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ORIGINAL ARTICLE

Drinking water contributes to excessive iodine intake among children in Hebei, China

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BACKGROUND/OBJECTIVES: In Hebei province, China, over six million people are potentially exposed to excessive iodine through consumption of high iodine underground drinking water and consumption of iodized salt. The aim of this study is to evaluate the contributions of drinking water and iodized salt on children's iodine nutrition in one area of Hebei province in order to refine strategies to correct the excessive iodine intake in these areas.
SUBJECTS/METHODS: To investigate the relationships between iodine content in water, iodized salt and urinary iodine content (UIC) in children (8–10 years), we randomly sampled three towns with a known median water iodine (MWI) of 150–300 μg/l in Hengshui City, Hebei province and collected water, salt and urine samples.
RESULTS: The median UIC was 518.1 μg/l, the overall MWI was 247.0 μg/l, and 83% of children sampled were found to have urinary iodine concentrations higher than the WHO criterion of 300 μg/l. There was a significant and positive correlation between the median UIC of the children and the MWI in the 12 villages where the children lived (Spearman $R = 0.79$, $P = 0.002$), but the UIC was not significantly correlated with the median salt intake (MSI) (Spearman $R = -0.17$, $P = 0.6$). A multiple linear regression analysis indicated that 68.7% of the variability in median UIC is associated with variability in MWI in the 12 villages.
CONCLUSIONS: Iodine in drinking water was identified to be the key contributor to this excessive iodine in children indicating that in these areas, intervention should focus on providing alternative drinking water supplies.

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INTRODUCTION

Excessive iodine intake over long periods of time can cause goiter, hypothyroidism and thyroiditis.[1] The published research indicates that excessive iodine intake mainly results from consuming high iodine seafood, for example, in Japan,[2] iodized salt with high iodine content in some African and American countries,[3] iodine-rich meat and milk in Iceland,[4] as well as iodine-rich drinking water in China.[5]

Areas with excessive iodine in underground drinking water are widely distributed in China. Such areas are found in 11 provinces mainly located in the ancient flood areas of the Yellow River and some coastal areas. According to National Criteria for Classifying High Iodine Regions,[6] a town with median water iodine (MWI) between 150 and 300 μg/l in drinking water is classified as a high iodine town. The iodine intake for populations in these areas is likely to be excessive and endemic goiter may or may not prevail. A town with MWI above 300 μg/l is classified as a high iodine endemic town where children's goiter rates usually exceed 5%.[6] A previous study reported that there are 488 high iodine towns and 246 endemic towns in the areas with excessive iodine in underground drinking water in China, affecting a population of over 30 million people.[7] In recent years, the issue of iodine excess has gained significant attention in the mass media and led to an increased awareness in the general population. This has had some adverse effects on the sustainable management of iodine deficiency disorders (IDD) in China.

Hebei is a province with widespread distribution of areas with excessive iodine in underground drinking water. It has 111 high iodine towns and 62 endemic towns, which are scattered across six cities with a population of over six million people.[8] Non-iodized salt has been available in these high iodine towns since 2010. However, during the Fukushima nuclear disaster, a rumor prevailed that iodized salt can prevent nuclear radiation and as a result, many families in iodine excessive areas appeared to have purchased a large amount of iodized salt. According to the unpublished household surveys of iodized salt in Hebei province by local Centres for Disease Prevention and Control in 2011, over 80% of the families in these areas still consumed iodized salt.

WHO recommends an iodine intake of 120 μg/day for children aged 6–12 years and that iodine excess can be defined as median urinary iodine content (UIC) higher than 300 μg/l.[9] In China, research indicates that very high iodine in drinking water, usually above 300 μg/l, can lead to extreme iodine excess in children whose median UIC is usually well above 500 μg/l.[10] Moreover, mildly excessive iodine in drinking water (150–300 μg/l) plus iodized salt has been found to result in noticeable excessive iodine intake (for example, median UIC of 418.2 μg/l) in children aged 8–10 years old.[11]

However, the respective contributions of iodine in drinking water and iodized salt to children's excessive iodine intake in the areas with mildly excessive iodine in drinking water remains unquantified in Hebei. The aim of this study is to clarify the contribution of iodine in drinking water and iodized salt on

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children's iodine nutrition. Better understanding relative contributions will assist with refining strategies in Hebei to control the possible harm caused by excessive iodine intake in these areas.

