Original Article

Effect of Reduction in Iodine Content of Edible Salt on the Iodine Status of the Chinese Population

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Abstract

Objective The aim of this study was to evaluate the impact of the revised Chinese National Standard GB26878-2011 'Iodine Content in Edible Salt' on the iodine status among the Chinese population.

Methods In 2011 and 2014, the probability proportionate to size sampling (PPS) was used in each Chinese province to obtain the representative data. In each sampling unit, school children aged 8-10 years and pregnant women were selected. Key indicators included urinary iodine concentration (UIC), thyroid volume (TV), and the iodine content in edible household salt.

Results The median urinary iodine concentration (MUIC) decreased between 2011 and 2014 from 238.6 to 197.9 μg/L in school-age children. The number of provinces with iodine excess decreased to zero. The proportion of children whose UIC was > 300 μg/L was 18.8% and decreased to 11% compared with 29.8% in 2011. There was no significant difference in UIC < 50 μg/L between 2014 (4.3%) and 2011 (3.7%) ($P > 0.05$). The MUIC among pregnant women in 2014 was more concentrated between 110 and 230 μg/L. The goiter rate among children aged 8-10 years was unchanged, both the goiter rate of 2011 and 2014 remaining below 5%, in view of the sustainable elimination of iodine deficiency disorders.

Conclusion The National Standard GB26878-2011 'Iodine Content in Edible Salt' that was introduced in March 2012 resulted in an overall improvement in iodine status, reducing the risk of excessive iodine intake in the Chinese population.

Key words: Urinary iodine concentration; Thyroid volume; PPS method

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INTRODUCTION

China has implemented mandatory iodization of edible salt nationwide since October 1994 as the primary strategy for reducing and preventing iodine deficiency disorders (IDD). A comprehensive and sophisticated surveillance system has provided the necessary information for assessing the performance and impact of the program, enabling necessary adjustments to fine-tune it. The surveillance system measures the total goiter rate of school-age children, the median urinary iodine concentration (MUIC) of school-age children and, starting from 2011, pregnant women, at the provincial levels on a periodic basis, and the iodine content of household salt at the county level on an annual basis. Since the start of the program, the standard for the required iodine content of edible salt has been adjusted two times to achieve optimal iodine status of the population. The most recent change took place in March 2012 when the iodine content of edible salt

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was lowered to ensure no excessive intakes of iodine in the diet and to decrease the MUIC of school-age children. Specifically, the national required iodine level was reduced from 35 ± 15 mg/kg (range: 20-50 mg/kg) to 20-30 mg/kg ± 30% (range: 14-39 mg/kg). Based on this national standard, individual provinces were authorized to set their own provincial level of either 20, 25, or 30 mg/kg ± 30% based on their conditions. A total of 13 provinces selected 30 mg/kg as their standard, while 14 provinces selected 25 mg/kg and 5 provinces selected a combination of 25 and 30 mg/kg (e.g., higher iodine content in salt labeled as suitable for pregnant women). No province selected the lowest iodine level of 20 mg/kg ± 30%. Sui et al believed that the iodine nutritional status in the Chinese population was at an appropriate and safe level in 2011[1]. This study was conducted to evaluate the impact of the revised Chinese National Standard GB26878-2011 'Iodine Content in Edible Salt' on the iodine status among the Chinese population.

MATERIALS AND METHODS

Sampling Method

China conducted two nationally representative surveys in 2011 and 2014. The surveys adopted similar methods and collected data on the iodine status of pregnant women and children aged 8-10 years in each of the 31 provinces, autonomous regions, and municipalities of China, plus Xinjiang Production and Construction Corps (hereafter referred to as '32 provinces'). The sample frame and the sample size in both surveys were statistically representative at the province level. In each province, 30 clusters were randomly selected as the primary sampling units using the principles of the probability proportionate to size sampling (PPS) method[2]. In each cluster, one elementary school was randomly selected with 12-50 children (12 children in 2011 and 50 children in 2014) aged 8-10 years. Thyroid volume (TV), urinary iodine concentration (UIC), and a sample of salt from their home were collected. In the vicinity of each chosen school, 15-20 (15 in 2011 and 20 in 2014) pregnant women had their UIC tested (for urban areas, the collection was done at county-level maternal and child health centers). Regardless of children or pregnant women, their urinary samples are casual spot samples.

