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Food sources of iodine in schoolchildren and relationship with 24-h urinary iodine excretion in Victoria, Australia

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Abstract

Dietary recalls have been used previously to identify food sources of iodine in Australian schoolchildren. Dietary assessment can provide information on the relative contributions of individual food groups which can be related to a robust objective measure of daily intake (24-h urinary iodine excretion (UIE)). In Australia, the government has mandated the use of iodised salt in breadmaking to address iodine deficiency. The aim of this study was to determine the dietary intake and food sources of iodine to assess their contribution to iodine excretion (UIE) in a sample of Australian schoolchildren. In 2011–2013, UIE was assessed using a single 24-h urine sample and dietary intake was assessed using one 24-h dietary recall in a convenience sample of primary schoolchildren from schools in Victoria, Australia. Of the 454 children with a valid recall and urine sample, 55 % were male (average age 10·1 (1·3 (SD) years). Mean UIE and dietary iodine intake were 108 (SD 54) and 172 (SD 74) μg/d, respectively. Dietary assessment indicated that bread and milk were the main food sources of iodine, contributing 27 and 25 %, respectively, to dietary iodine. Milk but not bread intake was positively associated with UIE. Multiple regression (adjusted for school cluster, age and sex) indicated that for every 100 g increase in milk consumption, there was a 3 μg/d increase in UIE ($\beta = 4{\cdot}0$ (SE 0·9), $P < 0{\cdot}001$). In conclusion, both bread and milk were important contributors to dietary iodine intake; however, consumption of bread was not associated with daily iodine excretion in this group of Australian schoolchildren.

Key words: **Iodine: Fortification: Food: Dietary: Sodium: Schoolchildren: Australia**

Iodine is a trace element found in low concentrations in soil, air and the sea[1–3] and is an important component of thyroid hormones, essential for normal growth, metabolism and maturation of the whole body[1–4]. The Australian population was believed to be iodine sufficient from the 1920s[5]. The most abundant food source of iodine was milk, both through naturally occurring iodine and the contamination of milk by iodophor-containing sanitisers used during milk processing[6–9]. Following the discovery of excessive thyroid hormone concentrations in a proportion of the population in the 1970s[10,11], the use of these sanitisers began to decline over the next few decades, resulting in a drop in iodine content in milk and dairy foods[5,12,13]. The re-emergence of iodine deficiency in Australia was first observed in 1999 by Gunton and colleagues in a proportion of the Sydney population[13]. Following this, a number of studies documented iodine deficiency in Australian schoolchildren over the next decade[14–18]. Following the success of voluntary fortification of bread with iodised salt in Tasmania[19], mandatory fortification of all commercially produced bread in Australia (excluding organic varieties) with iodised salt was implemented in 2009[20]. Studies conducted post-fortification with the use of iodised salt in bread have observed an improvement in iodine status[21–27].

Utilising dietary information obtained from a single 24-h recall, the 2011–2013 Australian Health Survey (AHS) reported that bread contributed 27 % and 24 % of iodine intake in 4–8- and 9–13-year-olds, respectively[28]. Milk was also found to make a comparable significant contribution to iodine intake, contributing 28 % and 26 % in 4–8- and 9–13-year-olds, respectively[28]. Furthermore, a recent analysis of the AHS data found that consumption of ≥100 g (about 3 slices per d) of bread per d was associated with 12 times greater odds of achieving adequate dietary iodine intakes above the age-specific EAR, amongst 2–18-year-olds[23]. The AHS was based purely on dietary intake derived from one 24-h dietary recall; however, 24-h urine samples have an advantage in that they are able to provide an objective measure of iodine intakes as approximately 90 % of dietary iodine is excreted in the urine[29,30].

Abbreviations: AHS, Australian Health Survey; UIE, urinary iodine excretion.

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To date, no studies have examined the association between food sources of iodine and urinary excretion of iodine over a 24-h period in children. Understanding the contribution of key food sources of iodine to urinary iodine excretion (UIE) is important when assessing the success of fortification strategies, as well determining how food choices may influence iodine intake in the Australian population. Therefore, the aims of the following study were to: (i) determine the dietary intake and food sources of iodine in a sample of Victorian schoolchildren and (ii) assess the relationship between dietary intake of iodine and the major food sources of iodine, including bread and milk, and urinary excretion of iodine over a 24-h period.

