Original Article

Iodine intake and status during pregnancy and lactation before and after government initiatives to improve iodine status, in Palmerston North, New Zealand: a pilot study

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Abstract

Iodine deficiency during pregnancy and lactation may adversely affect fetal and infant development. Two initiatives were introduced in New Zealand to prevent deficiency: (1) mandatory fortification of bread with iodised salt; and (2) provision of a subsidised iodine supplement (150 µg) for all pregnant and breastfeeding women. The aim of this study was to assess iodine intake and status among a self-selecting sample of pregnant and lactating women in Palmerston North, both before and after the two initiatives. Pregnant and breastfeeding women were recruited before ($n = 25$ and 32 ; 2009) and after ($n = 34$ and 36 ; 2011) the initiatives. Iodine concentration was determined in 24-h urine and breast milk samples using inductively-coupled plasma mass spectrometry. Use of supplements and salt, knowledge of iodine deficiency, and awareness of the initiatives were determined by questionnaire. Median urine iodine concentration (UIC) was higher in 2011 compared with 2009 for both pregnant (85 and 47 µg L⁻¹) and breastfeeding (74 and 34 µg L⁻¹) participants; median UIC were below the cut-offs for adequate iodine status. However, in 2011, the estimated daily iodine intake during pregnancy was 217 µg day⁻¹; 74% of women achieved the Estimated Average Requirement. Knowledge of the initiatives was low, only 28–56% were aware of the need for iodine supplements and only 15–22% were aware of the mandatory addition of iodised salt to bread. Despite initiatives, UIC of these women indicates iodine deficiency, however, dietary intakes appear adequate. Ongoing surveillance of supplement use and iodine status among pregnant and lactating women throughout New Zealand is needed to fully assess the efficacy of the initiatives. Alternative strategies may require evaluation to ensure all women have adequate iodine during pregnancy and breastfeeding.

Keywords: iodine deficiency, pregnancy, lactation, breastfeeding.

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Introduction

Iodine deficiency has been described as the single greatest cause of preventable mental impairment, with nearly 1.9 billion people estimated to have an inadequate dietary iodine intake (Andersson *et al.* 2012). Iodine is essential for the production of thyroid

hormones, thyroxine and triiodothyronine, required for the control of metabolic processes and growth and development, especially of the brain and central nervous system (WHO & FAO 2004). Iodine deficiency throughout the lifecycle can result in a range of adverse consequences termed iodine deficiency disorders (IDD). Severe deficiency during pregnancy has

the most serious effect and can result in cretinism; however, even mild to moderate deficiency in utero and in early life may affect neural and psychomotor development (Zimmermann 2012). Iodine requirement increases by around 50% during pregnancy due to an increase in maternal thyroxine for maintenance of euthyroidism in the mother and transfer to the fetus in early pregnancy, direct iodine transfer to the fetus in later pregnancy and increased maternal renal losses of iodine (Zimmermann 2012). During lactation, maternal iodine requirements increase as iodine is secreted into breast milk (Azizi *et al.* 2009). In Australia and New Zealand, the Estimated Average Requirement (EAR) and Recommended Dietary Intake (RDI) for iodine are 160 and 220 $\mu\text{g day}^{-1}$ during pregnancy and 190 and 270 $\mu\text{g day}^{-1}$ during lactation (National Health and Medical Research Council & New Zealand Ministry of Health 2006). The FAO and WHO have set the Reference Nutrient Intake (RNI) for pregnant and lactating women at 250 $\mu\text{g day}^{-1}$ (Andersson *et al.* 2007).

Iodine status is frequently assessed via urinary concentration (Swanson *et al.* 2012), and concentrations in breast milk have been used as a proxy measure for iodine intake in infants (Azizi *et al.* 2009). Thyroid hormones [thyroid stimulating hormone (TSH), thyroxine (T4) and triiodothyronine (T3)] are an insensitive measure of iodine status as deficient populations have concentrations within normal reference ranges (Zimmermann 2008). Thyroglobulin (Tg) is a useful measure of iodine status in children and adults, and it has been recommended that this should be evaluated in pregnant women (Swanson *et al.* 2012). However, there are currently no reference ranges for Tg during pregnancy and breastfeeding; furthermore, anti-thyroglobulin antibodies (anti-Tg) need to be

determined simultaneously to prevent underestimation of Tg (Zimmermann 2008).