Sampling was undertaken as follows. All provinces were treated in the same manner without stratification. A total of 30 sampling units were chosen per province in strict accordance with the PPS methods. For provinces with less than 30 counties, continuous selection was conducted in the present counties to determine the distribution of the 30 sampling units in all counties. For schools whose number of children was not sufficient for the survey, the gap was filled by children from the nearest primary school. China has 735 high-water-iodine townships where the iodine content in drinking water is > 150 μg/L, the majority of which are located in the Yellow River alluvial plain in Shandong, Hebei, and Henan provinces[3]. No IDDs exist in these areas; rather, iodine excess leading to a high prevalence of endemic goiter is a public health concern. Therefore, these areas were excluded from the two surveys.

Examination and Laboratory Testing

Urine Iodine Assay The analysis of iodine in urine was performed using the method of 'Spectrophotometic determination of arsenic cerium (WS/T 107)'[4]. Laboratory analysis of UIC was undertaken by provincial-level professional laboratories certified by the National Reference Laboratory.

Children's Thyroid Examination TV was assessed using B-mode ultrasonography, and classification was done in accordance with the 'Diagnostic Criteria of Endemic Goiter (WS 276)'[5]. All persons performing thyroid examination were professionals who had been trained by national-level or state-recognized provincial-level trainers.

Salt Iodine Determination The direct titration method was used to determine the iodine content of edible salt, and for Sichuan salt and other fortified edible salt, the arbitration method (GB/T13025.7)[6] was used. Laboratory titration to test for the iodine content in salt was undertaken by provincial-level professional laboratories certified by the National Reference Laboratory.

Evaluation Standard

Evaluation Criteria for Iodine Nutrition Levels The epidemiological criteria for assessing the urine iodine status were based on those recommended by the World Health Organization and other organizations. The MUIC reflected the level of iodine intake. Provinces in which the MUIC in children was < 100 μg/L were classified as iodine-deficient, provinces in which the MUIC was 100-199 μg/L were classified as iodine-suitable, those with 200-299 μg/L of MUIC were categorized as more than the appropriate amount, and those with > 300 μg/L of MUIC were classified as iodine excess[7].

Criteria for Judgment of Children's Goiter Children were classified as having a goiter if their TV exceeded the following levels: TV > 4.5 mL for 8-year-olds, TV > 5.0 mL for 9-year-olds, and TV > 6.0 mL for 10-year-olds[2,5].

Qualified Salt and Non-Iodized Salt The national standard for 'Edible Salt' (GB5461-2000) was applicable in the 2011 survey. Iodine levels in the range of 20-50 mg/kg were regarded as adequately iodized[8]. In the 2014 survey, the combination of the national standard 'Iodine Content in Edible Salt' (GB26878-2011) and the national standard for 'Edible Salt' (GB5461-2000) was applicable[9] and varied by province. Therefore, in provinces with an average salt iodine content of 25 mg/kg, salt samples with an iodine level of 18-50 mg/kg were deemed qualified, whereas in provinces with an average salt iodine content of 30 mg/kg, salt samples with an iodine level of 20-50 mg/kg were deemed qualified. Provinces that had chosen a combination of 25 and 30 mg/kg were expected to have iodine content of 18-50 mg/kg. Salt was considered to be non-iodized if the iodine level was < 5 mg/kg[10].

IDD Elimination Standard The Chinese National Criteria for Elimination of IDD (GB16006-2008) categorizes IDDs to have been eliminated in a county or province if the following three criteria have been met: (i) the proportion of 8-10-year-olds children with a UIC < 100 μg/L is < 50%, and the proportion of those with a UIC < 50 μg/L is < 20%; (ii) the goiter rate of 8-10-year-olds children is < 5%; and (iii) at least 95% of the population is consuming iodized salt and > 90% is consuming adequately iodized salt[11].

Quality Assurance

Planning meetings for the 2011 and 2014 surveys were organized by the Endemic Disease Control Center (EDCC) of the Chinese Center for Control and Prevention and were attended by the persons responsible for the IDD prevalence survey in each province. At the meetings, the IDD prevalence survey plan was introduced and details of the survey were standardized. The EDCC and the National IDD Reference Laboratory respectively held a TV B-mode ultrasonography and laboratory testing technology training course, through which technical professionals from every province were trained systematically. The National IDD Reference Laboratory assessed each province's external quality control for UIC and salt iodine determination.

Statistical Analysis

Following data collection, data were entered into electronic databases using the Epi Info version 6 software, and statistical analysis was carried out using the SPSS release 13.0 (Stats Data Mining Co. Ltd. Beijing, China). The median values for UIC and salt iodine, the prevalence of goiter, the coverage of iodized salt, and the coverage of adequately iodized salt were calculated. The Chi-square analysis was used to analyze the association between the categorical variables. The Z test was used to compare the differences between two proportions of two populations. $P < 0.05$ was considered to be statistically significant.