Methods

Study design and participants

The data for this study were taken from the Salt and Other Nutrient Intake in Children study, a cross-sectional study conducted in a convenience sample of Victorian primary schools from June 2010 to May 2013. The main outcomes of the Salt and Other Nutrient Intake in Children study[31] and findings related to iodine intakes[26] have been previously published.

A convenience sample of fifty-six schools from across Victoria, Australia agreed to participate in the study, and consent was obtained from 852 children (overall response rate for all children in Victoria = 6 %). Forty-one children withdrew from the study, and a further thirty-one participants were excluded as they were unable to attend an off-school campus data collection day at Deakin University (*n* 25) or were aged > 13 years (*n* 6), leaving a final sample of 780 participants. The child's primary caregiver was asked to complete a demographic questionnaire, which collected information about the child's date of birth, sex and other health information. Socio-Economic Indexes for Areas, Index of Relative Socio-Economic Disadvantage[32] was used to group participating schools, based on school postcode, into tertiles of socio-economic disadvantage. This marker was used to define socio-economic status, whereby the participant was grouped as either low, mid or high socio-economic status with reference to the tertile that the school they attended fell within. Height and weight were measured by trained research staff following standard protocols[33]. BMI values were converted to age- and sex-adjusted BMI *z*-scores using the 2000 US Centers for Disease Control and Prevention growth charts[34,35]. Participants were grouped into weight categories (underweight, healthy weight, overweight and obese) using the International Obesity Taskforce BMI reference cut-offs for children[36,37].

Twenty-four-hour dietary recall protocol

A single face-to-face 24-h dietary recall was completed by a trained research assistant at the school site[33]. Following the procedure used in the 2007 Australian Children's Nutrition and Physical Activity Survey, a three-pass method was used[38]. Children aged 8 years and older are recognised as having the cognitive ability required to recall their own food and beverage intake[39]. Thus, only recalls from children aged 8 years and older (*n* 552) were evaluated in the present analysis.

The completed 24-h dietary recalls were entered into the nutrient analysis software *FoodWorks* (version 8; Xyris), which is linked to the AUSNUT 2011–2013 nutrient database[40], to determine total energy (kJ/d) and iodine (μg/d) intakes. Each food and beverage item recorded was matched to an eight-digit food code, which corresponded to a set of nutrient data. Each eight-digit food code was derived from a five-digit food code that represented 'minor' food categories. Each minor food category falls under a three-digit sub-major food category, which then falls within a two-digit major food category. A detailed list of the food group classification system can be found in the AHS user guide[40]. This food group coding system was used to calculate the contribution of iodine from major, sub-major and minor food groups, using the population proportion method[41].

The paediatric-adjusted Goldberg cut-off method[42] was used to identify participants with implausible energy intakes. This method compares the participant's ratio of reported energy intake:estimated BMR with the Goldberg cut-off value. Age- and sex-specific Goldberg cut-off values were determined using the original adult Goldberg equation[42]. On this basis, participants (*n* 32, 5·8 %) with an EI:estimated BMR ratio <0·87 for 8–12-year-old males and 0·84 for 8–12-year-old females were classified as a low energy reporter and excluded. Thus, a total of 520 valid 24-h recalls were included in the final dietary analyses.

Twenty-four-hour urine collection protocol

Children could elect to complete the urine collection on either a school day or any convenient non-school day (i.e. weekends, public holiday or school holiday)[33]. Both the parent and child were carefully instructed on the correct collection protocol and provided with written instructions. The start and finish time, along with any missed collections and/or spillages, were recorded on a urine collection slip by the child's primary caregiver, which was returned with the completed urine sample. Validity of the urine samples was assessed using four criteria: (i) collection time <20 or >28 h, (ii) total volume was < 300ml, (iii) the participant reported missing > 1 collection or (iv) urinary creatinine excretion was < 0·1 mmol/kg body weight per d[43]. If the duration of the collection was not exactly 24 h but within 20–28 h, urinary electrolytes, creatinine and total volume were standardised to a 24-h period (i.e. (24 h/urine duration (h)) × urinary measure). Of the 520 participants who completed a valid 24-h dietary recall, 454 (90 %) participants also had a valid 24-h urine specimen available for iodine excretion analysis. Data for these 454 participants have been reported in the present analysis.