New Zealand has low levels of iodine in the soil and hence in the food supply. In the early 20th century, endemic goitre was seen throughout New Zealand. Iodised salt was introduced in New Zealand in 1924, but the effect was limited so, in 1938, the level of iodine in salt was increased and contributed to a significant reduction in rates of goitre until the 1980s (Mann & Aitken 2003). Since the 1990s, a number of studies in New Zealand have shown iodine deficiency has re-emerged within adults (Thomson *et al.* 1997), pregnant and breastfeeding women (Thomson *et al.* 2001; Mulrine *et al.* 2010; Pettigrew-Porter *et al.* 2011), school children (Skeaff *et al.* 2002) and breastfed infants and toddlers (Skeaff *et al.* 2005).

To combat iodine deficiency in New Zealand, two initiatives were introduced. The first was the mandatory fortification of all bread (except organic) with iodised salt in September 2009 (Food Standards Australia New Zealand 2009). This was predicted to improve the iodine intake for the majority of the population (73–100%), but would be insufficient for 63% of pregnant women (Schiess *et al.* 2012), and lactating women have even higher requirements, so it is unlikely to meet the needs for the majority of these women either. In July 2010, a subsidised iodine supplement (150 μg) was made available to all pregnant and breastfeeding women (Ministry of Health 2010).

The objective of this study is to compare iodine intake and status in samples of pregnant and lactating women in Palmerston North, New Zealand both before and after the two government initiatives to improve iodine intake. This is the first study in New Zealand to investigate iodine status in pregnant and breastfeeding women subsequent to these initiatives in New Zealand.

Key messages

- The New Zealand government has introduced two initiatives to prevent iodine deficiency in New Zealand.
- Since the government initiatives, iodine intake has increased; however, deficiency remains in a self-selected sample of educated pregnant and lactating New Zealand women.
- Awareness of the problem of iodine deficiency and the government initiatives in New Zealand was low.
- Many participants were not using the recommended iodine supplements, especially breastfeeding participants.

Methods

Women were recruited from the Palmerston North area of New Zealand prior to the two government initiatives to improve iodine status (January–July 2009) and subsequent to these initiatives (January–September 2011). Recruitment was via local newspapers, Massey University website, and fliers and posters placed in local maternity service providers. Volunteers were aged 16 years and older, who were in their third trimester of pregnancy (greater than 26 weeks gestation) or who were lactating at least 3 weeks after giving birth. Women who had medical complications during their pregnancy were excluded. Ethical approval was obtained from the Massey University Human Ethics Committee (Southern A 08/32 and 10/54). Written consent was obtained from all participants.

All the participants completed a researcher-led questionnaire, including questions regarding demographic information, use of iodine-containing supplements and salt, and knowledge of the problem of iodine deficiency in New Zealand. Participants recruited in 2011 were also questioned about their usual intake of bread using a semi-quantitative food frequency questionnaire (FFQ), and their awareness of the two government initiatives to improve iodine status.

Oral and written instructions were provided for collection of samples. Participants were asked to collect a 24-h urine sample and provided with an insulated box containing two polythene bottles for urine storage and frozen silica pads to keep the sample cool. Lactating women were asked to provide a breast milk sample (30 mL) and provided with a breast pump if required; timing of collection of breast milk samples was not standardised. All samples were brought immediately to the Human Nutrition Research Unit for processing after collection. The total volume of urine collected over 24 h was measured for each participant. Samples were stored without preservative at -20°C , prior to analysis. Iodine concentration in both urine and breast milk samples was determined by an accredited commercial laboratory (Hill Laboratories, Hamilton, New Zealand) using inductively coupled plasma

mass spectrometry (Fecher *et al.* 1998). Quality control procedures included analysis of blanks, analytical repeats and spiked samples to ensure accuracy and precision (data not available). Calibration standards and checks were undertaken on every run, and the limit of detection was 0.001 mg kg^{-1} for iodine. Estimations of the proportion of iodine excreted into urine during pregnancy vary from 80% to 90% (Thomson 2004; Andersson *et al.* 2007); using the upper level of 90% iodine intake for pregnant women was estimated by extrapolation of 24-h urinary iodine excretion. Iodine intake for breastfeeding women was not able to be estimated as the total amount of iodine secreted into breast milk was unknown.

