Iodine status of teenage girls on the island of Ireland

Mullan, K., Hamill, L., Doolan, K., Young, I., Smyth, P., Flynn, A., Walton, J., Meharg, A. A., Carey, M., McKernan, C., Bell, M., Black, N., Graham, U., McCance, D., McHugh, C., McMullan, P., McQuaid, S., O'Loughlin, A., Tuthill, A., ... Woodside, J. V. (2019). Iodine status of teenage girls on the island of Ireland. *European Journal of Nutrition*. Advance online publication. https://doi.org/10.1007/s00394-019-02037-x

Published in:
European Journal of Nutrition

Document Version:
Peer reviewed version

Queen's University Belfast - Research Portal:
Link to publication record in Queen's University Belfast Research Portal

Publisher rights
© 2019 Springer-Verlag GmbH Germany, part of Springer Nature.
This work is made available online in accordance with the publisher's policies. Please refer to any applicable terms of use of the publisher.

General rights
Copyright for the publications made accessible via the Queen's University Belfast Research Portal is retained by the author(s) and / or other copyright owners and it is a condition of accessing these publications that users recognise and abide by the legal requirements associated with these rights.

Take down policy
The Research Portal is Queen's institutional repository that provides access to Queen's research output. Every effort has been made to ensure that content in the Research Portal does not infringe any person's rights, or applicable UK laws. If you discover content in the Research Portal that you believe breaches copyright or violates any law, please contact openaccess@qub.ac.uk.

Open Access
This research has been made openly available by Queen's academics and its Open Research team. We would love to hear how access to this research benefits you. – Share your feedback with us: http://go.qub.ac.uk/oa-feedback

Download date:18. Jul. 2024

Iodine status of teenage girls on the island of Ireland

Karen Mullan[1], Lesley Hamill[2], Katy Doolan[2], Ian Young[2], Peter Smyth[3], Albert Flynn[4], Janette Walton[4], Andrew A. Meharg[2], Manus Carey[2], Claire McKernan[2],Marcia Bell[5], Neil Black[6], Una Graham[1], David McCance[1], Cathy McHugh[7], Paul McMullan[1], Siobhan McQuaid[8], Aonghus O'Loughlin[9], Antoinette Tuthill[10], Sarah C. Bath[11], Margaret Rayman[11], Jayne V. Woodside[2]

[1]RVH Belfast; [2]QUB Belfast; [3]NUI Galway .[4]UCCork; [5]UH Galway; [6]Altnagelvin H; [7]UH Sligo; [8]Mater H Dublin; [9]Roscommon GH; [10]Cork UH; [11] University of Surrey

Corresponding author: K Mullan MD; Regional Centre for Endocrinology and Diabetes Royal Victoria Hospital Belfast; karen.mullan@belfasttrust.hscni.net; 02890633480

Abstract

Purpose The trace element iodine is a vital constituent of thyroid hormones. Iodine requirements increase during pregnancy, when even mild deficiency may affect the neurocognitive development of the offspring. Urinary iodine concentration (UIC) is the means of assessing iodine status in population surveys; a median UIC of 100-199 µg/L is deemed sufficient in a non-pregnant population. Milk is the main dietary source of iodine in the UK and Ireland.

Methods We surveyed the iodine status of 903 girls aged 14-15 years in seven sites across the island of Ireland. Urine iodine concentration was measured in spot-urine samples collected between March 2014 and October 2015. Food group intake was estimated from iodine-specific food-frequency questionnaire. Milk iodine concentration was measured at each site in summer and winter.

Results The median UIC overall was 111 µg/L. Galway was the only site in the deficient range (median UIC 98 µg/L). All five of the Republic of Ireland sites had UIC ≤105µg/L. In the two sites surveyed twice, UIC was lower in summer vs winter months (117 µg/L (IQR 76-165) vs 130 µg/L (IQR 91-194) ($p<0.01$)). Milk samples collected from Galway and Roscommon had a lower mean iodine concentration than those from Derry/Londonderry ($p<0.05$). Milk intake was positively associated with UIC ($p<0.001$).

Conclusions This is the largest survey of its kind on the island of Ireland, which currently has no iodine fortification programme. Overall, the results suggest that this young female population sits at the low end of sufficiency, which has implications if, in future, they enter pregnancy with borderline status.

Keywords: iodine, teenagers, Ireland, nutrition

Funding: This survey forms part of a research program commissioned by *Safefood*, a public body which promotes awareness and knowledge of food issues on the island of Ireland.

Preliminary results were presented at Irish Endocrine Society Conference 2017 and appear in the abstract book of the conference.

Background

Iodine is an essential trace element required for the production of the thyroid hormones, thyroxine and triiodothyronine. Severe iodine deficiency is associated with cretinism and goitre [1] and although the significance of mild-to-moderate deficiency is less clear, a UK observational study showed that mild-to-moderate iodine deficiency in pregnant women was associated with lower IQ and readings scores in the offspring (8-9 years) in a dose-dependent manner [2].