Logistically, it was not possible to concurrently collect 24-h dietary recalls alongside the 24-h urine collection. Instead, 24-h recalls were collected with children on the day of testing procedures completed at the school site, and students could elect to perform their 24-h urine collection on a suitable day, preferably within 2 weeks of the dietary recall.

Urinalysis

The method for determining urinary Na has been described previously[33]. Urinary iodine concentration (μg/l) was determined using a modification of the method of Pino *et al.*[26,44]. The internal standard used was a pooled urine sample (mean (SD) iodine

concentration 84·1 (SD 3·8) μg/l) which gave a CV of 4·5 % (*n* 54). Seronorm (Seronorm Trace Elements Urine, Sero As, Stasjonsveien) was used as an external standard, giving a mean (SD) iodine concentration of 131·2 (SD 1·3) μg/l (expected range 131–150 μg/l) and a CV of 1·01 % (*n* 54). UIE (μg/24-h) was calculated using the following equation[45,46]:

$$\text{UIE } (\mu g/24\text{ h}) = \frac{\text{Urinary iodine concentration } (\mu g/\text{L}) \times \text{24-h urine volume } (\text{L}/24\text{h})}{0 \cdot 92}$$

Statistical analysis

Analyses were completed with STATA/se 14.0 software (StataCorp LP), and a *P-value* <0·05 was considered statistically significant, except for the secondary analysis where the data were split into three categories. Descriptive statistics (mean values and standard deviations or proportions and numbers) were used to describe participant characteristics, stratified by sex. Normality of continuous variables was assessed and confirmed using box plots, histograms and the Shapiro–Wilk test. Differences in the proportion of participants by sex across socio-demographic characteristics were determined using χ^2 tests. Multiple linear regression, which allows for the adjustment for clustering of students within schools, was used to examine the differences in energy intake, dietary iodine intake and UIE between sex. Pearson's correlation and multiple linear regression were used to assess the association between the two methods of estimating iodine intake (dietary assessment *v.* urinary excretion). Previous analyses in this sample determined that salt intakes were significantly higher on non-school days compared with school days[31]. Therefore, we examined the differences in iodine intakes and food sources between school days and non-school days using multiple linear regression (age, sex, energy intake and school clustering). The unstandardised beta-coefficient (β) and standard error have been presented for all regression analyses.

Contribution of food groups to total iodine intake was assessed using multiple linear regression and expressed as mean (SE)% with clustered robust standard errors used to account for the clustering of students within schools. A 'consumer' was defined as any participant who consumed > 0 g of the specified food on the day of the recall. Pearson's correlation and multiple regression analysis (adjusted for age, sex, energy intake and school cluster) were used to assess the relationship between intake of food sources of iodine > 1 % (g/d) and UIE.

As the primary vehicle for iodine fortification in Australia is iodised salt added to bread[20], we further examined the relationship between known iodine-fortified bread products and UIE specifically. For the purpose of these analyses, 'Bread' (g/d) includes all food items eaten within the 3-digit food group '122: Regular breads, and bread rolls (plain/unfilled/untopped varieties)' and '123: English-style muffins, flat breads, and savoury and sweet breads' food groups, excluding any home-made and organic varieties in accordance with the foods which are required to have iodised salt added to them under the 2009 mandatory fortification legislation[20]. This definition does not include bread which may have been consumed as a commercially produced sandwich/hamburger which would fall within the '135: Mixed dishes where cereal is the main ingredient category' and would encompass the contribution of iodine from all components of the dish, as opposed to the bread alone. In addition, as recent analyses of the AHS revealed that milk is still a major contributor to iodine intakes[23], we also examined the relationship between milk intake and UIE. 'Milk' (g/d) includes all items consumed within the three-digit sub-major food group '191: Dairy milk (cow, sheep and goat)'[40]. The association between consumption of > 100 g bread or milk per d and UIE was assessed using multiple linear regression, adjusted for age, sex, energy intake and school cluster.

To further examine the relationship between bread and/or milk consumption and UIE, multiple linear regression, adjusted for age, sex, energy intake and school clustering, was used to compare differences in UIE and iodine intake as assessed by 24-h recall between consumers and non-consumers of bread or milk. A second analysis whereby consumers were further broken down into consumers of neither (i.e. consumed neither bread nor milk on the day of the survey), either (i.e. reported consuming either bread or milk on the day of the recall) or both (i.e. consumed both bread and milk on the day of the recall). In this model which included multiple comparisons between the different consumption groups, non-consumers (i.e. did not report consuming both bread and milk on the day of the recall) were used as the reference group and the Bonferroni correction for *P*-values was used.