Non-fasting blood samples were collected into plain tubes for analysis of serum Tg and anti-thyroglobulin antibodies (TgAb). Tg was measured at Canterbury Health Laboratories, Christchurch, New Zealand, using the Access 2 analyser (Beckman Coulter Inc., Brea, CA, USA); the uncertainty of measurement was $0.1\text{ }\mu\text{g L}^{-1}$ for $<1\text{ }\mu\text{g L}^{-1}$ and 16% for $>1\text{ }\mu\text{g L}^{-1}$. TgAb were measured using Serodia-ATG, a semi-quantitative microtitre particle agglutination test, at Medlab Central, Palmerston North, New Zealand. This method involves adding increasingly diluted samples of serum to wells on a microtitre plate. Sensitised particles were added to each well, and unsensitised particles were added to another serum sample of the lowest dilution. Any sample displaying no agglutination with unsensitised cells but showing a reaction at any dilution $\geq 1:100$ with the sensitised cells was interpreted as positive. A sample showing no reaction with sensitised cells at dilution $\geq 1:100$ was interpreted as negative, regardless of the reaction pattern with unsensitised cells.

Data were analysed using IBM SPSS version 20. Normally distributed data is expressed as mean $\pm$ standard deviation (SD); non-parametric data is expressed as median with inter-quartile range (IQR). Urine iodine data ($\mu\text{g day}^{-1}$) and breast milk iodine data ($\mu\text{g L}^{-1}$) were normally distributed and were analysed using independent *t*-tests. Urine iodine concentration data ($\mu\text{g L}^{-1}$) were not normally distributed, but log₁₀ transformation resulted in normally distributed data, which were then analysed

using independent *t*-tests. Categorical associations were examined using χ^2 tests.

Results

One hundred twenty-seven women were recruited from the Palmerston North area; 59 (25 pregnant and 34 breastfeeding) in 2009 prior to and 68 (32 pregnant and 36 breastfeeding) in 2011 after initiatives to improve iodine status (Table 1). Participants were predominantly Caucasian (75–92%), educated at tertiary level or higher (61–92%), with around half being pregnant with or breastfeeding their first infant.

Iodine deficiency in a population is defined by a median urinary iodine concentration (UIC) $<150 \mu\text{g L}^{-1}$ in pregnancy and $<100 \mu\text{g L}^{-1}$ during breastfeeding (WHO *et al.* 2007). In the current study, median UIC was below these cut-offs for both pregnant (47 (27, 52) $\mu\text{g L}^{-1}$ and 85 (52, 150) $\mu\text{g L}^{-1}$) and breastfeeding (34 (25, 58) $\mu\text{g L}^{-1}$ and 74 (46, 117) $\mu\text{g L}^{-1}$) participants in 2009 and 2011, respectively. Although the median UIC increased significantly after the initiatives ($P < 0.001$; Table 2), deficiency within the population remained. In 2009, no participants had UIC above the cut off levels; however, in 2011, 24% of pregnant women and 33% of lactating women achieved the cut-off level.

Despite the recommendation that all pregnant and breastfeeding use a daily 150 μg iodine supplement, in 2011, only 56% of pregnant women and 28% of lactating women were aware of these recommendations, and only 70% of pregnant women and 36% of breastfeeding women were taking supplements containing iodine; some of which contained less than the amount recommended (100–125 μg ; Table 3).

In 2011, pregnant women using iodine-containing supplements on the day of sample collection had significantly higher UIC than non-users (median = 126 vs. 66 $\mu\text{g L}^{-1}$, $P = 0.008$ and mean 267 vs. 151 $\mu\text{g day}^{-1}$, $P < 0.001$; Table 4). For breastfeeding participants, UIC was significantly higher for iodine-containing supplement users when considering $\mu\text{g day}^{-1}$ (mean = 155 vs. 99 $\mu\text{g day}^{-1}$, $P = 0.008$) but not $\mu\text{g L}^{-1}$ (median = 67 vs. 74 $\mu\text{g L}^{-1}$ $P = 0.813$). For both pregnant and breastfeeding participants in 2011, median UIC for supplement users indicated deficiency.