Iodine deficiency in a population is defined on the basis of comparing median urinary iodine excretion (UIC) from school-aged children against World Health Organisation (WHO) cut-offs [3]: iodine sufficiency is defined as a median UIC of 100-199 µg/L, while mild, moderate or severe deficiency is defined by a median UIC of 50–99, 20–49, or <20 µg/L respectively, and iodine excess as a median above 300 µg/L [3]. The WHO estimates that 35% of the world's population have insufficient iodine intake although the number of countries with deficiency in the general population has decreased from 54 to 19 from 2003 to 2017 [4]. The picture is different for pregnant women, where many more countries have documented iodine deficiency in pregnancy (particularly mild-to-moderate deficiency), even if there is sufficiency in the general population [4,5]. The cut-off for sufficiency in pregnancy is a median UIC >150 µg/L$^{)}$[3] . This reflects the increase in iodine requirements during pregnancy and WHO recommends that regions develop strategies for ensuring adequate iodine intake during preconception, pregnancy, and lactation according to regional dietary patterns and iodized salt availability [3]. The UK (Great Britain and Northern Ireland) and the Republic of Ireland (ROI) have no programme of food or salt iodination and most salt in the UK is not iodised [6].

Historically, in parts of the UK, iodine deficiency and goitre was endemic in the 19th and early 20th century [7]. Goitre was eradicated after iodine was added to cattle feed to improve milk production in the 1930s and successive UK Governments also encouraged milk consumption (for general health, not iodine intake) in schoolchildren [7]. This has been described as "an unplanned and accidental public health triumph [7] as it was achieved through changes in the dairy-farming industry, not through a planned government intervention. Indeed now milk and dairy products are the main source of iodine in the UK diet [8], and previous UK studies have demonstrated that milk consumption is positively associated with urinary iodine status in children aged 8-10 [9], women of childbearing age [10] and pregnant women [12,13], but the results are less consistent for the relationship between iodine status and eggs, meat, and fish [10,11,13]. There are variations in milk-iodine content according to farming practice – winter milk has a higher iodine content than summer milk as cattle are more reliant on mineral-fortified feed when housed indoors in the winter [7,14], and previous research has found that organic milk has a lower iodine concentration than conventional milk [15-17].

From the 1980s, iodine sufficiency was assumed, but there was a lack of data [18]. That was until 2011 when a study, to which our group contributed, reported iodine status of over 700 schoolgirls aged 14-15 years across the UK including Northern Ireland (NI) and demonstrated mild iodine deficiency (median UIC 80 μg/L) [10]. By contrast, a multi-centre study in 8-10-year olds undertaken in three areas of the UK, including a site in NI demonstrated iodine sufficiency, even in the winter months [9]. This may be a result of the higher milk consumption typically observed in younger children (as compared to teenagers and adults) may explain the observed differences in status. Nationally-representative data are now available for the UK population through the National Diet and Nutrition Survey (NDNS) Rolling Programme. These data show borderline iodine sufficiency in women of childbearing age (median UIC 102 μg/L) and sufficiency in children aged 4 -10 (median UIC 166 μg/L) and also in 11-18 year olds (median UIC 120 μg/L) [8] for samples collected 2014-2016. However, NDNS does not include pregnant women and therefore evidence is only available from regional studies, all seven of which have suggested iodine deficiency in UK pregnant women [2,12,13,19-21].

The current situation in the ROI is less clear. In 1999, a survey of adults (n=132) in the ROI showed mild iodine deficiency (median 82 μg/L) and data published in 2006 demonstrated that in a cohort of pregnant women, 55% had moderate/severe iodine deficiency in summer months (July and August), and 23% in winter months (December and January) [22,23]. The latest data from the 2008-2010 National Adult Nutrition Survey (NANS) in the ROI shows borderline iodine sufficiency in women aged 18-90 years (n=563) on the basis of UIC data (median 101 μg/L) with sufficiency in men (median 116 μg/L) [24]; the dietary data shows the median intake was below the Reference Nutrient Intake (140 μg/day) for adult women at 104 μg/day.

As there is a lack of data, and the available data suggests that young women are vulnerable to iodine deficiency, we aimed to assess the current iodine status of 14-15 year-old females from seven centres across the island of Ireland. To investigate the environmental availability of iodine, during each sampling phase, we also collected a 5 ml sample of tap water at each site (i.e. school) at the same time as the urine sample collections were completed. In addition, data on dietary intake using an iodine-specific food frequency questionnaire (FFQ) were collected. We also collected bi-monthly samples of milk (one of the main dietary sources of iodine) across the island of Ireland over a one-year period to investigate any regional or seasonal variation.

Methods

Cross-sectional methodology was used to collect information on iodine status in females aged 14-15 years living on the island of Ireland. Based on WHO recommendations of assessing iodine status with at least 30 participants per site [3], recruitment was undertaken from seven sites: Belfast, Derry/ Londonderry, Dublin, Cork, Galway, Sligo, and the inland site of Roscommon (Figure 1). We also re-sampled girls living in Belfast and Derry/Londonderry to investigate potential seasonal variations in iodine status.