Ethics Statement

The ethical review board of Harbin Medical University approved this research, and informed consent was obtained from the primary caregiver of every pregnant woman and child.

RESULTS

In 2011, UIC was assessed in 14,975 children aged 8-10 years and 13,932 pregnant women[12] in 902 counties, TV examinations were conducted among 38,932 children[13], and iodine level was measured in 38,438 samples of edible salt. In 2014, UIC was assessed in 48,975 children and 19,500 pregnant women[12] in 899 counties, TV examinations were conducted among 49,214 children, and the iodine content was measured in 48,413 samples of edible salt, as shown in Table 1.

Table 1. Sample Size of Key Survey Indicators in 2011 and 2014

Year	Country	Children UIC	Pregnant women UIC	Children TV	Edible Salt
2011	902	14,975	13,932	38,932	38,438
2014	899	48,975	19,500	49,214	48,413

Results of the two surveys are listed in Table 2 according to the province, where 'Total' is the weighted average of the provinces, taking into account the sixth nationwide population census by the National Statistics Bureau[14].

In 2011, the MUIC in children and pregnant women were 238.6 and 184.4 μg/L, respectively. In 2014, the MUIC in children and pregnant women were 197.9 and 154.6 μg/L, respectively.

Iodized Salt Coverage

Overall, the median iodine content of salt decreased between 2014 and 2011 by 5.4 mg/kg, as did the national coverage of iodized and adequately iodized salt (from 98.0% to 96.3% and from 95.3% to 91.5% accordingly). More provinces experienced decreases in coverage of iodized and adequately iodized salt than increases. In 2014, the overall coverage of iodized salt was 96.3%, a slight decrease of 1.7% from the 2011 figure of 98.0%. A total of 19 provinces saw a decline in iodized salt coverage in 2014; in six provinces, the decrease was > 5% (Shanghai, Tianjin, Zhejiang, Shandong, Guangdong, and Jilin). A total of 13 provinces experienced an increase in iodized salt coverage, the biggest rise being 9.9% in Beijing. For adequately iodized salt, the coverage was 91.5% in 2014 compared to 95.3% in 2011, a fall of 3.8%, but still above the goal of 90% for reaching the Chinese IDD Elimination Standard. The coverage of adequately iodized salt decreased in 26 provinces between 2011 and 2014. In 10 provinces, the coverage decreased by > 5%. Six provinces experienced an increase in coverage of adequately iodized salt; the biggest increase was 11.8% in Beijing. Overall, a number of provinces that have achieved IDD elimination by national standards has decreased; 9 provinces had coverage with iodized salt < 95% in 2014 compared to 7 provinces in 2011 and 9 provinces that had coverage with adequately iodized salt < 90% in 2014 compared to 4 in 2011. The median iodine content of edible salt was 25.0 mg/kg in 2014, with a drop of 5.4 mg/kg from the 2011 figure of 30.4 mg/kg. All provinces saw some decrease in their median salt iodine content, with a drop of > 5 mg/kg occurring in 18 provinces, the largest being in Tibet (-11.8 mg/kg). It should be noted that while there were declines in the median iodine content in salt, no province has an iodine content < 22 mg/kg in 2014.

Urinary Iodine

Urinary Iodine Levels in Children In 2014, the MUIC of Chinese children aged 8-10 years in 32 provinces was 197.9 μg/L, a drop of 40.7 μg/L from the 2011 figure of 238.6 μg/L, bringing China to an optimal iodine status (100-199 μg/L). The MUIC decreased in all but three provinces, one of which was Tianjin where the MUIC increased from 177.9 to 196.8 μg/L. The MUIC was 100-199 μg/L in 19 provinces and 200-299 μg/L in 13 provinces. No province had MUIC > 300 μg/L. In contrast to this, in 2011, the MUIC were 100-199 μg/L in 10 provinces, 200-299 μg/L in 18 provinces, and > 300 μg/L in 4 provinces. In 2014, the proportion of children with a UIC of < 100 μg/L was 15.8%, whereas it was 12.2% in 2011. The proportion of children whose UIC was < 50 μg/L was 4.3% in 2014, which was not much different from the 2011 figure of 3.7%. The proportion of children whose UIC was > 300 μg/L was 18.8% in 2014, a drop of 11% from the 2011 figure of 29.8%. Thus, the overall decline in MUIC increased the proportion of provinces with children MUIC in the adequate range and reduced the proportion of provinces with children MUIC in more than adequate and excess ranges. The proportion of provinces with excessive MUIC was reduced to zero, as shown in Table 3.

