR[b]	NNR ≥ RI[c]	% of all	IOM < EAR[b]	NNR ≥ RI[c]
4-year-olds	399	101 (73-134)	109 (52)	103 (29)	7	64	89	6	67
Boys	204	103 (79-136)	114 (55)	108 (29)	4	75	94	4	75
Girls	195	95 (67-133)	104 (45)	97 (29)	11	54	85	8	56
9-year-olds	636	97 (69-135)	109 (58)	105 (29)	12	29	78	8	32
Boys	295	108 (77-144)	119 (59)	115 (25)	3	40	80	2	43
Girls	341	90 (60-125)	100 (56)	97 (30)	19	19	77	13	22
13-year-olds	687	89 (61-136)	107 (68)	102 (39)	24	11	73	18	13
Boys	332	101 (66-149)	119 (73)	113 (35)	11	14	74	7	17
Girls	355	80 (58-122)	96 (61)	91 (39)	36	8	72	29	9

[a] Estimated usual mean intakes calculated using the Multiple Source Method (MSM)[21].
[b] Estimated average requirement (EAR) from the Institute of Medicine (IOM) from 2006, age specific: 65 μg/day, for 4-8-year-olds, 73 μg/day for 9-13-year-olds (for both sexes).
[c] Recommended intake from the Nordic Nutrition Recommendations (NNR) from 2012, age specific: 90 μg/day, for 4-year-olds, 120 μg/day for 9-year-olds and 150 μg/day for 13-year-olds (for both sexes).
[d] Acceptable reporters of energy. Defined as individuals with a reported energy intake divided by their estimated basal metabolic rate (BMR), within the 95% CL of agreement of an age-specific physical activity level (PAL).

Table 2
Factors associated with total mean iodine intake

	N (%) of participants[a]	B (95% CI), iodine in µg/day		
		MODEL 1 Unadjusted (n = 1695)	MODEL 2 Adjusted[b] (n = 1695)	MODEL 3 AR-Adjusted[b,c] (n = 1336)
All	1695 (100)			
Age group				
4-year olds (reference)	392 (23)			
9-year-olds	629 (37)	0 (-7, 8)		
13-year-olds	674 (40)	−2 (-9, 6)		
Sex				
Boys (reference)	820 (48)			
Girls	875 (52)	−18 (-24, -12)	−18 (-24, -12)	−17 (-23, -11)
Educational level, mother				
Middle school or lower	62 (4)	−28 (-43, -12)	−28 (-43, -12)	−34 (-55, -14)
High school	429 (25)	−15 (-22, -7)	−15 (-22, -7)	−13 (-21, -4)
University- or university college (≤4 y) (reference)	609 (36)			
University- or university college (> 4 y)	595 (35)	7 (-0.1, 14)	8 (1, 14)	3 (-4, 10)
Area of residence[d]				
Capital city and surroundings (reference)	367 (22)			
Eastern-inland area	123 (7)	7 (-5, 19)	12 (-0.1, 24)	15 (1, 28)
South-east Norway	262 (15)	1 (-9, 10)	5 (-5, 14)	5 (-6, 15)
Southern part of Norway	261 (15)	1 (-8, 11)	5 (-5, 14)	5 (-6, 15)
Western part of Norway	305 (18)	15 (6, 24)	17 (8, 26)	15 (5, 25)
Mid-Norway	239 (14)	17 (7, 27)	18 (8, 28)	19 (8, 29)
Northern part of Norway	138 (8)	10 (-2, 22)	15 (3, 27)	15 (2, 28)

[a] Participants with complete data only. A total of 27 individuals had not data specifying the educational level of their mother, and were excluded.
[b] Adjusted for all other variables in the model, except for 'age group', in multiple linear regression analyses.
[c] Model includes only participants defined as acceptable reporters of energy intake (AR).
[d] The different areas correspond to (in the following order): Oslo og Akershus, Hedmark og Oppland, Sør-Østlandet, Agder og Rogaland, Vestlandet, Trøndelag, Nord-Norge.

Table 3
The mean contribution of iodine from different food groups, in percentage of the total iodine intake, presented for all and consumers separately.