The study received ethical approval from the School of Medicine, Dentistry and Biomedical Sciences Research Ethics Committee (reference number: 13/42v2), for Northern Irish Centres. Ethical approval for the ROI centres was granted from the following regional ethics boards; Dublin - Royal College of Physicians of Ireland, reference number: RCPI RECSAF 27; Cork – Clinical Research Ethics Committee of the Cork Teaching Hospitals, University College Cork, reference number: ECM 3 (oo) 02109114; Galway, Roscommon and Sligo – Galway Regional Hospitals Clinical Research Ethics Committee, reference number: C.A. 1149.

All post primary schools with female pupils from the sites listed were eligible (222) and, although the plan initially was to approach them at random, in the end all were approached given the low uptake by schools. The sampling phases were March-June 2014 (Spring/Summer), October-December 2014 (Autumn/Winter) in NI. All the ROI schools took part from January-May 2015, except the Galway schools which took part in October 2015. Each schoolgirl who provided consent was asked to provide an early morning spot-urine sample, and to complete a food-frequency questionnaire (adapted from Bath *et al* [12]) and a demographic questionnaire. Samples were collected from schoolgirls on early morning arrival to school. They were permitted to either provide a sample at home after breakfast and bring it into school for collection or provide one on arrival at school.

Urinary iodine excretion was measured using a multiplate persulphate digestion method followed by Sandel-Kolthoff colorimetry with results expressed as µg/L [16]. One laboratory (Belfast) was used for all sites and was registered with the Ensuring the Quality of Urinary Iodine Procedures (EQUIP) quality assurance programme via the Centre for Disease Control (CDC Atlanta, Georgia, USA). During the analysis of samples for the current study, two rounds of quality assurance were conducted, where unknown samples were received, analysed and data returned to the co-ordinating laboratory. On both occasions, values were within the expected range. Samples were analysed in triplicate and the limit of detection was 10 µg/L. Urinary creatinine was measured using an ILAB 600 Chemistry analyser (Werfen, UK) using the Jaffe rate method [16].

We report results as both the UIC and the iodine-to-creatinine ratio. UIC is the method recommended for population assessment and we compared our median values (overall and by site) to the WHO threshold for adequacy; we also report the percentage of UIC values <50 µg/L, which WHO state should not be more than 20% of samples if the population is iodine-sufficient [3]. As UIC cannot be used as a measure of iodine status in an individual, we also present results as the iodine-to-creatinine ratio (I:creat); this can correct for intra-individual variation in daily urine volume and therefore dilution, which affects the UIC measure.

Tap water at each sample site (i.e. school) was collected in iodine-free containers and kept at -20 °C until analysis was undertaken. Samples were analysed using inductively coupled plasma mass spectrometry (ICP-MS). At each location, semi-skimmed milk was purchased bi-monthly. This type of milk was chosen as it is the most commonly consumed milk, and its iodine concentration has been reported to not differ from skimmed and full-fat milk(23). The brands chosen included: own-brand supermarket milk, branded and organic milk. Milk samples were stored at the collection sites at -20°C and analysed via inductively-coupled plasma mass spectrometry (ICP-MS) (Thermo Scientific Icap Q, Thermo Scientific, US). Results were verified using the certified reference material (CRM) Skimmed Milk Powder ERM-BD151 (European Reference Materials, Belgium).

Statistical analyses

Statistical analyses were conducted using the Statistical Package for the Social Sciences (Version 21.0; SPSS, Inc., Chicago, USA) and significance was set at $p<0.05$. UIC values were not normally distributed and therefore UIC (and all iodine variables) was presented as median (interquartile range) values to allow interpretation against WHO criteria and comparison with other studies. Following logarithmic transformation, residuals followed a normal distribution. One-way ANOVA was used to explore relationships between UIC and food groups from the FFQ, sample site locations and any ethnicity differences. Independent *t*-tests were used to explore potential seasonal variation in UIC and milk iodine concentration between summer (defined as May to October) and winter (defined as November to April) sampling. Independent t-tests were also used to explore the effects of consumption of multi-vitamin/mineral supplements, kelp/seaweed supplements, organic milk, and iodized salt on UIC.

The iodine concentration of milk samples was not normally distributed therefore data were logarithmically transformed to allow for parametric testing. Independent *t* tests were used to test differences between organic and conventional milks; branded and own-brand supermarket milks, and between spring/summer and autumn/winter collections.

Tap-water concentration of iodine was not normally distributed. Distribution was not improved by log transformation, therefore non-parametric tests were used. Spearman's Rank correlation coefficients were used to assess the relationship between tap-water iodine content and median UIC in each sampling location. A Mann-Whitney test was used to explore potential seasonal variations in iodine concentration of tap water samples and a Kruskall-Wallis test was used to explore potential sampling-site differences.