Results

Descriptive characteristics of participants

Of the 454 participants who provided valid urinary and dietary data, 55 % were male with an average age of 10 years (Table 1). Most (81 %) participants completed the 24-h recall on a school day, whereas just under half (49 %) completed the 24-h urine collection on a school day. The number of days between dietary recall and urine collection ranged between 0 and 10 (median 8) d: 49 % of participants (*n* 224) completed the urine and dietary recall on the same type of day (i.e. school day/non-school day), with a further 84 % (*n* 380) completing dietary assessment and urine collections within a week of each other. Of this, 3 % (*n* 12) completed the two components on the same day, 40 % (*n* 63) within 2 d of one another, 47 % (*n* 214) within 1 week, 7 % (*n* 33) within a 2-week period and 3 % (*n* 14) collected within a 6-week period[33]. Mean energy intake was 8561(SD 2660) kJ/d, with males having a significantly higher energy intake than females (Table 1).

Iodine intakes

Mean UIE and dietary iodine were 108 (SD 54) μg/24-h and 172 (SD 74) μg/d, respectively (Table 1). Males had significantly higher intakes of dietary iodine and UIE (both $P < 0{\cdot}001$, Table 1). Whilst UIE was 10 % higher on non-school days compared with school days (Table 1), there was no difference in

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Table 1. Descriptive characteristics of participants
(Mean values and standard deviation; numbers and percentages)

	All				Boys				Girls			
	n	%	Mean	SD	*n*	%	Mean	SD	*n*	%	Mean	SD
Number of participants	454	100			249	55			205	45		
Age (years)			10·1	1·25			10·3	1·3			9·9	1·2
SES												
Lowest tertile	82	18			36	14			46	22		
Mid tertile	88	19			42	17			46	22		
High tertile	284	63			171	69*			113	56		
BMI category												
Underweight	33	7			14	6			19	9		
Healthy	330	73			191	77			139	68		
Overweight	76	17			36	14			40	20		
Obese	15	3			8	3			7	3		
Day type of recall												
School day	369	81			206	83			163	80		
Non-school day	58	19			43	17			42	20		
Energy intake (kJ/d)			8561	49			8897	62†			8152	63
Iodine intake (μg/d)			172	2			183	64†			159	65
School day (μg/d)			172	66			182	67†			160	68
Non-school day (μg/d)			169	69			185	70†			154	71
Day type of urine												
School day	221	49			124	50			97	47		
Non-school day	233	51			125	50			108	53		
UIE (μg/24-h)			108	1			118	59†			95	50
School day (μg/24-h)			102	53‡			111	55†,‡			90‡	47
Non-school day (μg/24-h)			113	59‡			125	72†,‡			100	51‡

SES, socio-economic status; UIE: Urinary Iodine Excretion.
* χ^2 *P*-value < 0·01.
† Multiple regression adjusted for age and school cluster $P < 0·05$ for difference between sex.
‡ Multiple regression adjusted for age, sex and school cluster $P < 0·05$ for difference between school day and non-school day.

dietary iodine intake assessed by 24-h dietary recall between the different day types.

There was a significant, weak, positive relationship between dietary iodine and UIE ($r = 0·233$, $P < 0·001$). Regression analysis revealed that a 10 μg/d increase in dietary iodine was associated with a 1·7μg/24 h increase in UIE ($R^2 = 0·054$, $\beta = 1·7$ (SE 0·3), $P < 0·001$). In participants who completed the recall and urine components on the same day, a 10 μg/d increase in dietary iodine was associated with a 3·2 μg/24-h increase in UIE ($R^2 = 0·186$, $\beta = 3·2$ (SE 0·07), $P < 0·001$).