	Percentage of total iodine intake		
	All (n = 1722)	Consumers only	
	Mean (SD)	% of total n	Mean (SD)
Milk, cream, ice cream and yogurt	41 (21)	97	42 (20)
Milk	32 (21)	90	35 (19)
Yoghurt	7 (9)	59	12 (10)
Cheese	15 (14)	95	16 (14)
Standard cheese [a]	8 (9)	92	9 (9)
Whey cheese [b]	7 (13)	36	20 (15)
Fish and shellfish	13 (19)	63	20 (20)
Lean fish	6 (15)	15	39 (16)
Fatty fish	1 (2)	23	3 (3)
Mixed dishes and products [c]	5 (11)	27	17 (16)
Eggs	4 (7)	44	9 (8)
Meat, blood, offal meat	4 (5)	99	4 (5)
Bread	3 (3)	100	3 (3)
Cakes	3 (5)	69	5 (6)
Cereals	3 (6)	96	3 (6)
Fruits and berries	3 (3)	94	3 (3)
Sweets, desserts, sugar	2 (5)	84	3 (5)
Supplements	1 (8)	50	3 (12)

[a] Cheese containing water and fat within a coagulated casein-protein structure. E.g. Jarlsberg, Parmesan, Cottage cheese.
[b] A solid or semi-solid food obtained by concentration of whey with the addition of milk, cream or milk products. E.g. Brown cheese, Prim cheese.
[c] Fish or shellfish-based dishes or products. E.g. Fish cakes, Fish fingers.

iodine intake for consumers of these foods.

Fifty percent of the participants were supplement users (Table 3), out of which four percent consumed supplements containing iodine. An extended version of Table 3, stratified by age group, is presented in supplementary files.

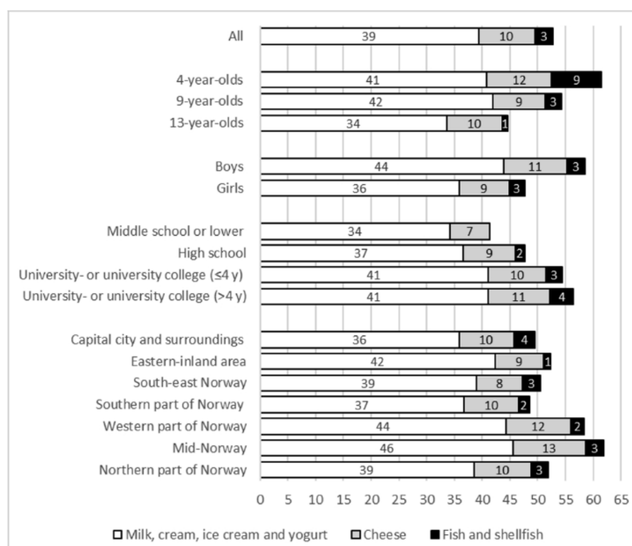

Fig. 1. Median intake of iodine (µg/day) from the three food categories that contributed the most to the total mean iodine intake, shown for all participants (n = 1722), and separately by age group, sex, maternal educational level and place of residence. A total of 27 individuals had missing data for maternal educational level.

In Fig. 1, the median intake of iodine, in µg/day, from the three food categories that contributed most to the total mean iodine intake, are given for all participants, and separately by age group, sex, maternal educational level and place of residence.

The median intake of iodine from "milk, cream, ice cream and yogurt" and "cheese" differed significantly across age group, sex, maternal educational level and area of residence. Moreover, the intake of iodine from "fish and shellfish" were significantly different across age groups and maternal educational level, but not across sex or area of residence.

4. Discussion

Our estimates in this study showed that 3-36% of children and adolescents in Norway had an increased risk of a suboptimal usual intake of iodine (below EAR) when we included all participants, and 2-29% when using a conservative estimate excluding misreporters of energy. The estimated proportion having suboptimal usual iodine intakes (below EAR) were higher with increasing age and for girls. Excessive usual iodine intakes (above UL) were not observed in any age group. A lower mean iodine intake was associated with being a girl and a low maternal educational level. Moreover, children and adolescents living in the western part and Mid-Norway had significantly higher mean iodine intakes than those living in the capital city and surroundings. Milk, milk products, cheese, fish and fish products were the main contributors to the total iodine intake for all and across the three age groups investigated in this paper. Dietary supplements contributed little to the total iodine intake.

4.1. A comparison with recent literature in the field

A few recent studies have reported data on iodine status and intake in groups of children and adolescents in Norway [7–9].

Nerhus et al. presented data on iodine status and intake among 220 5-year-olds from the western part of Norway, using both UIC and a food frequency questionnaire [8]. They concluded that the iodine status was satisfactory, due to the median UIC of 132 μg/L. A total of 29% and 5% had a UIC below 100 and 50 μg/L, respectively, and a low intake of milk and dairy products was associated with a low iodine status. These findings corroborate with our study, in which the 4-year-olds had a median total intake of iodine above the RI (adequate), and the percentage below EAR (suboptimal) was only 7%, which was the lowest among all age groups. The study of Nerhus et al. was from the western part of Norway, which is among the areas were participants had high mean iodine intakes in our study and may not be representative for all parts of Norway. Nevertheless, iodine intake appears satisfactory for most 4-year-olds in Norway, probably except non supplement users with no or low intake of both milk, dairy, fish and shellfish.