Results

Approaches were made to 222 schools, of which 27 agreed to participate (12%). The average sample return rate on an individual level within a school was 38%. A total of 903 schoolgirls participated in the survey. Of these, 901 provided a spot urine sample and 892 provided FFQ and demographic information.

The median UIC of the study sample was 111 μg/L (IQR 72-165 μg/L) and just 9.2% had UIC below 50 μg/L, therefore classifying the population as iodine-sufficient on the basis of WHO criteria(3). Median UIC differed significantly between centres (*p*<0.001), with the lowest measurements recorded in

Galway (98 µg/L) and highest in Belfast (125 µg/L). Other sites included Derry/Londonderry (119 µg/L), Dublin (105 µg/L), Cork (101 µg/L), Sligo (101 µg/L), Roscommon (105 µg/L). When creatinine-adjusted iodine data were analysed, all medians were below 100 µg/L.

Formal re-sampling was undertaken in the two sites in NI (Belfast and Derry/Londonderry) to allow for investigation of seasonal effects on iodine status. UIC was lower during summer months (*n*=228) than in winter (*n*=197), with a median of 117 µg/L (IQR 76-165) and 130 µg/L (IQR 91-194) respectively (*p* <0.01).

Table 2 shows self-reported consumption of dairy products and eggs. The most commonly consumed type of milk was cows' milk (*n*= 866; 96%). In addition, six participants were consumers of goat's milk, sixteen of milk alternatives (soya, almond or rice milk), and three participants reported that they did not consume milk at all. UIC was associated with type of milk consumed, with those who reported using milk alternatives displaying the lowest UIC (66.4 µg/L) and those who reported using goat's milk displaying the highest UIC (135.7 µg/L) (*p*=0.016). Organic milk was reportedly used by 106 participants (12%); there was no difference in urinary iodine excretion between organic and conventional cows' milk consumers.

Higher intake of milk (*p*<0.001), cream (*p*<0.05) and dairy based desserts (*p*<0.005) were associated with higher median UIC. UIC was not associated with self-reported intake of eggs, cheese, butter or yoghurt nor with self-reported intake of meat, poultry or fish (white, oily or shellfish; data not shown). When creatinine-adjusted iodine data were analysed, only milk intake was significantly associated with iodine: creatinine ratio, with the differences for cream and dairy-based desserts losing statistical significance (Table 2).

Information on supplement use was provided by 888 participants. There was no significant difference in UIC between those who reported using a vitamin or mineral supplement or those who did not, though there was a trend towards higher concentrations in those who reported supplement use (*p*=0.07). Self-reported supplement use was highest in Dublin (32%) and lowest in Roscommon (10%). When only iodine-containing supplements were included, however, UIC was significantly higher in those who reported use of iodine supplements (n=31) or reported using supplements where the level of detail given did not allow determination of whether these contained iodine or not (n=19), than in those who reported using supplements which did not contain iodine (n=132) or who reported not using supplements (n=719; p=0.04)). There was no difference in UIC between those who reported using kelp/seaweed supplements (n=16) or iodised salt (n=27) and those who did not, but the numbers of consumers were very small.

There was no difference in UIC between ethnic groups, although numbers were too small to draw conclusions, with 95% of the population being Caucasian.

Water and milk sample analysis

A total of 190 milk samples were collected from the seven centres. Of these, five were excluded from the final dataset, as milk was either not semi-skimmed (n=4), or where labelling of the sample did not allow milk type to be identified (n=1). Of the remaining 185 milk samples, 22 were organic and 165 were conventional; 52 were own-brand supermarket milk while 135 were branded milk. Milk collected in May and July and September was considered as summer samples (n=92) while those collected in November, January, and March were considered winter samples (n=95).

One-way ANOVA demonstrated that iodine concentration of milk samples differed significantly by sampling site location. Samples collected in Derry/Londonderry had a higher iodine concentration than those collected in Galway (p=0.029) and Roscommon (p=0.016).

The iodine concentration of own-brand supermarket milks did not differ significantly from branded milks. There was no statistically significant difference in geometric mean iodine concentration between organic (148 μg/kg) and conventional milk samples (217 μg/kg), although the number of organic samples collected was small (n=22; p=0.12). There was a statistically significant difference in geometric mean iodine concentration between milk samples collected in summer (geometric mean 134 μg/kg) and winter (318 μg/kg; p<0.001).

In contrast to the milk results, there was no difference between sampling site locations and iodine concentration of tap-water samples (Table 1). There was no correlation between the iodine content of tap-water samples collected and median UIC calculated for each site. For samples collected in NI where seasonal re-sampling was undertaken, no seasonal difference was observed in tap-water iodine concentration between summer (median 1.5 µg/L) and winter months (median 1.4 µg/L). Tap water iodine concentrations were, however, low in all locations and thus tap water was unlikely to have been a major contributor to iodine intakes.