Food sources of iodine

Mean iodine concentration of bread and milk was 58·1 (SD 15·2) and 22·1 (SD 3·9) μg/100 g, respectively. Table 2 presents the food groups which contributed ≥1 % of total dietary iodine. The two major sources of dietary iodine were 'Cereals and cereal products' (35 %) and 'milk products and dishes' (35 %). Ninety-eight percentage of participants (*n* 445) reported consuming a food from the 'cereals and cereal products' major food category on the day of the recall and 89 % (*n* 402) consumed an item from the 'milk products and dishes' major food category. 'Regular breads and bread rolls' contributed 27 % of total dietary iodine intake, with 78 % of participants consuming an item from this category (Table 2). Similarly, 'Dairy milk (cow sheep and goat)' contributed 25 % of total dietary iodine, with 69 % of participants consuming dairy milk on the day of the recall. When intake of iodine-fortified bread products (i.e. based on the previously defined 'bread' definition) was examined, bread contributed 31 % of total dietary iodine intake. Whilst consumption of bread was significantly higher on school days compared with non-school days (93·3 (SEM 5·4) g/d *v.* 70·0 (SEM 7·5) g/d, $P = 0·02$), there was no difference in milk intake between school days and non-school days (196·3 (SEM 11·8) g/d *v.* 171·4 (SEM 14·7) g/d, $P = 0·2$).

Relationship between food sources of iodine and urinary iodine excretion

The total amount of bread consumed (g/d) was not associated with UIE ($R^2 = 0·08$, $\beta = 0·05$ (SE 0·04), $P = 0·25$) (Fig. 1). There was, however, a significant association between the amount of milk consumed (g/d) and UIE, which accounted for 9 % of the variance ($R^2 = 0·09$ $\beta = 0·032$ (SE 0·10), $P = 0·003$). Fig. 2 presents a significant, weak correlation between the amount of milk consumed (g/d) and UIE ($r = 0·15$, $P = 0·001$ (Fig. 2)). Thirty-seven percentage of participants consumed >100 g bread/d; however, consumption of >100 g was not significantly associated with UIE ($R^2 = 0·08$, $\beta = 7·32$ (SE 6·4), $P = 0·26$). Comparatively, 62 % of participants reported consuming >100 g milk/d, and regression analyses indicated that consumption of >100 g milk/d was associated with a 10·8 μg/d increase in UIE after adjustment for age, sex, energy intake and school cluster ($R^2 = 0·09$, $\beta = 10·77$ (SE 4·6), $P = 0·02$).

The combined weight of bread and milk (g/d) consumed was also associated with UIE, accounting for 9 % of the variance in intakes ($R^2 = 0·09$, $\beta = 0·035$ (SE 0·01), $P < 0·001$). Additionally, there was a significant, moderate positive correlation between

Table 2. Food sources of iodine in Victorian schoolchildren > 8 year-old (*n* 454)

Food group name[42]	Proportion consuming (%)	% Contribution
Non-alcoholic beverages (total %)	94	5·5
Fruit and vegetable juices, and drinks	37	1·4
Fruit juices, commercially prepared	32	1·2
Waters, municipal and bottled, unflavoured	77	1·9
Domestic water (including tap, tank/rain water)	77	1·9
Cereals and cereal products (total %)	98	35·4
Regular breads, and bread rolls (plain/unfilled/untopped varieties)	78	26·7
Breads, and bread rolls, white, mandatorily fortified	18	5·8
Breads, and bread rolls, white, not stated as to fortification	35	9·1
Breads, and bread rolls, mixed grain, mandatorily fortified	5	1·2
Breads, and bread rolls, mixed grain, not stated as to fortification	8	2·2
Breads, and bread rolls, wholemeal and brown, mandatorily fortified	8	2·5
Breads, and bread rolls, wholemeal, not stated as to fortification	11	3·7
English-style muffins, flat breads, and savoury and sweet breads	21	5·0
Flat breads (e.g. Pita bread), wheat based	6	1·3
Savoury filled or topped breads and bread rolls	5	1·2
Breakfast cereals, hot porridge style	7	1·7
Porridge style, oat-based	7	1·7
Cereal-based products and dishes (total %)	86	11·7
Cakes, muffins, scones, cake-type desserts	28	2·7
Mixed dishes where cereal is the major ingredient	31	6·5
Pizza, saturated fat ≤ 5 g/100 g	7	1·7
Savoury pasta/noodle and sauce dishes, saturated fat ≤ 5 g/100 g	9	1·1
Fish and seafood products and dishes (total %)	14	2·2
Fish and seafood products (home-made and takeaway)	4	1·0
Egg products and dishes (total %)	9	2·0
Eggs	7	1·3
Eggs, chicken	7	1·3
Meat, poultry and game products and dishes (total %)	75	2·5
Mixed dishes where poultry or feathered game is the major component	11	1·1
Milk products and dishes (total %)	89	35·3
Dairy milk (cow, sheep and goat)	69	24·9
Milk, cow, fluid, regular whole, full fat	32	11·9
Milk, cow, fluid, reduced fat, <2 g/100 g	21	7·6
Milk, fluid, unspecified	14	4·0
Yogurt	15	2·6
Yogurt, flavoured or added fruit, full fat	9	1·7
Cheese	40	2·0
Cheese, hard cheese ripened styles	29	1·6
Frozen milk products	22	2·9
Ice cream, tub varieties, fat content > 10 g/100 g	13	1·9
Flavoured milks and milkshakes	6	2·0
Milk, coffee/chocolate flavoured and milk-based drinks, full fat	4	1·5
Vegetable products and dishes (total %)	69	1·7
Other*	–	3·7