Brantsaeter et al. assessed the probability of having an adequate iodine intake in 47 children (3-9 years) and 46 adolescents (10-17 years), recruited by convenience sampling using UIC and two dietary record days [9]. They reported median UIC of 148 μg/L and only 11% had UIC below the WHO cut-off for adequate status of 100 μg/L. Median total estimated iodine intake was 93 μg/day for 3-9- year-olds. We observed slightly higher median iodine intakes: 101 and 97 μg/day for the 4-, and 9- year-olds, respectively. Based on the UIC data from Brantsaeter et al. and the intakes among the 4-year-olds in our study, the iodine situation for the youngest seems satisfactory. Although there was no significant difference in mean iodine intake between the different age groups in the current study, our estimates showed that a larger proportion of the 9-year-olds than the 4-year-olds had a suboptimal usual intake (below EAR) due to different cut-offs. Importantly to note, it is solely the 9-year-old girls that is responsible for this effect, with 19% having a suboptimal usual iodine intake (below EAR) compared to only 3% of the 9-year-old boys. The 10-17-year-olds in the study by Brantsaeter et al. had median UIC of 109 μg/L, which is considered satisfactory; yet 41 % had UIC below the WHO cut-off for adequate iodine status. Moreover, the median total iodine intake of 108 μg/day was below the RIs for the relevant age groups. Hence, the participants > 10 years in Brantsaeter et al.'s study had a higher probability of inadequate intakes compared to the younger children. In line with this, the 13-year-olds in the current study had a total median iodine intake of 89 μg/day, and 24% had an increased risk of a suboptimal usual intake (below EAR), which is inferior compared to the younger age groups in our study.

Another relevant study is the FINS-TEENS randomized controlled trial, which included 415 14-15-year-olds from eight schools from Bergen on the west coast of Norway [7]. They observed median UIC of 123 μg/L at baseline, indicating an adequate iodine status. Moreover, the reported median UIC in the FINS-TEENS study was higher than what was reported in the study by Brantsaeter et al. [9], indicating a somewhat better iodine status among the FINS-TEENS participants. An explanation for this observation may be that the FINS-TEENS study was conducted in the western part of Norway, an area in which the participants in our study had higher iodine intakes compared to several other parts of Norway. Still, 40% in the FIN-TEENS study had UIC below 100 μg/L [14], which is similar to the 10-17-year-olds in the study by Brantsaeter et al. [9]. This indicates that a larger proportion of older children and adolescents may not have adequate status compared to younger children, which support our findings on iodine intake.

Pregnant and lactating women in Norway have mild to moderate iodine deficiency, according to recent literature [25–27]. Non-pregnant young women in Norway have recently also been observed to have an inadequate iodine status and intakes [10]. Data from the latest Norwegian dietary survey among adults, showed that 46% of all women aged 18-29 had iodine intakes below the average requirement level from NNR2012 [28]. In comparison, we estimated that 36% of the 13-year-old girls in the current study had a suboptimal usual intake (below EAR). Observations of the iodine status in adolescent girls from the United Kingdom also support our findings [29]. Data from the United Kingdom is especially comparable to data from Norway due to similar non-fortification practice [6,29]. Around two-thirds of the girls in the study from the United Kingdom had insufficient iodine status [29].

Available data from Sweden and Denmark for children and adolescents indicate an adequate iodine status [30,31]. However, this was expected, due to differences in iodine fortification strategies of salt in these countries as compared to Norway. Denmark has mandatory fortification of household salt and salt in bread (13 μg/gram); the iodine fortification of table salt in Sweden is voluntary but high (50 μg/gram) [6]. The contribution of iodine from salt is small in Norway, as the iodine fortification of household salt in Norway is voluntary and low (max. 5 μg/gram) [32]. Although the Danish study showed adequate iodine status in children, they observed a higher UIC among the boys, compared to girls [31]; this trend is in line with the observations in our study. In Iceland, the use of iodized table salt is uncommon [33]. Hence, fortified salt is not a major contributor to the total iodine intake in Iceland, like the situation in Norway and the United Kingdom. However, the intake of iodine rich foods like fish and milk and milk products have traditionally been higher in Iceland than the other Nordic countries [6]. This has now changed, and adolescent girls in Iceland have reduced their intake of fish, milk and dairy significantly, but their UIC levels still indicate that their iodine status is adequate [33].