Discussion

This study is the largest of its kind on the island of Ireland and suggests that schoolgirls living here are currently iodine sufficient with a median UIC of 111 µg/L, albeit at the low end of the sufficient range (100-199 µg/L). This is in contrast the UK study of 14-15 year-old schoolgirls in 2011 in the UK where mild iodine deficiency was demonstrated with a median UIC of 80 µg/L [9]. The finding of iodine sufficiency in our study echoes the findings from the UK National Diet and Nutrition Survey and ROI National Adult Nutrition Survey [8,25,26]. In fact the median UIC value in our study was very similar to the UK NDNS data from girls (median UIC 112 µg/L) with a wider age range than our in study (11-18 years) [8] but was higher than the median in 18-35 year old women in NANS (median 103 µg/L) [26].

Six of the seven sites demonstrated sufficiency although all of the ROI sites were very close to the cut-off (100 µg/L) with UIC all ≤105 µg/L. The highest UIC values were seen at the two NI sites. Galway fell just short of the WHO cut-off for sufficiency with a median UIC of 98 µg/L. There was no difference between iodine concentration of tap water in Galway and that in other sites. However the milk collected from Galway and Roscommon was significantly lower in iodine concentration than that from Derry/Londonderry, a site of iodine sufficiency. This finding of variation in milk-iodine concentration by geographical area is in keeping with the results reported by Bath *et al.* who observed regional differences in iodine concentrations of milk samples collected in the UK [15].

The UIC results of the NI cohort within this current study were higher than within the previous NI cohort of the 2011 UK study of schoolgirls (median UIC 120-125 vs 65 µg/L) [10]. There may be a number of reasons for this. Firstly, schoolgirls in the previous UK study were recruited from across NI as opposed to the two city sites in the current study. There is likely to be significant sampling bias in these types of studies. We have found challenges in sampling schoolgirls using the gold standard method of median spot urinary iodine concentration because of reticence about participation among this age group. In the current study only 12% of the schools approached entered and only 38% of schoolgirls returned a sample. Socio-economic data were not collected, and dietary information was self-reported and therefore it is difficult to ascertain the extent of any differences in the girls recruited to each study. Secondly this may reflect the fact that the UK study included a higher proportion of samples in the summer months, when iodine status was lower [10]. Furthermore, the NI cohort in this study had a higher median UIC than 8-10 year-old boys and girls that were part of a multi-centre study of young schoolchildren (median UIC 120-125 vs. 149 μg/L) [9]. This may be as a result of the higher milk intake in younger schoolchildren. It is also possible that publicity from the 2011 study was a factor in inter-study differences.

Seasonal variation in iodine status was found with ~10% lower median UIC during spring/summer months than in winter months, and the seasonal difference may to some extent explain our observation of differences across geographical locations, as there was variation in when the sampling occurred (e.g. Galway was only sampled in October, classified as summer). This is in keeping with other authors who also found lower UIC in summer months [9,10] and was supported by the analysis of milk-iodine content, which was significantly lower in summer than winter. This study did not collect specific details on the production of individual milk samples (seasonal feed-type, housing and soil content) although we have shown that tap water iodine concentration does not appear to change significantly with season.

We found that median UIC was higher in those with higher cows' milk consumption, in keeping with previous studies [9-13]. Higher intakes of dairy-based desserts and cream were also associated with higher median UIC. Milk consumption (45% consumed ≥ 280 mls/day) appeared higher than the national average among 11-18 year-old girls in the UK who reported consuming 110 g of milk/day [24] and may partly explain the higher UIC found in this study than in the comparable UK study of teenage schoolgirls [10].

There was no significant difference in median UIC between those who reported consuming conventional milk and those who consumed organic milk, in support of findings in the UK study of 8-10 year-old children [25]. Furthermore, we found that organic milk was lower in iodine concentration than conventional milk but that the difference was not statistically significant (p=0.12), although the number of organic-milk samples available for analysis was small (*n*=22). This is in contrast to previous UK studies that have found that the iodine concentration of organic milk was 36 - 44% lower iodine than conventional milk [15-17].

Those who reported using milk alternatives (e.g. soya) displayed the lowest UIC (66 µg/L) and those who reported using goats' milk displayed the highest UIC (136 µg/L), although numbers were very small and we have no data on the iodine content of the reported soya and goats' milk. Recent research conducted in the UK has suggested that most milk-alternative drinks are not fortified with iodine and are therefore a poor source of iodine [26], while data from the UK Food Standards Agency shows that goats' milk has a higher iodine concentration than cow's milk [29].

Iodised salt use was low (3%) in the current study, as expected, and reflects the lack of salt-iodisation programme in NI and the ROI [6,29,34]. Previous research has either not recorded supplement use or excluded individuals who were currently using iodine containing supplements. Approximately 20% of participants in the current study reported general dietary supplement use, but only 3% reported using supplements which definitely contained iodine. Median UIC was significantly higher in those reporting iodine supplement use.