* Other includes foods contributing <1 % iodine – fats and oils; fruit products and dishes; dairy & meat substitutes; soup; seed and nut products and dishes; savoury sauces and condiments; legume and pulse products and dishes; snack foods; sugar products and dishes; alcoholic beverages; special dietary foods; miscellaneous; and infant formulae and foods.

the two ($r = 0{\cdot}67$, $P < 0{\cdot}001$ (Fig. 3)). A 100 g increased intake of bread and milk combined was associated with a 3·5 μg/d higher UIE and accounted for 10 % of the variance in UIE ($R^2 = 0{\cdot}03$, $\beta = 4{\cdot}2$ (SE 0·90), $P < 0{\cdot}001$). Both associations remained significant after adjustment for age, sex and energy intake.

Differences in dietary iodine intake and urinary iodine excretion between consumers and non-consumers of bread and milk

Eighty-five percentage of participants (*n* 386) reported consuming a known iodine-fortified bread product on the day of the recall (Table 3). Consumers of bread had 22 % higher dietary iodine intake compared with non-consumers ($P < 0{\cdot}001$, Table 3); however, there was no difference in UIE. In contrast, consumers of milk (*n* 313, 69 % of participants) had 55 % higher dietary iodine intake which was reflected by a 12 % greater UIE, compared with non-consumers ($P < 0{\cdot}001$, Table 3).

Participants who consumed either bread or milk on the day of the survey had 32 % higher UIE and 30 % higher total dietary iodine intake than participants who consumed neither (both $P < 0{\cdot}001$, Table 3). Participants who reported consuming both bread and milk on the day of the recall had 38 % higher UIE and 48 % higher total dietary iodine intake than participants who consumed neither bread nor milk (both $P < 0{\cdot}001$, Table 3). Although total dietary iodine intake was 26 % higher in participants who consumed both bread and milk compared with those who only consumed either bread or milk ($P < 0{\cdot}001$, Table 3), there was no difference in UIE.

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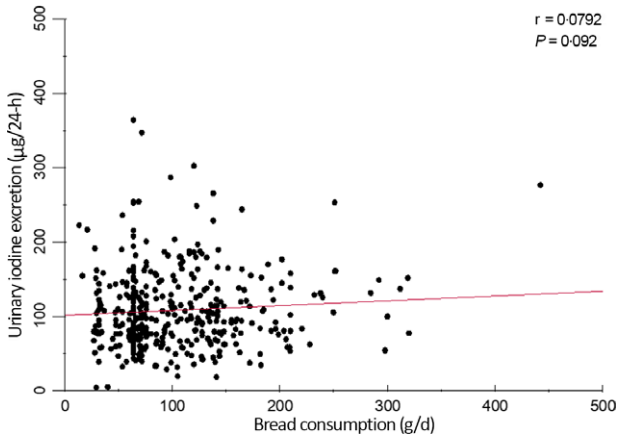

Fig. 1. Relationship between grams of bread consumed and 24-h urinary iodine excretion (*n* 454).

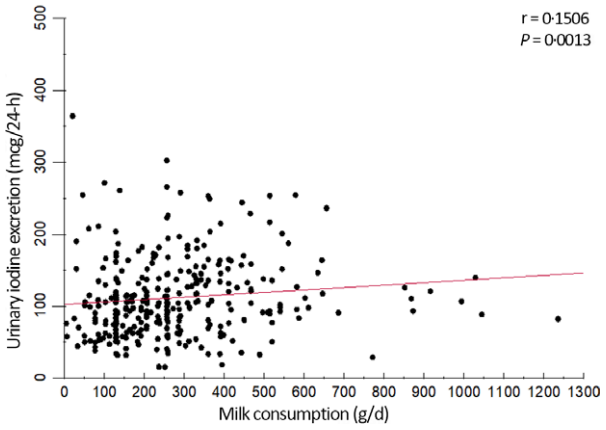

Fig. 2. Relationship between grams of milk consumed and 24-h urinary iodine excretion (*n* 454).