Urinary Iodine levels in Pregnant Women Similar to children, the MUIC of pregnant women also decreased between 2011 and 2014 from 184.4 to 154.6 μg/L. In 2014 the MUIC of pregnant women was 150-250 μg/L in 13 provinces; the MUIC in Guangxi, Ningxia, Fujian, Shanghai, and Tibet was 120-130 μg/L; and the MUIC in pregnant women in Inner Mongolia was 111.6 μg/L. In 2011, the MUIC in pregnant women in Guangxi, Fujian, Guangdong, Shanghai, Tianjin, and Tibet was 130-150 μg/L.

Compared with the situation in 2011, the MUIC of pregnant women was more concentrated, the lowest provincial MUIC being > 110 μg/L and the highest provincial MUIC being < 230 μg/L (Table 2).

Children Goiter Rate Based on the results of the B-mode ultrasound examination, the prevalence of goiter among Chinese children was 2.6% in 2014, which was virtually identical to the 2.4% level noted in 2011, a non-significant difference. In 2014, among the goiter rate of children in China, only that in Shandong was > 5% (5.6%). In 2011, among the goiter rate of children in China, only that in Chongqing was > 5% (5.5%). These results were also found to be similar.

Relationship Between Children's UIC, Salt Iodine, and Goiter Rate in 2014

As shown in Table 4, the goiter rate among children in the 200-299 μg/L group was 2.6%, which

Table 2. 2011 and 2014 Province Survey Results

Province	MUIC Children (μg/L)		MUIC Pregnant Women (μg/L)		Goiter Rate (%)		Median Iodine Content in Salt (mg/kg)		Coverage of Iodized Salt (%)		Coverage of Adequately Iodized Salt (%)		Salt Iodine Content Adopted (mg/kg)	
	2011	2014	2011	2014	2011	2014	2011	2014	2011	2014	2011	2014		
Anhui	355.3	242.2	199.7	158.2	2.8	4.3	31.1	23.8	98.4	99.2	96.8	95.0	25	25
Jiangsu	345.2	208.0	174.6	155	0.1	2.6	29.9	23.4	98.8	97.4	97.2	93.9	25	25
Jiangxi	309.0	212.1	209.8	152.2	1.3	0.3	30.9	24.4	99.7	99.4	97.0	96.1	25	25
Guizhou	308.9	215.4	231.9	172.9	0.7	0.8	32.3	26.9	98.9	99.6	96.6	96.4	30	30
Shannxi	287.9	248.0	234.0	195.2	3.6	1.5	32.6	26.2	99.6	100.0	98.1	94.4	25	25
Shanxi	274.6	224.6	279.6	177.0	2.7	4.5	30.5	24.5	97.6	95.4	95.2	80.8	25	25
Yunnan	274.1	180.9	217.3	143.7	1.7	2.1	30.0	23.7	99.1	99.2	95.2	89.2	25	25
Hunan	270.8	222.4	221.9	177.1	2.3	1.0	30.7	26.1	99.6	99.0	97.1	93.7	30	30
Hubei	270.0	241.0	203.0	177.0	0.6	2.5	32.0	24.4	99.5	99.8	97.8	95.9	25	25
Inner Mongolia	259.9	150.9	212.6	111.6	3.1	1.5	30.3	23.2	99.3	98.8	98.1	90.4	25	25
Chongqing	254.1	222.7	223.8	162.7	5.5	3.2	29.9	25.9	99.7	98.8	96.7	94.5	30	30
Zhejiang	237.1	172.0	159.6	134.1	4.1	4.9	28.3	23.9	95.1	88.4	91.8	84.8	25	25
Guangxi	236.1	179.6	136.4	126.1	0.2	1.4	31.2	24.2	97.9	99.2	93.5	92.3	25	25
Xinjiang Bingtuan	235.3	207.3	183.0	139.4	3.5	0.7	31.6	29.7	97.5	99.9	96.0	99.2	30	30
Ningxia	229.0	148.0	172.7	122.6	2.0	1.2	31.0	24.9	98.3	98.0	93.5	89.6	30	30
Fujian	223.0	154.3	147.2	120.1	4.6	3.1	29.3	24.8	96.1	93.9	94.4	92.0	25	25
Qinghai	217.2	209.4	200.0	133.2	0.2	0.3	32.7	26.2	93.3	93.8	90.0	84.2	30	30
Hebei	216.9	179.3	159.5	133.0	2.8	1.2	29.9	23.1	93.9	95.8	90.0	92.3	25	30
Gansu	215.6	169.8	177.0	161.8	2.8	3.4	27.6	26.6	98.0	99.5	88.5	96.7	30	30
Heilongjiang	213.0	197.8	203.0	185.4	1.4	1.3	29.7	24.8	100	99.0	99.0	96.6	25	30
Hainan	204.3	181.6	153.6	130.5	0.2	0.3	32.3	25.4	94.9	98.5	92.3	95.7	25	25
Sichuan	202.2	179.2	170.9	138.4	4.1	4.9	32.8	28.3	99.9	99.6	98.1	96.8	30	30
Jilin	195.4	157.4	189.2	146.5	2.5	1.7	31.3	22.8	99.2	83.2	96.4	70.8	25	25
Liaoning	189.0	159.1	163.2	131.5	2.4	1.8	30.2	23.7	99.3	98.9	97.9	95.3	25	30
Henan	188.6	230.2	224.9	225.0	4.3	1.7	28.7	26.7	97.8	96.9	93.1	90.5	30	30
Guangdong	186.5	171.2	133.5	131.6	3.5	3.0	32.1	25.4	97.5	92.2	96.1	90.6	25	30
Shandong	186.0	214.7	151.7	144.4	1.9	5.6	27.7	24.1	99.4	91.4	96.2	86.1	25	25
Xinjiang	185.0	178.0	193.9	162.4	2.2	1.6	30.2	26.4	99.6	99.9	97.5	97.8	30	30
Shanghai	181.6	171.4	139.8	126.5	0.1	0.9	28.7	25.8	92.3	85.6	88.2	76.0	30	30
Beijing	178.9	177.0	155.2	148.2	0.1	0.7	30.0	25.5	89.1	99.0	86.4	98.2	25	30
Tianjin	177.9	196.8	145.3	149.9	2.5	1.6	29.6	27.2	93.1	87.7	90.1	81.9	30	30
Tibet	166.1	140.0	132.7	129.2	1.0	2.4	38.4	26.6	94.6	90.7	88.1	86.9	30	30
Total*	238.6	197.9	184.4	154.6	2.4	2.6	30.4	25.0	98.0	96.3	95.3	91.5		