Estimated mean daily iodine intake for pregnant participants in the current study was 119 $\mu\text{g day}^{-1}$ in 2009 (Table 2) below the EAR and indicating the sample is at risk of deficiency. However, in 2011, estimated mean intake was 217 $\mu\text{g day}^{-1}$ above the EAR, but below the RDI and RNI, indicating a low risk of deficiency; this is contradictory to the indication of

Table 1. Description of pregnant and breastfeeding participants

	Pregnant		Breastfeeding	
	2009	2011	2009	2011
<i>n</i> (%)	25	34	32	36
Age, years (mean $\pm$ SD)	31.7 $\pm$ 5.6	31.6 $\pm$ 5.8	31.8 $\pm$ 4.5	30.9 $\pm$ 5.4
Education				
Tertiary	23 (92)	28 (82)	25 (78)	22 (61)
Less than tertiary	2 (8)	6 (18)	7 (22)	14 (39)
Ethnicity				
Caucasian	23 (92)	26 (76)	29 (91)	27 (75)
Māori	1 (4)	6 (18)	3 (9)	6 (17)
Asian	1 (4)	2 (6)		1 (3)
Others (African, Pacific Islander)				2 (5)
Parity				
Nulliparous	12 (48)	18 (53)	–	–
Multiparous	13 (52)	16 (47)	–	–
Lactation				
First time lactation	–	–	14 (44)	18 (50)
Age of infants, days (mean $\pm$ SD)	–	–	81 $\pm$ 56	135 $\pm$ 99

Table 2. Iodine intake and status and bread intake among pregnant and breastfeeding participants

	Pregnant		<i>P</i>	Breastfeeding		<i>P</i>
	2009	2011		2009	2011	
<i>n</i> (%)	25	34		32	36	
Urinary iodine concentration, $\mu\text{g L}^{-1}$ (median, IQR)	47 (27, 52)	85 (52, 150)	<0.001*	34 (25, 58)	74 (46, 117)	<0.001*
Urinary iodine concentration, $\mu\text{g day}^{-1}$ (mean $\pm$ SD)	108 $\pm$ 70	195 $\pm$ 78	<0.001 [†]	78 $\pm$ 36	107 $\pm$ 44	0.005 [†]
[‡] Urine volume, mL day ⁻¹ (Mean $\pm$ SD)	2419 $\pm$ 998	2122 $\pm$ 944		2263 $\pm$ 942	1585 $\pm$ 873	
[§] Achieving adequate urinary iodine concentration	0	8 (24)		0	12 (33)	
[¶] Estimated 24 h iodine intake, $\mu\text{g day}^{-1}$ (mean $\pm$ SD)	119 $\pm$ 77	217 $\pm$ 87	<0.001 [†]			
**Achieving iodine intake of 250 $\mu\text{g day}^{-1}$	1 (4)	11 (32)		–	–	
^{††} Achieving EAR	5 (20)	25 (74)		–	–	
^{‡‡} Breast milk iodine, $\mu\text{g L}^{-1}$ (mean $\pm$ SD)				55 $\pm$ 48	63 $\pm$ 44	0.495 [†]
^{§§} Achieving adequate breast milk iodine	–	–		4 (13)	12 (36)	
^{¶¶} Thyroglobulin, $\mu\text{g L}^{-1}$ (median, IQR)	–	15.9 (8.4, 25.6)		–	13.9 (9.6, 22.4)	
Median bread intake, slices day ⁻¹ (median, IQR)		1.6 (1.3, 1.9)			1.5 (1.3, 2.0)	

IQR, inter-quartile range. *Based on an independent *t*-test of log10 data comparing 2009 and 2011 data. [†]Based on an independent *t*-test comparing 2009 and 2011 data. [‡]Range of urine volume, mL day⁻¹: pregnancy 780–3910 (2009), 580–4470 (2011); breastfeeding 980–4830 (2009), 360–4250 (2011). [§]Defined as 150–249 $\mu\text{g L}^{-1}$ during pregnancy and >100 $\mu\text{g L}^{-1}$ during breastfeeding. [¶]Based on 90% excretion of dietary iodine. **FAO/WHO Reference Nutrient Intake for pregnancy and lactation (Andersson *et al.* 2007). ^{††}Estimated Average Requirement, 160 $\mu\text{g day}^{-1}$ during pregnancy. ^{‡‡}31 Breast milk samples in 2009 and 33 breast milk samples in 2011. ^{§§}75 $\mu\text{g L}^{-1}$ based on (Azizi *et al.* 2009). ^{¶¶}29 Pregnant women and 20 breastfeeding women in 2011.