MATERIALS AND METHODS

Selection of high iodine towns

Hengshui is a small city administrating 118 towns. Based on a survey conducted in 2004, 15 towns in the city were identified as high iodine towns as their MWI was between 150 and 300 μg/l according to the National Criteria for Classifying High Iodine Regions. These high iodine towns are concentrated in a small area enabling the convenient conduct of the field survey. The local children have a similar diet and life style. Their diet consists mainly of wheat, rice, egg, pork, chicken and vegetables. The wheat, pork, chicken and vegetables are locally grown, while the rice is mainly imported from north-east China. Residents seldom eat seafood minimizing the potentially significant dietary iodine contribution from this source. From these 15 high iodine towns, 3 towns (Fangzhuang, Qinghan and Liuzhimiao) were randomly selected for the study.

Children's urine sample collection

In each of the three towns chosen, three to five village schools or one township level school were randomly selected. From each of these schools, children aged 8 to 10-years-old were randomly selected for urine sample collection. Only those children who had lived in the three towns since birth were included. One-hundred and nineteen, 104 and 103 pupils were randomly selected from the selected schools in Fangzhuang, Qinghan and Liuzhimiao, respectively and a total of 326 urine samples were collected from these children who lived in 12 villages. This survey was approved by Hebei Provincial Bureau of Science and Technology. Written consent for urinary sample collection was obtained from the headmasters (on behalf of the children's parents) of the investigated schools. The survey was conducted in June 2011.

Drinking water sample collection

Drinking water samples were collected from households in the 12 villages in the three towns where those investigated children had lived since birth. The population of the 12 villages was between 1000 and 3000. As the drinking water supply in all of them was centralized (tap water), only two water samples were randomly collected from two households in each village.

Household edible salt sample collection

Edible salt samples were also collected at the villages where the investigated children were born and lived. A systematic sampling method was used according to their location of east, west, north, south or center of the village. Four households were randomly selected in each location to collect edible salt to measure iodine content. A total of 20 salt samples were collected in each village. This many samples is required as villager's source of edible salt is varied. Residents may buy edible salt at the nearby village store, which usually sources iodized salt from the local salt industry, or they may buy edible salt (mostly non-iodized) from mobile vendors at a much lower price.

Laboratory measurement and data analysis

The laboratory analysis for iodine content in the biological and environmental samples were conducted by the IDD laboratory in Hengshui Municipal Centre for Disease Prevention and Control, which has been accredited to conduct such analysis by the National IDD Reference Laboratory.

The iodine content of urine samples was measured by the method of ammonium persulfate oxidation.[12] Urinary iodine values from populations are usually not normally distributed. Therefore, the median rather than the mean should be used as the measure of central tendency. Median UIC concentrations of 300 μg/l and above define a population as having iodine excess.[3]

The iodine content of salt was determined quantitatively using a titration method.[13] According to the Chinese national surveillance plan for IDDs, edible salt with <5 mg/kg iodine is classified as non-iodized salt, and edible salt with iodine content higher than 5 mg/kg is defined as iodized salt.[14]

The iodine content in drinking water was determined by the method of arsenic-cerium oxidation–reduction spectrophotometry.[15] Based on the National Criteria for Classifying High Iodine Regions, drinking water containing more than 150 μg/l iodine is classified as excessive.[6]

An important quality control measure used for the study was that the provincial iodine deficiency laboratory conducted duplicate analysis for 5% of all collected samples. The accordance between the two laboratories was above 95%.