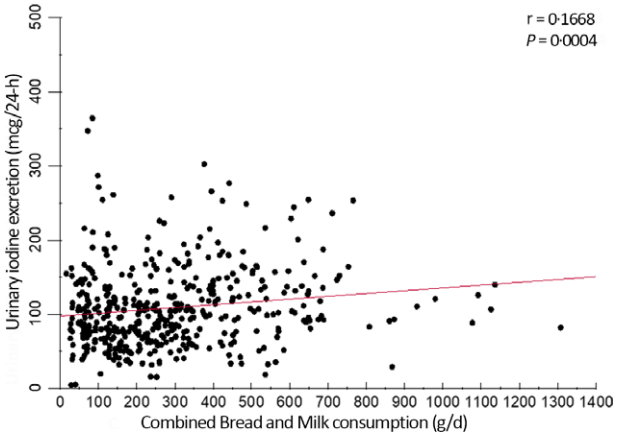

Fig. 3. Relationship between grams of bread and milk consumed and 24-h urinary iodine excretion (*n* 454).

Discussion

While iodised salt has been available for purchase since the early 20th century, this is the first Australian study to assess the contribution of food sources of iodine to urinary excretion following the mandatory fortification of bread with iodised salt. This study found that the mean dietary intake of iodine estimated from 24-h recalls of both 4–8- and 9–13-year-olds was more than double the recommended EAR of 65 µg/d and 75 µg/d, respectively[47]. In this sample of children who were consuming adequate dietary iodine, the major contributors to dietary intakes were bread and bread products (31 %) and milk (25 %). These results are similar to a recent analysis of the 2011–2013 AHS, which found that milk products and dishes contributed 26 % of dietary iodine intake in 4–13-year-olds[23].

Although milk intake was significantly associated with UIE, we did not find any association between total bread intake and UIE. Mandatory fortification of bread with iodised salt appears to have been successful in improving iodine intakes, with bread proven to be a significant contributor to iodine intakes in Australian schoolchildren[7,23,27]. However, we were unable to find an association between bread consumption and UIE. This contradicts recent findings from another Australian study, which found that bread consumption accounted for 14 % of the variation in urinary iodine concentration[27]. However, the previous study utilised FFQ to determine dietary iodine and average serves of bread, and spot urine samples to determine urinary iodine concentration, compared with the use of 24-h urines and 24-h dietary recalls in our study. We were also unable to confirm the findings of a previous analysis of the 2011–2013 AHS which found that consumption of >100 g of bread per d was associated with 12 times greater odds of achieving an adequate dietary iodine intake in 2–18-year-olds[23]. Differences in the methods used to assess iodine intakes and food sources of iodine could be a reason for the discrepancy between our study and previous studies. Within the present study, 37 % of participants consumed > 100 g of bread per d and there was no association between consumption of >100 g/d and UIE. A factor which may have contributed to this is our inability to include bread from mixed dishes (hamburgers, hot dogs breadcrumbs, etc.), resulting in a potential underestimate of total bread intake. The present study does, however, provide evidence that bread and bread products do contribute a significant proportion of dietary iodine amongst schoolchildren in Australia.

Although it has been hypothesised that a reduction in the use of iodophores by the dairy industry was a reason for the re-emergence of iodine deficiency in Australia in the late 1990s[13], our study found that milk contributed 25 % of total iodine intake and was significantly associated with UIE, even after adjustment for age, sex and energy intake. The proportion of dietary iodine from milk products observed in Australian schoolchildren is comparable to that observed in New Zealand[48], the UK[49], Germany[50] and the USA[51] and indicates that milk is still a valuable source of iodine amongst Australian schoolchildren. Similar to our own study, the studies in the UK, Germany and the USA found that higher milk intakes were associated with an increase in iodine excretion[49–51]. The iodine content of milk is influenced by contamination from iodophores[52], although there is some naturally occurring iodine which is present within milk[53]. The naturally occurring iodine is, however, highly variable and is largely dependent on the iodine intake of the cow itself[52,53]. Factors such as the supplementation of cow feed and salt licks, the cow species and farm location can impact the level of naturally occurring iodine in milk[52–54]. Currently within Australia, iodophores are still permitted for use in the dairy industry and it has been