We reported results using both UIC and with creatinine adjustment (iodine-to-creatinine ratio). However, when relating food intake to iodine status, the creatinine-adjusted results were not consistent with the UIC data. For example, dairy-based desserts were not significantly related to the iodine-to-creatinine ratio, though the relationship with milk was the same as for UIC, in that the iodine-to-creatinine ratio was increased with reported milk intake. Furthermore, the median iodine-to-creatinine ratio, both overall and by site, was below 100 µg/g, which is suggestive of deficiency and is in contrast to the conclusion based on the UIC data. Although the WHO do not recommend creatinine-adjustment in general, the same cut-off for sufficiency would be applied on the basis that both methods (UIC and iodine-to-creatinine) should relate to 24-hr iodine excretion; this is only true if the children excrete 1 litre of urine and 1 gram of creatinine. While creatinine-adjustment in adults may give a closer estimate of 24-hour iodine excretion than concentration alone [31,32], this may not be true in children [9]. Creatinine excretion is affected by muscle mass and research has shown that adjustment of creatinine according to body weight or height is required for children <18 years [33].

Strengths of the current study include the large sample size and the use of similar methodology to the previous UK survey of teenage schoolgirls [10]. This allowed direct comparison, as well as overlap for the Northern Ireland centres, where the lowest levels of iodine excretion were seen in the original UK survey. Furthermore, we included resampling in two centres to allow the effects of seasonal variation to be explored. By including direct measurement of water and milk concentrations within the study centres, we provide novel data that relates environmental exposure to local iodine status. Limitations of our study include the collection of limited demographic data from study participants (e.g. weight and height which may have improved the use of creatinine-adjusted data). In some study centres the sample size was small, and below the 30 recommended participants per site for estimation of population iodine status, according to WHO guidelines [3]. We used an iodine-specific food frequency questionnaire to estimate food intake rather than more robust diary methods, as this was considered to be too onerous for schoolgirl participants and schools. However, as food frequency questionnaires tend to reflect dietary intake over the long term, and spot-urine iodine results reflect iodine status in the short term, the ability to relate dietary intake to status may have been limited, particularly for food items such as fish, which are consumed episodically.

Overall the results suggest that this population of schoolgirls on the island of Ireland sit at the low end of sufficiency, with no protection afforded from an iodine-fortification programme. During pregnancy in particular, when requirements rise considerably, our population may be vulnerable to seasonal, environmental and husbandry shifts.

Conflict of Interest:

On behalf of all authors, the corresponding author states that there is no conflict of interest.

Ethical standards statement:

All human studies have been approved by the appropriate ethics committee and have therefore been performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and its later amendments.

Declaration:

All authors declare that the submitted work has not been published before (neither in English nor in any other language) and that the work is not under consideration for publication elsewhere.

References

1. Pearce EN, Lazarus JH, Moreno-Reyes R *et al.* (2016) Consequences of iodine deficiency and excess in pregnant women: an overview of current knowns and unknowns. *Am J Clin Nutr*. 2016;104 Suppl 3:918S-23S

2. Bath SC, Steer CD, Golding J *et al.* (2013) Effect of inadequate iodine status in UK pregnant women on cognitive outcomes in their children: results from the Avon Longitudinal Study of Parents and Children (ALSPAC). *Lancet* **382**, 331-337.
3. WHO, UNICEF & ICCIDD (2007) *Assessment of iodine deficiency disorders and monitoring their elimination.* Geneva: WHO.
4. Iodine Global Network (2017) Global scorecard of iodine nutrition in 2017 in the general population and in pregnant women. Available at: http://www.ign.org/cm_data/IGN_Global_Scorecard_AllPop_and_PW_May2017.pdf (Accesed 14 August 2018).
5. Bath SC (2017) The challenges of harmonising the iodine supply across Europe. *Lancet Diabetes Endocrinol* **5**, 411-412.
6. Bath SC, Button S & Rayman MP (2014) Availability of iodised table salt in the UK – is it likely to influence population iodine intake? *Public Health Nutr* **17**, 450-454.
7. Phillips DI (1997) Iodine, milk, and the elimination of endemic goitre in Britain: the story of an accidental public health triumph. *J Epidemiol Community Health* **51**, 391-393.
8. Public Health England (2018) National Diet and Nutrition Survey Results from Years 7 and 8 (combined) of the Rolling Programme (2014/2015 to 2015/2016). A survey carried out on behalf of Public Health England and the Food Standards Agency. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/699241/NDNS_results_years_7_and_8.pdf (accessed 6 July 2018).
9. Bath SC, Combet E, Scully P *et al.* (2016) A multi-centre pilot study of iodine status in UK schoolchildren, aged 8-10 years. *Eur J Nutr* **55**, 2001-2009.
10. Vanderpump MP, Lazarus JH, Smyth PP *et al.* (2011) Iodine status of UK schoolgirls: a cross-sectional survey. *Lancet* **377**, 2007-2012.
11. Bath SC, Sleeth ML, McKenna M *et al.* (2014) Iodine intake and status of UK women of childbearing age recruited at the University of Surrey in the winter. *Br J Nutr* **112**, 1715-1723.
12. Bath SC, Furmidge-Owen VL, Redman CW *et al.* (2015) Gestational changes in iodine status in a cohort study of pregnant women from the United Kingdom: season as an effect modifier. *Am J Clin Nutr* **101**, 1180-1187.
13. Bath SC, Walter A, Taylor A *et al.* (2014) Iodine deficiency in pregnant women living in the South East of the UK: the influence of diet and nutritional supplements on iodine status. *Br J Nutr* **111**, 1622-1631.
14. Bath SC & Rayman MP (2016) Trace element concentration in organic and conventional milk – what are the nutritional implications of the recently-reported differences? *Br J Nutr* **E-pub 6 May 16;**, doi:10.1017/S0007114516001616.
15. Bath SC, Button S & Rayman MP (2012) Iodine concentration of organic and conventional milk: implications for iodine intake. *Br J Nutr* **107**, 935-940.
16. Stevenson MC, Drake C & Givens DI (2018) Further studies on the iodine concentration of conventional, organic and UHT semi-skimmed milk at retail in the UK. *Food Chem* **239**, 551-555.
17. Payling LM, Juniper DT, Drake C *et al.* (2015) Effect of milk type and processing on iodine concentration of organic and conventional winter milk at retail: implications for nutrition. *Food Chem* **178**, 327-330.
18. Bath SC & Rayman MP (2013) Iodine deficiency in the UK: an overlooked cause of impaired neurodevelopment? *Proc Nutr Soc* **72**, 226-235.