Table 3. Awareness of iodine deficiency New Zealand and use of iodine-containing supplements and salt among pregnant and breastfeeding participants

	Pregnant		<i>P</i> *	Breastfeeding		<i>P</i> *
	2009	2011		2009	2011	
<i>n</i> (%)	25	34		32	36	
Using government subsidised iodine supplement	–	14 (41)		–	7 (19)	
Using any other supplement containing iodine	4 (16)	10 (29)		6 (19)	6 (17)	
Aware of iodine deficiency in New Zealand (%)	17 (68)	14 (41)	0.041	26 (81)	15 (42)	0.001
Aware of mandatory addition of iodised salt to bread in New Zealand	–	5 (15)		–	8 (22)	
Access to iodised salt at home	22 (88)	27 (79)		27 (84)	25 (69)	
Exclusive use of iodised salt at home	–	13 (38)	0.147	–	13 (36)	0.385
Aware of government subsidised iodine supplement	–	19 (56)		–	10 (28)	

*Based on χ^2 test.

deficiency as determined by UIC. In 2011, 74% of participants achieved the EAR compared with only 20% in 2011.

There is currently no recommendation for iodine concentrations in breast milk; however, a breast milk iodine concentration of >75 $\mu\text{g L}^{-1}$ has been suggested as an index of sufficient iodine intake (Azizi *et al.* 2009). Mean iodine concentrations in breast milk samples increased from 55 $\mu\text{g L}^{-1}$ in 2009 to 63 $\mu\text{g L}^{-1}$ in 2011 (non-significant), with 13% achieving

75 $\mu\text{g L}^{-1}$ in 2009 increasing to 36% in 2011. Participants taking iodine-containing supplements on the day of sample collection had significantly higher mean breast milk iodine concentrations (126 $\mu\text{g L}^{-1}$ vs. 58 $\mu\text{g L}^{-1}$ $P < 0.001$; Table 4), and achieved a mean concentration greater than the suggested cut off.

All TgAb measures were negative and would not affect Tg concentrations. Tg concentrations were not correlated with UIC, and Tg concentrations were not higher in women using iodine supplements compared

Table 4. Iodine status by iodine supplement use on day of sample collection among pregnant and breastfeeding participants in 2011

	Iodine supplement users	Non-iodine supplement users	Significance <i>P</i>
Pregnancy			
<i>N</i>	13	21	
Urinary iodine concentration, $\mu\text{g L}^{-1}$ (median, IQR)	126 (94, 171)	66 (48, 133)	0.008*
Urinary iodine concentration, $\mu\text{g day}^{-1}$ (mean $\pm$ SD)	267 $\pm$ 58	151 $\pm$ 52	<0.001†
Breastfeeding			
<i>N</i>	5	31	
Urinary iodine concentration, $\mu\text{g L}^{-1}$ (median, IQR)	67 (37, 135)	74 (47, 119)	0.813*
Urinary iodine concentration $\mu\text{g day}^{-1}$ (mean $\pm$ SD)	155 $\pm$ 60	99 $\pm$ 37	0.008†
<i>n</i>	5	28	
Breast milk iodine $\mu\text{g L}^{-1}$ (mean $\pm$ SD)	126 $\pm$ 55	58 $\pm$ 29	<0.001†

IQR, inter-quartile range. *Based on an independent *t*-test comparing log10 data. †Based on an independent *t*-test.

with non-iodine supplement users. One Tg for a breastfeeding participant was not included in the analysis as it was excessively high.

There was greater awareness of iodine deficiency being a problem in New Zealand in 2009 than 2011 in both pregnancy (68% vs. 41%; $P = 0.041$) and breastfeeding (81% vs. 42%; $P = 0.001$; Table 3); although there was no difference in access to iodised salt at home. In 2011, awareness of the two government initiatives was low; only 15% and 22% were aware of the mandatory addition of iodised salt to bread and only 56% and 28% were aware of the recommendation for an iodine supplement for pregnant and breastfeeding participants, respectively. The majority of participants had access to iodised salt at home (69–88%); in 2011, women were also asked if they used exclusively iodised salt, and only 36–38% followed this recommendation. In 2011, participants had an estimated median intake of less than two slices of bread per day.

Discussion

Despite initiatives to improve the iodine status of pregnant and breastfeeding women in New Zealand, iodine deficiency is still a problem among these women in Palmerston North in 2011, with median UIC of 85 and 74 $\mu\text{g L}^{-1}$, respectively. Although median UICs had increased significantly from before the initiatives (47 and 34 $\mu\text{g L}^{-1}$ for pregnant and breastfeeding women, respectively, in 2009; $P < 0.001$ for both), the increase was not sufficient to eliminate

deficiency. Correspondingly, a recent study subsequent to mandatory iodine fortification has found that in New Zealand school-aged children (aged 8–10 years), although iodine intake has increased, serum thyroglobulin concentrations indicate that mild deficiency is still a problem (Skeaff & Lonsdale-Cooper 2012).