Table 3. Urinary iodine excretion (UIE) and dietary iodine intake by consumption of bread and milk (*n* 454) (Mean values and standard deviations)

	Bread*				Milk*				Bread & Milk‡					
	Non-consumers		Consumers		Non-consumers		Consumers		Neither		Either		Both	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
n	68		386		141		313		11		187		256	
%	15 %		85 %		31 %		69 %		3 %		41 %		56 %	
Dietary iodine (μg/24-h)	138	65	178	2†	140	55·4	186	70†	101	56	144	59§	195	70‖,¶
UIE (μg/24-h)	102	73	109	56	98	50·7	112	57†	70	39	103	1§	113	56‖

* Linear regression with adjustment for age, sex, energy intake and school cluster.
† Consumers *v.* non-consumers, $P < 0{\cdot}05$.
‡ Bonferroni adjustment for multiple comparisons used to examine differences between subgroups. Sub-group differences indicated by:
§ Either *v.* neither $P < 0{\cdot}05$.
‖ Both *v.* neither $P < 0{\cdot}05$.
¶ Both *v.* either $P < 0{\cdot}05$.

estimated that approximately 33 % of Australian dairy farmers still utilise these sanitisers[55]. However, iodophore use is not monitored, and the exact proportion of farmers currently using them is not known, nor is the concentration at which they are used (*Kathryn Davis, Dairy Australia, Personal Communication, January 2017)*. As such, it is difficult to determine the level of contamination of milk by iodophores and this, in combination with the variation in the naturally occurring iodine content of milk, means that the iodine content of Australian milk could vary considerably both within and between producers. The results from this study, however, clearly indicate that milk intake is a major contributor to daily iodine excretion, and accordingly dietary intake.

The major strength of the present study is the use of both 24-h recalls and 24-h urine samples for the assessment of iodine intake. There are some limitations to this study, namely that we were unable to conduct the 24-h recalls over the same time period as the 24-h urine collection some children completed the urine samples over a week after the original 24-h recall (i.e. *n* 29, 7 % collected within a 2-week period)[33]. As we only utilised one 24-h dietary recall and one 24-h urine sample, the variation in the number of days between the urine collection and the dietary recall may have contributed to our inability to detect an association between bread intake and UIE. Furthermore, the observation that there was a significant difference in bread, but not milk intake, between school days and non-school days indicates that bread intake may be more variable than milk intake. This should be interpreted with caution, however, due to the small number of participants (19 %) who completed the recall on a non-school day.

In addition, there are some inaccuracies inherent with dietary assessment methodologies to assess the iodine content of food. In Australia, the main source of iodine in bread is the iodised salt added during production[20,56] and the current level of iodine in salt added to bread in Australia varies more than two-fold: between 25 and 65 mg iodine per kg of salt[57]. Furthermore, the Na content of bread ranges between 200 and 800 mg/100 g[58]. AUSNUT 2011–2013, the food database used in the present study utilises the mean Na and iodine content of each of the bread and milk products and does not account for the variation in either Na or iodine contents of breads[40]. Additionally, seasonal differences in the iodine concentration of milk could have been impacted by variations in the iodine concentration of the feed provided to dairy cattle during different periods of the year, a factor which may not be accurately captured by current food databases. In comparison with countries such as the UK or Canada however, Australia and New Zealand do not experience extreme changes in temperature between seasons. As such, cattle are not required to feed on pellets during periods when grass may not be as readily available and the animals feed on either pasture or grass dried during summer, ameliorating potential variations in the nutrient content of milk across the seasons[52].

In summary, our study found that bread and milk were important contributors to dietary iodine in Victorian schoolchildren, echoing results from the 2011–2013 AHS. We also found that milk intake, but not bread intake, was associated with 24-h UIE. Future longitudinal research whereby 24-h recalls and 24-h urine samples are collected concurrently, preferably on more than one day, is needed to confirm these findings and to further elucidate the impact of bread-based Na reformulation strategies on UIE among children. Furthermore, it is important that both dietary and urinary iodine intakes are tracked over time to ensure that Na reduction targets do not reduce the iodine content of foods, particularly bread, to a level which might impact the iodine intakes and status of Australians.

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