19. Knight BA, Shields BM, He X *et al.* (2016) Iodine deficiency amongst pregnant women in South-West England. *Clin Endocrinol (Oxf)* **86**, 451-455.
20. Pearce EN, Lazarus JH, Smyth PP *et al.* (2010) Perchlorate and thiocyanate exposure and thyroid function in first-trimester pregnant women. *J Clin Endocrinol Metab* **95**, 3207-3215.
21. Barnett C, Visser T, Williams F *et al.* (2002) Inadequate iodine intake of 40% of pregnant women from a region in Scotland. *J Endocrinol. Invest.* **25**, (Supp. No. 7) 90.
22. Nawoor Z, Burns R, Smith DF, Sheehan S, O'Herlihy C & Smyth PP. Iodine intake in pregnancy in Ireland—a cause for concern? Ir J Med Sci 2006 175:21–24
23. Smyth PP, Hetherton AM, Smith DF, Radcliff M, O'Herlihy C. Maternal iodine status and thyroid volume during pregnancy: correlation with neonatal iodine intake. J Clin Endocrinol Metab. 1997 Sep;82(9):2840-3

24. McNulty BA, Nugent AP, Walton J *et al.* (2017) Iodine intakes and status in Irish adults: is there cause for concern? *Br J Nutr* **117**, 422-431.

25. Ministry of Agriculture Fisheries and Food (MAFF) (2000) MAFF Iodine In Milk Food Survey Information Sheet Number 198. Available at: http://archive.food.gov.uk/maff/archive/food/infsheet/2000/no198/198milk.htm (accessed 12 October 2010).
26. Public Health England (2014) National Diet and Nutrition Survey, Results from Years 1-4 of the Rolling Programme., [B Bates, A Lennox, A Prentice, C Bates, P Page, SK Nicholson and G Swan, editors]. Available at: www.gov.uk/government/uploads/system/uploads/attachment_data/file/310995/NDNS_Y1_to_4_UK_report.pdf: Public Health England, London.
27. van den Briel T, West CE, Hautvast JG *et al.* (2001) Mild iodine deficiency is associated with elevated hearing thresholds in children in Benin. *Eur J Clin Nutr* **55**, 763-768.
28. Bath SC, Hill S, Infante HG *et al.* (2017) Iodine concentration of milk-alternative drinks available in the UK in comparison with cows' milk. *Br J Nutr* **118**, 525-532.
29. Food Standards Agency (2008) Retail Survey of Iodine in UK produced dairy foods. FSIS 02/08. Available at: http://tna.europarchive.org/20140306205048/http://www.food.gov.uk/science/research/surveillance/fsisbranch2008/fsis0208 (Accessed: 29 April 2015).
30. Lazarus JH & Smyth PP (2008) Iodine deficiency in the UK and Ireland. *Lancet* **372**, 888.
31. Konig F, Andersson M, Hotz K *et al.* (2011) Ten repeat collections for urinary iodine from spot samples or 24-hour samples are needed to reliably estimate individual iodine status in women. *J Nutr* **141**, 2049-2054.
32. Knudsen N, Christiansen E, Brandt-Christensen M *et al.* (2000) Age- and sex-adjusted iodine/creatinine ratio. A new standard in epidemiological surveys? Evaluation of three different estimates of iodine excretion based on casual urine samples and comparison to 24 h values. *Eur J Clin Nutr* **54**, 361-363.
33. Remer T, Neubert A & Maser-Gluth C (2002) Anthropometry-based reference values for 24-h urinary creatinine excretion during growth and their use in endocrine and nutritional research. *Am J Clin Nutr* **75**, 561-569.