Note. *Total implies weighted average of the provinces. In the year 2014, some children aged 7 and 11 years were included in Shandong survey; some children aged 7, 11, and 12 years were included in Henan survey. 25, 30 implies for the general population, 25 mg/kg; for pregnant women, 30 mg/kg.

was higher than that in the 100-199 μg/L group (Z = 33.60, P < 0.05), indicating that the appropriate range of urine iodine in children extended to 100-299 μg/L was not suitable for the general population in China[15].

According to Table 5, there was an U-shaped association between household iodine level in salt or MUIC and the goiter prevalence among children[16]. At an iodized salt level of 5-19.9 mg/kg, the MUIC was found to be within the range of adequate iodine concentration (179.2 μg/L) and also corresponded to the lowest goiter rate (1.9%).

DISCUSSION

Before discussing the results referring to the article, we describe China's History of Salt Iodization and IDD Monitoring. From the year 2011 to 2014, the iodized salt coverage at the household level ranged from 98.0% to 96.3%. The discussion is based on these iodized salt coverage values. The order of the discussion is the national standard for edible salt, the UIC level in the population, and the goiter rate among children aged 8-10 years.

Table 3. Children's Urinary Iodine Frequency Distribution in 2011 and 2014

Year	< 50 μg/L	< 100 μg/L	> 300 μg/L
2011	3.70%	12.20%	29.80%
2014	4.30%	15.80%	18.80%

Table 4. UIC of Children, Median Salt Iodine Level, and Goiter Rate

UIC (μg/L)	Iodine Content of Salt (mg/kg)		Goiter Rate (%)	
	Sample Size	Median Iodine Content	Sample Size	Goiter Rate
< 50	1,920	25.0	1,988	2.1
50-99	5,600	25.0	5,866	2.1
100-199	17,142	25.1	17,707	2.0
200-299	12,854	25.4	12,888	2.6
> 300	8,927	25.4	8,776	2.7

Table 5. Household Salt Iodine Content, Children's MUIC, and Goiter Rate

Household Iodine Level in Salt (mg/kg)	Children MUIC (μg/L)		Goiter Rate (%)	
	Sample Size	MUIC	Sample Size	Goiter Rate
< 5	1,823	157.2	1,773	2.4
5-19.9	4,404	179.2	4,254	1.9
20-49.9	42,070	192.6	40,524	2.3
> 50	111	235.5	106	2.8

China's History of Salt Iodization and IDD Monitoring

Before October 1994, China implemented a strategy of iodizing salt in IDD-prevalent areas but not in non-IDD-prevalent areas[17]. Potassium iodide was added to edible salt before 1989, which was changed to potassium iodate after 1989[18]. Starting from October 1, 1994, a national universal salt iodization strategy was implemented throughout the country in which all edible salt was iodized, except the salt distributed in high-water-iodine areas. At the start of the program, the national standard was stipulated and the average iodization level was 50 mg/kg, with a minimum of 40 mg/kg for salt leaving the factory, with no less than 30 mg/kg at the retail level and finally, no less than 20 mg/kg in households. The legislation also required that salt used by the food processing industry and animal husbandry should be iodized[19-20]. The national standard for the iodine content was lowered to 35 mg/kg on October 1, 2000[8], and again, on March 15, 2012, it was reduced to 25 or 30 mg/kg, as decided by provinces according to their own circumstances[9].