Data processing and statistical analysis

Data processing and statistical analyses were performed using statistical software packages Epi–Info 2002 (Centers for Disease Control and Prevention, Atlanta, GA, USA) and SPSS version 13.0 (SPSS Inc., Chicago, IL, USA). As the distributions of iodine in edible salt, drinking water and children's urine are not normal, the median was used to describe their central tendency. The differences in children's MUI by gender and age were tested by Mann–Whitney and Kruskal–Wallis. The alpha was set at 95%. The One-Sample Kolmogorov–Smirnov test was used to analyze the distributions of median UIC, MWI and median salt intake (MSI). Spearman was used to determine associations between children's median UIC and MWI and MSI. Following the correlation analysis a multiple linear regression model was developed.

RESULTS

Iodine content in drinking water and edible salt

A total of 24 drinking water samples were collected from 12 villages. The MWI ranged from 177 to 344 μg/l, with the majority (10 out of 12) between 150 and 300 μg/l, and an overall MWI of 247 μg/l. MWI for each of the 12 villages is provided in Figure 1.

A total of 240 edible salt samples were collected in the households of these villages. Forty-six salt samples (19.2%) were non-iodized salt and 194 were iodized salt (80.8%). The coverage rate of iodized salt (CR), described as the portion of iodized salt samples in the total edible salt samples, in each of the 12 villages ranged from 60 to 100%, with the overall CR being $\sim$81%. The MSI was between 10 mg/kg and 34 mg/kg, with the overall MSI being 24 mg/kg. The details for iodized salt in the 12 villages are provided in Figure 2.

Iodine content in urine samples of children aged 8–10 years

The median UIC was 518 μg/l and the percentage of children with UIC higher than 300 μg/l (the criteria for iodine excess recommended by WHO) was 83% (269/326). The median UIC in these three towns was 571, 520 and 478 μg/l, respectively, and there was no statistically significant difference among them (Kruskal–Wallis test, $\chi^2 = 1.62$, $P = 0.44$). The median UIC and the frequency distribution of children's UIC in these three high iodine towns are shown in Table 1.

The median UIC in boys and girls was 518 μg/l ($n = 167$) and 520 μg/l ($n = 159$), respectively, with no statistically significant difference identified (Mann–Whitney, $U = 12660.50$, $P = 0.66$). The number of urine samples collected from children aged 8, 9 and 10 years were 93, 105 and 128, and their median UIC was 513 μg/l, 520 μg/l and 522 μg/l, respectively, with no statistically significant difference identified (Mann–Whitney, $H = 1.563$, $P = 0.458$. Kruskal–Wallis Test, $\chi^2 = 0.26$, $P = 0.88$).

Further classification based on age and sex shows that the percentage of urine samples with iodine content higher than 300 μg/l in each age and sex group varied from 77.1 to 87.1%. The median UIC and frequency distribution of UIC across age and gender in children aged 8–10 years are included in Table 2.

Correlation between children's median UIC and MWI

The relationships between children's MUI and MWI, and MUI and MSI in the 12 villages were analyzed, respectively. The median UIC of children was significantly positively correlated with the MWI in the 12 villages where the children lived (Spearman, $R = 0.79$,

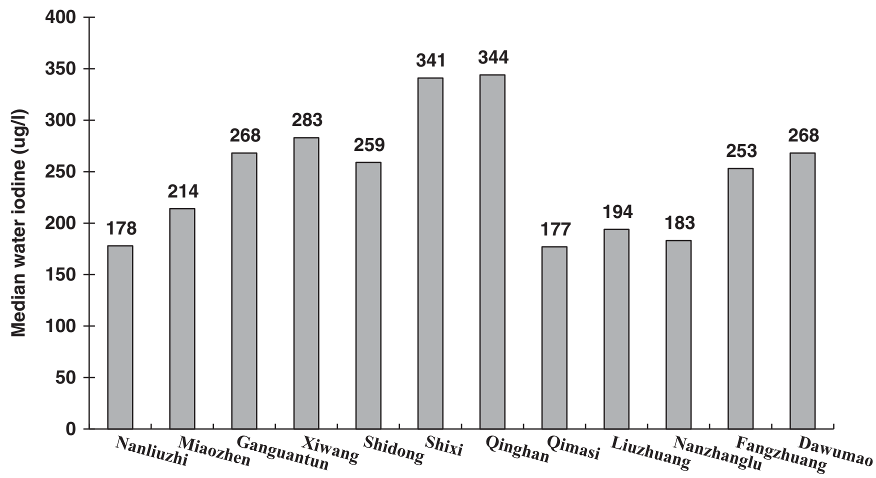

Figure 1. MWI (μg/l) in 12 villages of three high iodine towns in Hengshui city, Hebei Province, China, June 2011.