The median UIC among pregnant participants in the current study prior to the initiatives (47 $\mu\text{g L}^{-1}$ in 2009) was similar to that found in 2005 in a study of 170 women, throughout New Zealand, in the third trimester of pregnancy (37 $\mu\text{g L}^{-1}$) (Pettigrew-Porter *et al.* 2011). In a previous study of pregnant women in Dunedin, median daily iodine intakes were estimated to be 60–70 $\mu\text{g day}^{-1}$ (Thomson *et al.* 2001) – lower than in the current study prior to the initiatives, where mean iodine intakes for pregnant participants were estimated at 119 $\mu\text{g day}^{-1}$, well below the EAR (160 $\mu\text{g day}^{-1}$) and indicating the population had an inadequate dietary intake. In 2011, mean estimated iodine intake in pregnancy had increased to 217 $\mu\text{g day}^{-1}$, above the EAR, but below the RDI (220 $\mu\text{g day}^{-1}$) and RNI (250 $\mu\text{g day}^{-1}$). Only 20% of pregnant participants achieved the EAR in 2009, compared with 74% in 2011. This would suggest an adequate intake of iodine for many of the group sampled after the initiatives; however, this is inconsistent with the median UIC results which indicate deficiency. A possible explanation for this discrepancy is the assumption of 90% iodine excretion into urine; during pregnancy renal loss of iodine is thought to increase,

thus using this value may have overestimated iodine intake. Although the pregnant iodine supplement users in the present study had a higher median UIC than non-users post the government initiatives, the median UIC indicated deficiency remained among supplement users. This could be because women were taking a supplement with insufficient iodine, as some participants were using supplements containing only 100–125 µg. Alternatively, participants may have been receiving insufficient iodine from other sources, such as from bread, because most participants were estimated to be consuming less than two slices of bread per day.

In a recent review paper, Zimmermann & Andersson (2012) suggest that the UIC cut-off used for adults ($100 \mu\text{g L}^{-1}$) may be too high and could over-estimate iodine deficiency in a population. They suggest the use of the EAR cut-point method and compare estimated intake of the population to the EAR. This method requires the collection of multiple urine samples in a subset to adjust for intra-individual variation; this, together with the small sample size, mean the EAR cut-point method cannot be applied to the current results. However, another possible interpretation of the discrepancy in the current study results is that the study population had a sufficient intake; the seemingly low iodine intakes when expressing UIC as $\mu\text{g L}^{-1}$ could be due to dilution as some 24-h urine volumes were high ($>3 \text{ L}$). Further research is required to determine the validity of the UIC cut-offs currently used for both pregnancy and lactation by comparison with 24-h urine samples.

For breastfeeding participants in the present study, the median UIC before the initiatives ($34 \mu\text{g L}^{-1}$ in 2009) was similar to a study of 56 unsupplemented breastfeeding women in Dunedin in 1998/1999 ($20\text{--}41 \mu\text{g L}^{-1}$) (Mulrine *et al.* 2010). A post-iodine fortification study of 60 breastfeeding women in Australia found a much higher median UIC ($123 \mu\text{g L}^{-1}$) than the current study ($74 \mu\text{g L}^{-1}$), suggesting low risk of deficiency in the Australian population (Axford *et al.* 2011). These results are not unexpected, as Australia has higher levels of iodine within the food supply compared with New Zealand (Thoma *et al.* 2011), and also 45% of the Australian participants were taking iodine-containing supplements compared with 14%

on the day of sample collection in the present study. Post-fortification, Australian women not using iodine-containing supplements had a lower median UIC ($97 \mu\text{g L}^{-1}$) compared with users ($206 \mu\text{g L}^{-1}$); the median intake was below the recommended cut-off, suggesting deficiency among these women (Axford *et al.* 2011). Mean UIC ($\mu\text{g day}^{-1}$) in 2011 in the present study was significantly higher in iodine supplement users than non-users for both pregnant and breastfeeding women; however, median UIC ($\mu\text{g L}^{-1}$) was only significantly higher for pregnant users than non-users. Iodine concentration in urine can be affected by time of day and hydration status, collecting a full 24-h urine sample removes any of these effects (Thomson *et al.* 1996); this is a strength of the current study over studies where only a spot urine sample is collected.