China started to monitor IDD in 1990 by establishing 22 monitoring points in 16 provinces, with monitoring indicators including household coverage of iodized salt and adequately iodized salt, UIC, and goiter. In 1994, the principles of PPS sampling methods were adopted for some national IDD surveys. In 1995, the monitoring scope was expanded to cover the entire country, and the monitoring system was divided into the following two distinct activities: annual county-level monitoring of iodized salt and provincial-level IDD surveys carried out every 2-5 years. In 2008, monitoring of IDD-high-risk areas was included in the original monitoring system. Thus, the current monitoring system consists of the following three elements: iodized salt monitoring, IDD-high-risk area monitoring, and disease surveillance[21]. The data from the two national IDD surveys in 2011 and 2014 discussed in this article were actually derived from two rounds of IDD prevalence surveillance in China.

National Standards for Edible Salt

The GB26878-2011 is a national standard for iodized salt implemented as of March 15, 2012[9]. According to the 'Notice on the Implementation of the National Standard for Iodine Content in Edible Salt' issued by eight ministries, including the former Ministry of Health, 'starting from 15 March 2012, all producers of iodized salt shall follow the new standard in their production. Iodized salt produced before that date may continue to be sold until the shelf life expires, and products not marked with a date of expiration may be sold within three years after the date of production[22]'. Thus, iodized salt produced in accordance with the old standard (35 mg/kg) was sold until March 15, 2015. Therefore the coverage of adequately iodized salt for 2014 in the 'buffer period' was calculated based on the combination of the new and the old standards. After the national standard was adjusted in 2012, the provincial standard of 25 mg/kg ± 30% (18-33 mg/kg) was adopted in 14 provinces, including Shaanxi; 30 mg/kg ± 30% (21-39 mg/kg) in 13 provinces, including Sichuan; and in 5 provinces, including Heilongjiang, Hebei, Liaoning, Guangdong, and Beijing, a separate standard of 30 mg/kg ± 30% (21-39 mg/kg) was adopted for pregnant women, while the standard of 25 mg/kg ± 30% was applied to salt for the rest of the population. We calculated the MUIC in children and pregnant women from the provinces using 25 mg/kg and those using 30 mg/kg. The MUIC in children were 193.3 μg/L from 14 provinces using 25 mg/kg and 189.9 μg/L from 13 provinces using 30 mg/kg. No difference was detected between these values. Similarly, the MUIC in pregnant women from 14 provinces using 25 mg/kg was 145.6 μg/L, which was not different from the value 150.7 μg/L obtained from 13 provinces using 30 mg/kg. Such a minor difference from the concentration of iodized salt could not lead to any difference among the MUIC in children and pregnant women in 2014. However, for the period between 2011 and 2014, every 1 mg/kg decrease in the iodine level of domestic salt led to a reduction of 7.5 μg/L in children's MUIC and a reduction of 5.5 μg/L in pregnant women's MUIC.

Population's UIC Level

The UIC of children aged 8-10 years was used as a proxy to represent the iodine status of the general population. In 2011, the MUIC of children was in excess in some provinces, including Anhui (355.3 μg/L), Jiangsu (345.2 μg/L), Jiangxi (309.0 μg/L), and Guizhou (308.9 μg/L), but by 2014, all these figures had declined to above the adequate level, at 242.2, 208.0, 212.1, and 215.4 μg/L, respectively. The number of provinces classified as above the adequate level was 18 in 2011 and 13 in 2014. The number of provinces classified as having optimal status increased from 10 in 2011 to 19 in 2014. Although three provinces (Henan, Shandong, and Tianjin) experienced an increase instead of a decrease in children's MUIC in 2014, the observed levels were still < 300 μg/L. No province was observed to have iodine excess in 2014. Among the 32 provinces nationwide, 29 experienced a decline in MUIC, accounting for 90.6%, which represented the overall trends for iodine status of the general population in 2014. The overall decline in the iodine levels was the direct consequence of a reduction in the iodine levels in iodized salt. In 2014, the median iodine content in iodized salt was decreased by 5.4 mg/kg, and all provinces showed a declining trend without exception, compared with that in 2011. In 2014, the median iodine content of domestic salt was 25.0 mg/kg, ranging from 22.8 to 29.7 mg/kg. With adjustment of the iodine content in household salt, the UIC level of children declined to an appropriate level, both nationally and provincially. Results of these analyses confirm that the new National Standard GB26878-2011 'Iodine Content in Edible Salt' has effectively improved the iodine status among children, and by extension, it may be concluded that the iodine status of the entire Chinese population is approaching an optimal level.