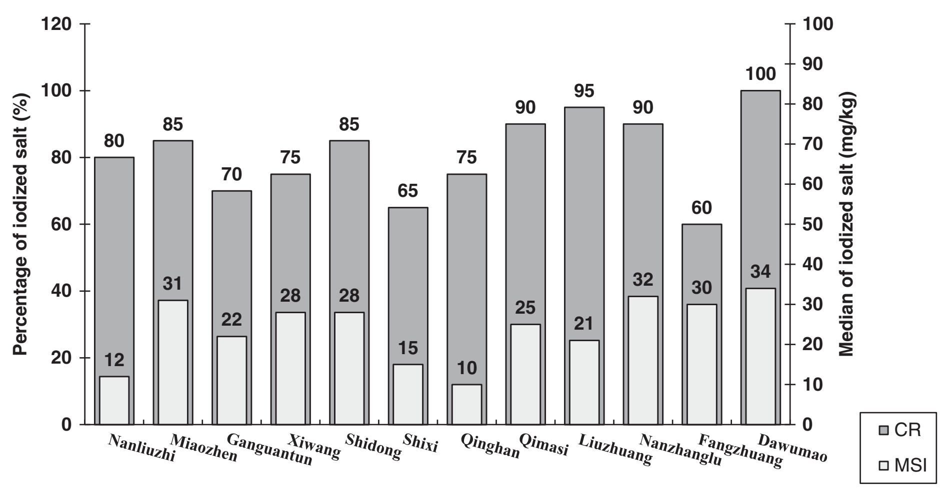

Figure 2. Coverage rate of iodized salt (CR) and MSI in 12 villages of three high iodine towns in Hengshui city, Hebei Province, China, June 2011.

Table 1. The median UIC of children aged 8–10 years and frequency distribution of their UIC in the three high iodine towns in Hengshui city, Hebei Province, China (June 2011)

Town	*Urine samples*	*Median UIC (μg/l)*	*Frequency distribution*		
			<100 μg/l (%)	*100–300 μg/l (%)*	*>300 μg/l (%)*
Fangzhuang	119	571	0 (0)	16 (13.4)	103 (86.6)
Qinghan	104	520	1 (1.0)	22 (21.1)	81 (77.9)
Liuzhimiao	103	478	0 (0)	18 (17.5)	85 (82.5)
Total	326	518	1 (0.3)	56 (17.2)	269 (82.5)

Abbreviation: UIC, urinary iodine content.

$P = 0.002$), however, UIC did not correlate significantly with the MSI of the villages they lived in (Spearman, $R = -0.17$, $P = 0.6$).

The One-Sample Kolmogorov–Smirnov test found that children's median UIC, MWI and MSI in the 12 villages were all normally distributed (median UIC: $Z = 0.712$, $P = 0.691$. MWI: $Z = 0.510$, $P = 0.958$. MSI: $Z = 0.634$, $P = 0.816$). Hence, the relationships between children's median UIC and MWI and MSI in the 12 villages were analyzed by multiple linear regression. When both MWI and MSI were included in the model, the overall model was statistically significant ($F = 10.318$, $P = 0.005$) and the Beta was positive and statistically significant ($\beta = 0.858$, $t = 4.466$, $P = 0.002$) for MWI, but not statistically significant for MSI ($\beta = 0.099$, $t = 0.517$, $P = 0.618$). Based on this, MSI was excluded from the model and with only MWI in the model, it was statistically significant ($F = 21.979$, $P = 0.001$) with a significant Beta ($\beta = 0.829$, $t = 4.688$, $P = 0.001$). The R^2 for MWI in the model was 0.687,