Mean breast milk iodine concentrations in the present study increased slightly, although non-significantly, subsequent to the initiatives ($55 \mu\text{g L}^{-1}$ in 2009 to $63 \mu\text{g L}^{-1}$ in 2011); however, both were below the level suggested as adequate ($75 \mu\text{g L}^{-1}$) (Azizi *et al.* 2009). In 2011, only 36% achieved the adequate level, although this was an improvement from 13% in 2009, suggesting that exclusively breastfed infants are at risk of insufficient iodine intake. The mean iodine concentration in breast milk samples prior to the initiatives was similar that seen in a 1990 study of Wellington lactating women with infants over 3 months old ($50 \mu\text{g L}^{-1}$) (Johnson *et al.* 1990). However, another study of breastfeeding mothers conducted in the South Island between May 1998 and March 1999, found a much lower mean iodine concentration ($22 \mu\text{g L}^{-1}$) (Skeaff *et al.* 2005). In the present study, participants using iodine-containing supplements had significantly higher median breast milk iodine concentrations than non-users with a mean concentration above the adequate level, suggesting the level of supplementation was sufficient. However, the median UIC for the breastfeeding supplement users suggested deficiency. Care must be taken in interpreting this data as only a small number of breastfeeding participants (five) were taking supplements.

In the present study, median Tg post fortification was $15.9 \mu\text{g L}^{-1}$ for pregnant women and $13.9 \mu\text{g L}^{-1}$ for breastfeeding women. Median Tg for pregnant

women was similar to that seen in a French study of women considered iodine deficient ($16.2 \mu\text{g L}^{-1}$) (Raverot *et al.* 2012), although it was also similar to those seen in euthyroid pregnant women in the United States ($16 \mu\text{g L}^{-1}$) (Mitchell *et al.* 2003). Median Tg concentrations seen in the breastfeeding women of the present study are also similar to those seen in iodine-replete Swedish women 1 year postpartum ($13.95 \mu\text{g L}^{-1}$) (Soldin *et al.* 2004). It is difficult to interpret Tg concentrations in the present study and, furthermore, they were not correlated with UIC and iodine supplement use did not affect concentrations.

The low knowledge of the recommendations and use of supplements containing iodine, especially among breastfeeding women is of concern, although not unexpected. Use of folic acid supplements is known to be low among younger, socially disadvantaged and some ethnic minority groups both internationally (Brough *et al.* 2009) and among Māori Pacific and Asian women in New Zealand (Mallard *et al.* 2012). More women might be expected to use the recommended supplements during pregnancy when they have regular care with health professionals who can recommend supplementation and provide prescriptions. However, after delivery, women are seen less frequently by health professionals and there is less opportunity to provide supplements. Although the supplements are subsidised, the cost may prevent some women from using them. Antenatal care is free in New Zealand, and prescriptions are provided free of charge during this period until 6 weeks after delivery. If a lactating woman needed more supplements, she would need to pay to visit her GP and prescription charges, which may be difficult for those on a tight budget.

Knowledge of the problem of iodine deficiency in New Zealand was low, and few participants were aware of the mandatory addition of iodised salt to bread in New Zealand. It is recommended that salt intake should be limited, and that any discretionary salt should be iodised (Ministry of Health 2006). However, in the current study, only just over one-third of participants (36–38%) used iodised salt exclusively at home despite the majority having access to iodised salt.

This small sample of self-selected women is not representative of the New Zealand population; however, such women who volunteer to participate in such studies are often motivated towards health and would not be expected to have a poorer health status than the population as a whole. That iodine deficiency may remain in this population after initiatives to improve iodine status is of concern. This study highlights the need for ongoing surveillance of supplement use and iodine status among pregnant and lactating women throughout New Zealand to assess the efficacy of the initiatives to improve iodine status. If these results are corroborated with larger studies, alternative strategies will need to be evaluated to ensure all women have adequate iodine during pregnancy and breastfeeding.

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Conflicts of interest

The authors declare that they have no conflicts of interest.

Contributions

All authors were involved in the study design. YJ and LB recruited the participants and collected and analysed the data. All authors contributed to the writing and reviewing of the paper and approved the final version.

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