The UIC of pregnant women serves as a biomarker to represent the iodine status of the specific population. The recommended iodine intake of pregnant women is more than that of children. The national MUIC of pregnant women in China declined from 184.4 μg/L in 2011 to 154.6 μg/L in 2014, both levels being > 150 μg/L. No province had an MUIC > 250 μg/L among pregnant women in 2014. In 2014, the highest MUIC was 225.0 μg/L, and the lowest MUIC was 111.6 μg/L; in 2011, the highest MUIC was 279.6 μg/L, and the lowest was 132.7 μg/L. These ranges indicated that the iodine levels of pregnant women tend to concentrate in 2014 compared with those in 2011. However, between 2011 and 2014, the number of provinces where the MUIC of pregnant women was 100-150 μg/L increased from 6 to 19, according to the iodine suitable standard of 150-249 μg/L recommended by the WHO and other international organizations in

2007[23], a MUIC of 100-150 μg/L implies iodine deficiency level; however, further research is required to determine whether the cut-off point of 150 μg/L for pregnant women is correct. The reported cut-off of 150 μg/L for adequate MUIC in pregnant women has been established by the WHO assuming a daily urinary volume of 1.5 L. During pregnancy, there may be an increase in the glomerular filtration rate, thus leading to an increased daily urinary volume (> 1.5 L), which could lead to an overestimation of iodine deficiency in pregnant women. Therefore, the UIC measured using a casual spot urinary sample in pregnant women could be inaccurate and could not be used as an indicator for estimating the iodine intake.

Goiter among Children Aged 8-10 Years

The goiter rate among children aged 8-10 years represents their state of IDD. Examined using the B-mode ultrasound, the goiter rates among children aged 8-10 years were 2.4% and 2.6% in 2011 and 2014, respectively, showing no significant change, and both values were below the Chinese IDD Elimination Standard of 5%. Only one province had a goiter rate of > 5% in the two surveys, and the condition was mild. Chongqing had a goiter rate of 5.5% in 2011 and Shandong had 5.6% in 2014. Compared with the situation in 2011, the goiter rate was decreased in 16 provinces and increased in the other 16 provinces in 2014, although all the rates were < 5%, indicating that sustainable elimination of IDD had been achieved. However, the data of the 2011 and 2014 surveys are limited to only diffuse goiter, not covering nodular goiter. Therefore, one of the tasks of future research is how to include nodular goiter into the scope of goiter survey.

In summary, compared with the situation in 2011, the year before the implementation of GB26878-2011, children's MUIC dropped from above the adequate level to the adequate level in 2014, i.e., 2 years after the implementation of GB26878-2011. The diffuse goiter rate was not increased, still remaining below 5%. IDDs in China have been eliminated sustainably. In conclusion, the prevailing national standard GB26878-2011 'Iodine Content in Edible Salt' is more appropriate for the Chinese population, and the Chinese government's decision to reduce iodine concentration in iodized salt has been a correct and programmatically appropriate adjustment.

The study population, which is from all provinces in China, covers a wide range of people, including children aged 8-10 years who represent the general population and pregnant women who represent the special needs population. The detection indicators included urinary iodine, salt iodine, and total goiter rate, and the epidemiological analysis of the relationship among the three indicators was conducted in depth, which revealed some regularities. The time points selected in the two surveys are appropriate, respectively. The year 2011 is one year before adjusting the iodized salt concentration, and the year 2014 is two years after reducing the iodine content in salt. The two surveys had a similar design, and the samples were randomized. Comparison of the results between the two surveys demonstrated the effect of reducing the iodized salt concentrations.

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AUTHOR CONTRIBUTIONS

HE Qian performed the data analyses and wrote the manuscript; SU Xiao Hui contributed significantly to analysis and manuscript preparation; LIU Peng performed the data collection and provided constructive advices; FAN Li Jun contributed to data analysis; MENG Fan Gang was responsible for the ultrasound; LIU Li Xiang and LI Ming helped in manuscript preparation; and LIU Shou Jun contributed to the conception of the study.