Table 2. The median UIC and frequency distribution of urinary iodine content across age and gender in children aged 8–10 years in Hengshui prefecture, Hebei Province, China (June 2011)

Group	*Urine samples*	*Median UIC (μg/l)*	*Frequency distribution*		
			<100 μg/l (%)	*100–300 μg/l (%)*	*>300 μg/l (%)*
Boys	167	518	1 (0.6)	30 (18.0)	136 (81.4)
Girls	159	520	0 (0)	26 (16.3)	133 (83.7)
8 years	93	513	0 (0)	12 (12.9)	81 (87.1)
9 years	105	520	1 (0.9)	23 (12.0)	81 (77.1)
10 years	128	524	0 (0)	21 (16.4)	107 (83.6)
Total	326	518	1 (0.3)	56 (17.2)	269 (82.5)

Abbreviation: UIC, urinary iodine content.

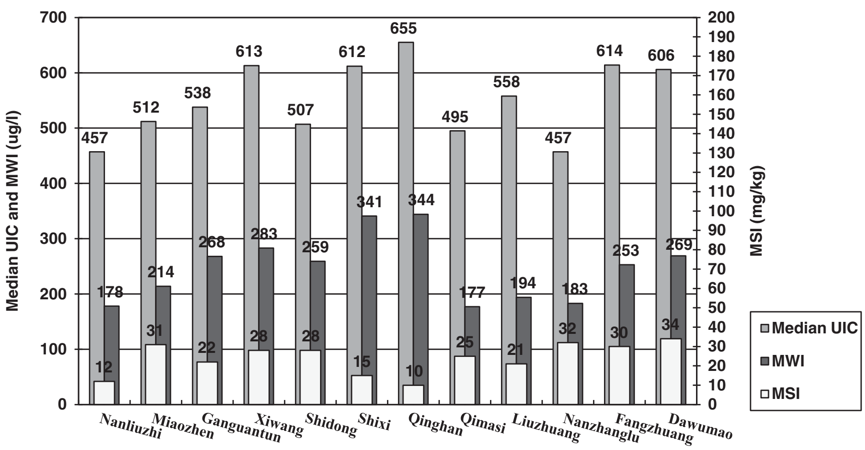

Figure 3. Children's median UIC, MWI and MSI in the 12 villages of three high iodine towns in Hengshui city, Hebei province, China, June 2011.

indicating that ~69% of the variability in median UIC was associated with variability in MWI in the 12 villages. The children's median UIC, MWI and MSI in the 12 villages are illustrated in Figure 3.

DISCUSSION

The median UIC of 518 μg/l of children aged 8–10 years living in the three towns of Hengshui city, exceeds the criteria for iodine excess of 300 μg/l recommended by WHO.[3] The proportion of urine samples with iodine content higher than 300 μg/l accounted for ~83%, indicating that a majority of these children's iodine intake is excessive. The implications of this are significant for the health of these children because if such exposures were to remain high for long periods of time, health conditions such as goiter, hypothyroidism and thyroiditis are highly likely.

There are two potential explanations for the high UIC in children. One is the high iodine content in the drinking water. The WMI in the villages of investigated children ranged from 177 to 344 μg/l, with the overall MWI being 247 μg/l. The overall MWI is approaching the Chinese national criteria for severe water iodine excess, which is 300 μg/l in drinking water.[6] Thus, local children are ingesting much more iodine than they need from drinking water. The potential other contributing exposure is the iodized salt. The data from this survey suggests that a large percentage of the surveyed residents were consuming iodized salt (CR ~81%), despite recognition of the problem and distribution of non-iodized salt in 2010. So, local children were ingesting extra iodine from iodized salt exacerbating their excessive iodine intake from drinking water.

Another potential contributor to dietary iodine is through common food consumption. In general, common food except for seafood contain low iodine levels in China. According to the 2009 China Food Composition (which reported the average iodine content in various foods taken from all across China),[16] grain (including wheat powder, rice and millet) usually contains <30 μg/kg of iodine, and a majority of vegetables contain <25 μg/kg of iodine. There is little iodine content in pork and cow's milk, with pork containing 17 μg/kg, sterilized cow's milk containing 19 μg/kg, though chicken and eggs were reported to contain higher iodine contents of 124 μg/kg and 272 μg/kg, respectively.