34. Smyth P, Burns R, Casey M, Mullan K, O'Herlihy C, O'Dowd C (2016) .Iodine Status over 2 decades: Influence of Seaweed Exposure. *Ir Med J*,**109**(6):421.

Figure 1 **Map of sites**

Table 1 Urinary iodine concentration (UIC) in Irish schoolgirls, alongside iodine content of tap water and milk collected within each sampling location

Location	***n***	**Median UIC (25th,75th percentile) (µg/L)**	**Median I:Creat ratio (25th,75th percentile) (µg/g)**	**Median iodine content tap water (25th,75th percentile) (µg/l)**	**Median iodine content milk (25th,75th percentile) (µg/kg)**
Belfast	294 (48% summer)	125 (85,179)	89 (64,139)	2.95 (0.90,3.41)	260 (218,328)
Londonderry/Derry	131 (58% summer)	120 (81,172)	84 (60,121)	0.80 (0.48,2.14)	371 (290,421)
Dublin	97 (57% summer)	105 (64,178)	87 (55,157)	0.59 (0.36,0.59)	195 (134,471)
Cork	146 (29% summer)	101 (70,168)	86 (57,129)	1.80 (0.35,1.90)	152 (111,399)
Sligo	109 (76% summer)	101 (59,140)	77 (45,132)	2.56 (0.32,2.56)	214 (131,400)
Roscommon	52 (98% summer)	105 (64,150)	89 (56,135)	1.91 (1.90,2.15)	143 (95,343)
Galway	72 (100% summer)	98 (64,134)	77 (50,97)	0.50	133 (78,335)

Table 2 Urinary iodine concentration according to intake of dairy products and eggs

	Number of participants	Median UIC (25th,75th percentile) (µg/L)	*p* value*	Median I:Creat ratio (25th,75th percentile) (µg/g)	*p* value*
Cows' Milk consumed per day (*n*=864)					
None	50 (6%)	90 (63,116)^{a}		50 (37,76)^{a}	
140 ml	197 (23%)	92 (63-124)^{a}		69 (47,93)^{b}	
140-279 ml	230 (27%)	115 (73-158)^{b}		83 (57,123)^{b,c}	
280-242 ml	166 (19%)	120 (89-165)^{b}		98 (66,142)^{c,d}	
425-570 ml	110 (13%)	139 (81-204)^{b,c}		113 (72,164)^{d,e}	
More than 570 ml	111 (13%)	145 (103-243)^{d}		117 (73,189)^{e,f}	
			<0.001		<0.001
Cream (*n*=885)					
Never/less than once a month	571(65%)	108 (69-162)^{a,b}		86 (56,135)	
Once in two weeks	229 (26%)	115 (81 -166)^{b}		84 (59,122)	
≥Once a week	85 (10%)	122 (93-196)^{b,c}		84 (61,132)	
			0.027		0.85
Dairy desserts (*n*=891)					
Never/less than once a month	485(54%)	104 (68-152)^{a}		83 (56,130)	
Once in two weeks	235 (26%)	117 (75-172)^{b}		90 (59,139)	
≥Once a week	171 (19%)	128 (86-172)^{b}		84 (59,130)	
			0.004		0.19
Cheese (*n*=888)					
Never/less than once a month	159 (18%)	105 (68-155)		72 (52,124)	
Once in two weeks	107 (12%)	108 (70-153)		85 (61,132)	
≥Once a week	622 (70%)	114 (75-168)		86 (58,134)	
			0.16		0.19
Eggs (*n*=890)					
None	242 (27%)	105 (68-157)		82 (54,133)	

One per week	245 (27%)	126 (90-178)		91 (65,141)	
Two per week	213 (24%)	106 (70-159)		86 (57,124)	
Three per week	101 (11%)	106 (67-157)		84 (56,134)	
Four or more per week	89 (10%)	115 (69-150)		75 (58,107)	
			0.14		0.17
Yoghurt					
***Low fat* (*n*=887)**					
Never/less than once a month	443 (49%)	106 (72-166)		84 (55,133)	
Once in two weeks	133 (15%)	113 (62-154)		89 (58,134)	
≥Once a week	311 (34%)	119 (77-167)		85 (60,130)	
			0.21		0.82
***Full fat or greek* (*n*=884)**					
Never/less than once a month	520 (58%)	109 (72-164)		84 (56,135)	
Once in two weeks	144 (16%)	115 (72-150)		85 (56,123)	
≥Once a week	220 (24%)	119 (70-170)		85 (62,130)	
			0.76		0.97

*One-way ANOVA, different letters represent statistically significant differences in UIC for each FFQ category.