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REFERENCES

1. Sui HX, Li JW, Mao WF, et al. Dietary iodine intake in the Chinese population. Biomed Environ Sci, 2011; 24, 617-23.
2. World Health Organization, UNICEF, ICCIDD. Indicators for assessing iodine deficiency disorders and their control programmes. Review version. Geneva: WHO, 1993.
3. Ministry of Health, Ministry of Industry and Information. Notice on Further Improving the Supply and Management of

Non-iodized Edible Salt. Issued by Bureau of Disease Control and Prevention in Ministry of Health, 2009. (In Chinese)

4. Yan YQ, Zhang YP, Liu LJ, et al. Method for determination of iodine in urine by As^{3+}-Ce^{4+} catalytic spectrophotometry. Health standard of China (Beijing), 2006; WS/T107-2006. (In Chinese)
5. Liu SJ, Chen ZH, Jia QZ, et al. Diagnostic criteria for endemic goiter. Health Standard of China (Beijing), 2007; WS276-2007. (In Chinese)
6. National Quality Technical Supervision Department. The determination of the general method of iodine test in the salt industry. National Standards of China (Beijing), 1999; GB/T 13025.7-1999. (In Chinese)
7. WHO, UNICEF, ICCIDD. Assessment of iodine deficiency disorders and monitoring their elimination: a guide for programme managers. 2nd ed. Geneva: WHO, 2001.
8. National Quality Technical Supervision Department. Edible salt. National Standards of China (Beijing), 2000; GB5461-2000. (In Chinese)
9. Ministry of Health. Iodine concentration in edible salt. National Standards of China (Beijing), 2011; GB26878-2011. (In Chinese)
10. Ministry of Health. Notice on issuing Plan of National Iodized Salt Monitoring. Issued by General Office in Ministry of Health, 2004. (In Chinese)
11. Ministry of Health, National Standardization Management Committee. Criteria for elimination of iodine deficiency disorders. National Standards of China (Beijing), 2008; GB16006-2008. (In Chinese)
12. Liu P, Su XH, Li M, et al. Should urinary iodine concentrations of school-aged children continue to be used as proxy for different population? Analysis of data from Chinese national surveys. Br J Nutr, 2016; 107, 1-9.
13. Chao H, Zhang YF, Liu P, et al. Relationship between iodine content in household iodized salt and thyroid volume distribution in children. Biomed Environ Sci, 2016; 29, 391-7.
14. The sixth census bulletin. State Statistics Bureau, 2011. http://www.stats.gov.cn/tifx/jdfx/t20110429_402722512.htm. [2018-7-1]. (In Chinese)
15. Zimmermann MB, Aeberli I, Andersson M, et al. Thyroglobulin is a sensitive measure of both deficient and excess iodine intakes in children and indicates no adverse effects on thyroid function in the UIC range of 100-299 μg/L: a UNICEF/ICCIDD Study Group report. J Clin Endocrinol Metab, 2013; 98, 1271-80.
16. Cui SL, Liu P, Su XH, et al. Surveys in areas of high risk of iodine deficiency and iodine excess in China，2012-2014：current status and examination of the relationship between urinary iodine concentration and goiter prevalence in children aged 8-10 years. Biomed Environ Sci, 2017; 30, 88-96.
17. State Council of the People 's Republic of China. Interim Measures for Prevention and Treatment of Endemic Goiter by Salt Iodization. State Council [1979] No.296 document, 1980. (In Chinese)
18. Ministry of Health, Ministry of Communications, State Administration for Industry and Commerce, et al. Joint Notification of Potassium Iodate instead of Potassium Iodide Processing Iodized Salt. Issued by Ministry of Health, 1989. (In Chinese)
19. Regulations of the State Council of the People 's Republic of China on the Administration of the Elimination of Iodine Deficiency Hazards in Salt Iodization. The State Council [1994] No. 163 document, 1994. (In Chinese)
20. State Council General Office. China Program for the Elimination of Iodine Deficiency Disorders in 2000. Issued by General Office of State Council, 1994. (In Chinese)
21. Endemic Disease Control Center of the Chinese Center for Disease Control and Prevention. Notice on the issuance of the National Monitoring Program for Iodine Deficiency Disorders and Other Endemic Diseases. Issued by Disease Control Center of the Chinese Center for Disease Control and Prevention, 2012. (In Chinese)
22. Ministry of Health. Notice on the Implementation of the National Standard for Iodine Content in Edible Salt. Issued by eight Ministries, 2012. (In Chinese)
23. WHO, UNICEF, ICCIDD. Assessment of iodine deficiency disorders and monitoring their elimination, a guide for programmes managers. 3rd ed. Geneva: WHO, 2007.