Iodine found in grains and vegetables comes from the water and soil from which crops are irrigated and grown. Theoretically, grains and vegetables grown in areas with excessive iodine are likely to contain a higher iodine content, though one study conducted in one iodine excessive province in China reported that grains and vegetables grown in areas with high water iodine did not appear to take up more iodine. This study reported that the grain and vegetables grown in areas with water iodine ranging from 380 to 1775 μg/l contained similar iodine content to those grown in areas with water iodine of 36 μg/l.[17] Given the MWI in the present study is only 247 μg/l, the locally grown grain and vegetables might not be expected to contain a high iodine content and would contribute little to the iodine intake of the children. Therefore, it is assumed that general food does not contribute much to the children's iodine intake in the region.

The food that could confound the UIC is seafood. Seafood with high iodine content, such as seaweed and fish, is an important iodine source from diet,[3] however, the local residents seldom eat seafood in their ordinary daily meals due to the high price. Hence, seafood is thought to have contributed little to the children's excessive iodine intake. Another possible iodine source is dietary supplements such as multi-vitamins and mineral tablets containing iodine. However, according to our investigation, the use of such supplements in children in this region is low. Nevertheless, to fully clarify the dietary contribution to children's iodine intake, future studies should consider all exposure pathways, including a more comprehensive exploration of dietary habits and dietary iodine for high consumption foods to get a better understanding of total exposure to iodine.

Despite the high proportion of households consuming iodized salt, it is likely that one of the reasons for MSI to only make a small and statistically insignificant contribution to overall median UIC relates to the low salt dose. According to the literature, Chinese adult's normal daily water intake is 2.5 l,[18] and rural residents' average salt uptake is 8 g.[19] Assuming a child's daily water and salt intake, respectively, is 1.5 l and 5 g, based on the MWI and MSI obtained in this survey, that is, 247 μg/l and24 mg/kg, a child's iodine intake from drinking water and edible salt would be 370 μg and 96 μg, respectively (after deducting 20% loss during cooking and serving[20]). The child's iodine dose from drinking water was much higher than that from iodized salt. So, the drinking water in these villages investigated could cause children's excessive iodine intake alone, while iodized salt could not lead to excessive iodine intake alone. Therefore, in these areas, the underlying exposure accounting for children's excessive iodine level was drinking water. These results suggest that withdrawing iodized salt currently commonly available in these areas in China is not sufficient on its own to reduce exposure to excessive iodine intake and that consuming drinking water with lower iodine content would be a more effective intervening measure. In the places where the shallow underground water contains high content of iodine, deep underground water (usually below 100 meters in depth) may contain lower iodine concentrations. Other water sources with low iodine content, which could be considered include ground surface water, such as river water, lake water and precipitation. Although changing the drinking water source is more expensive and technologically more challenging to implement, it is the most effective way to address the iodine excess given the significant contribution of drinking water to urine iodine concentrations. Using an alternative drinking water source has been widely applied in the control of endemic fluorosis in Hebei province, as well as in China. Therefore, similar measures are achievable for the control of iodine excess in drinking water.

CONCLUSION

This study assesses the respective contributions that iodine content in drinking water and consumption of iodized salt have on children's iodine nutrition. It indicates that excessive iodine in drinking water was the key contributor to children's excessive iodine intake. This study adds to the knowledge on the causes of population's excessive iodine intake in iodine excessive areas in China. It also implicates that withdrawing iodized salt in these areas in China is not sufficient alone to correct children's excessive iodine intake; a finding that provides valuable information on which to base future strategies to control excessive iodine intake in these areas. Iodine excess has emerged as a prominent public health issue posing a threat to the successful control of IDD in China. Appropriately targeted solutions to iodine excess are also conducive to the sustainable control of IDD in China.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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