It was expected that the major sources if iodine in the age groups included in this study would be milk and milk products, cheese and fish and fish products. This is because iodized salt in Norway is not mandatory and has a relatively low iodine content, as previously described [32], and because the tap water available is also low in iodine [4]. We observed that milk and milk products were the largest single source of iodine in the current study. Interestingly, a steady and considerable reduction in intake of these foods has been observed over the last decades. The nationally dietary surveys in Norway show that, e.g. 13-year old girls reported intakes of milk and milk products of about 700 g/day in 1993 [34], 340 g/day in 2000 [35], and 270 g/day in 2015 [13], out of which the two latest surveys used comparable methodology. The decrease in milk and milk product consumption is also evident for 4- and 9-year-old girls and boys, and 13-year-old boys; the intake was reduced by about 70 to 130 g/day from the year 2000 [35,36] to 2015/2016 [13,14]. Additionally, the intake of fish and shellfish has also decreased slightly in the general Norwegian population [37]. Data from the past 15 years show a minor decrease only for 9-

year-old children of both sexes and 13-year-old girls [13,14,35,36]. The intake of cheese has on the other hand increased from around 20-25 g/day, in the year 2000 [35,36], to around 30-40 g/day in 2015-16 for the 4-, 9- and 13-year olds [13,14]. In total, the decrease in milk and milk product intake, and continuously low intake of fish and shellfish seems to have put an increasing proportion of all children and adolescents in Norway at risk of inadequate iodine intakes, especially adolescent girls. Monitoring both the dietary intake and preferably the iodine status, in different age groups and geographical regions, using UIC will be important in the years to come.

4.2. Methodological considerations

There are several strengths in this study. First, we have a relatively large sample size. Moreover, we add an important contribution to the field by including data from all regions of Norway in this study. In addition, we have included three different age groups, and use material collected in 2015 and 2016, providing a relatively up-to-date status on iodine intakes.

The dietary assessment method used to collect the data has been validated using objective reference methods [16–18]. Four consecutive days of recorded dietary intake, including a weekend day, were available for most of the included participants. In addition, our data enable us to get an insight into the dietary sources of iodine, in addition to the total iodine intake. Moreover, the food composition database used for the estimation of iodine intake in the current study has very recently been updated [28], which is a strength. Yet, the values in the food composition database will never be able to reflect the content of all foods available for the population at all times. Iodine values for some imported foods, mostly bakery products which may contain iodized salt, have not been included in the current version of the food composition database used in the current study [28]. This may have resulted in a small underestimation of the total iodine intake in the current study. Also, the dietary assessment method used in the current study relies on self-reports, for which measurement error is unavoidable [38]. Iodine intake from iodized salt is especially difficult to estimate when using self-reported dietary assessment methods [12]. However, as previously mentioned, iodized salt contributes very little to the total iodine intake in Norway [32]. Nevertheless, it would have been valuable to have measures of biomarkers of iodine intake. Measures of UIC, serum thyroglobulin or serum thyroxine are considered useful to assess iodine status in children and adolescents [39], but were not available in the current study.

The use of the American dietary reference intakes introduces some challenges for the interpretation of the results in this paper, as they are partly based on data from balance studies for iodine from the US [20]. These balance studies have been criticized by the European Food Safety Authority (EFSA) for having severe methodological limitations, and EFSA states that they cannot be generalized to other populations [40]. Specifically, it means that the proportion of individuals under and over these American cut-offs must be interpreted with caution. One could argue that a better approach would be to use the cut-offs for adults from the NNR2012 [19]. However, as cut-off levels are higher for adults than for younger children, using the average requirement cut-off for adults would inflate the proportion of children with an increased probability for insufficient iodine intakes. Also, EFSA's report from 2014 states that we lack sufficient data to derive any reference values other than an estimate for adequate intake (AI) – for both children, adolescents and adults alike [40]. No firm conclusion can therefore be made based on these cut-offs alone.

Selection bias may have been an issue. Especially for the 4-year-olds, in which only 20% out of the invited completed the study. It is well known that a higher socio-economic position is associated with a better diet quality, adhering more to the dietary guidelines [41], also evident in the data from the current study. The Norwegian health authorities promote the intake of low-fat milk and dairy, and fish [42]. If selection bias is a major issue in this study, it is likely that the observed intake of these foods is higher than what is the usual intake in the general population of children and adolescents. Hence, this could mean that the true iodine intake is lower, and the true proportion of individuals with a higher risk of suboptimal usual intakes larger, than what we estimated in the current study.

5. Conclusion

We have shown that the 4-year-olds seem to have adequate usual iodine intakes, while a larger proportion of the older children and especially girls have a suboptimal usual iodine intake (below EAR). A lower mean iodine intake is associated with being a girl, lower maternal educational level and living in other parts of Norway than the western- and mid-part. Milk, milk products and dairy, fish and shellfish are major contributors of iodine in the diet of children and adolescents in Norway.

There is a need for more studies investigating the iodine intake and status of older children and especially adolescent girls in other areas than the western part of Norway, preferably using UIC in addition to an assessment of dietary intake. Monitoring the dietary iodine intake and status of children and adolescents in other age groups will also be important in the years to come, as the dietary intake is constantly changing.

Declaration of Competing Interest

None.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.jtemb.2019.126427.

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