CLINICAL RESEARCH

Micro-environment and the Iodine Status of Children: an Intervention Study

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Abstract
Purpose: To assess the iodine status of 10–12-year-old children, studying the role of environmental factors and the effect of iodine supplementation on those who were deficient.

Design: Population survey of 10 randomly selected schools, with a placebo-controlled intervention study of the administration of iodine supplements to those found to be deficient.

Methods: A total of 770 children were screened for urinary iodine estimation and estimation of the iodine in salt. A general profile and various micro-environmental factors, such as socio-economic status, sanitary status, personal hygiene, and goitrogen intake, were also studied. Selected deficient children were supplemented with an iodine solution.

Results: The results of urinary iodine excretion revealed that 44.7% of the children suffered from iodine deficiency. Iodized salt was consumed by 92% of the families. The total goitre rate was 35.2% in the studied population. Significant differences were found in the socio-economic status, housing and sanitary conditions of the families of deficient and non-deficient children. The dietary intake pattern revealed that the diet of the children was low in calories, iodine and β-carotene. The supplementation of 112 mg of iodine to the experimental group over 10 weeks significantly decreased the deficiency. The analysis of the results showed that for iodine-deficient children the concentration of iodine in salt should be 60 ppm.

Conclusion: The micro-environment plays an important role in iodine deficiency disorders. The deficient children in the area required a therapeutic dose of iodine to improve their low iodine status. The study urges the need for intervention to control iodine deficiency disorders.

Keywords: micro-environment, iodine, children, socio-economic status, sanitary status, personal hygiene, goitrogen intake, urinary iodine excretion, goitre.

INTRODUCTION
It is estimated that 1000 million people in the world suffer from an iodine deficiency problem [1]. Iodine deficiency was probably the first nutritional disease recognized by mankind. Both the effects of iodine deficiency in the form of goitre and cretinism and its dietary treatment have been known since ancient times [2]. The thyroid gland requires iodine to produce its hormone. Its response to chronic iodine deficiency is characteristic. As the circulating thyroid stimulating hormone (TSH) rises, the response to TSH in the pituitary gland also increases. The thyroid gland undergoes hypertrophy and hyperplasia followed by nodular transformation at multiple sites throughout the gland. Therefore, there
is enhanced trapping of iodine by the gland with faster turnover and diminished urinary excretion of iodine. There is an altered pattern of distribution of tracer iodine in the gland, resulting in increased monoiodothyronine/diiodothyronine and T₃/T₄ ratio and the circulating T₄ levels may be reduced while those of T₃ are either maintained or increased [3]. Goitre and cretinism are not the only outcome of iodine deficiency, as it causes a broad spectrum of disorders that may begin before birth and persist throughout the life cycle. Infants born to iodine-deficient women may be cretins, with a short life expectancy, or be mentally handicapped, deaf, mute and spastic [4]. Although the quantity of iodine required by an individual does not exceed a teaspoonful over a lifetime, its deficiency continues to be a major public health problem [5].

In spite of the recognition of iodine deficiency as a cause of crippling disorders affecting millions of people and the subsequent implementation of the National Iodine Deficiency Disorders Control Programme, the problem continues unabated. Today there is an urgent need to recognize the problem of iodine deficiency in its true perspective and to take immediate and appropriate steps to eradicate it. Iodine deficiency disorder morbidity is entirely preventable with an appropriate dose of iodine. The disorder can be totally eliminated by prophylaxis using iodine administration in salt, oil, water or any other appropriate vehicle [6]. The prevention of iodine deficiency in childhood and adolescence needs to be a public health issue.

Evidence of the prevalence of iodine deficiency and goitre has been reported in the Tarai belt of India. Studies have also revealed that in this area, in spite of the use of iodized salt, there is a deficiency of iodine, leading to the conclusion that the level of iodine in the salt is not adequate enough to meet the requirements of the people in the area, or that there is an interplay of other factors that show goitrogenic roles [7]. The micro-environmental factors of children include overcrowding, sanitary conditions, garbage disposal, practices related to personal hygiene, inadequate dietary intake, poor knowledge and education, possession of modern facilities [8]. The present study was carried out to assess the iodine deficiency status of 10–12-year-old children, combined with a study of the micro-environmental factors and the effect of supplementation on the iodine status of these children.

SUBJECTS AND METHODS

Study Design

The study was planned in four phases. In phase I, 10 primary schools from Udham Singh Nagar district were selected at random. The earlier study has shown goitre prevalence of 34.5% [7]. For the expected prevalence between 30–40% at 99% level of confidence and 5% desired absolute precision, the number of subjects should not be less than 637 [9]. For the present study all 770 children of 10–12 years age group from 10 schools included mode adequate sample size. In phase II, the urinary iodine, salt iodine and goitre grade of all the selected children were estimated. The general profile of the children was also studied. In phase III, experimental and control cohorts were formed randomly. The experimental cohort was given a supplementary iodine solution for 10 weeks. In phase IV, urinary iodine excretion of the experimental and control cohorts was estimated to study the effect of intervention.

Study Area

The study was conducted in villages situated under the Kumaon foothills of Uttar Pradesh, India, commonly known as the Tarai belt of the Himalayas. The climate of this region is characterized by fairly long and severe winters, hot and humid summers with active monsoon seasons.
Urinary Iodine Estimation

Iodine was estimated from morning urine samples of the subjects using the procedure of Dunn and Harr [10].

Assessment of Goitre Grade

The subjects were clinically examined for goitre grade using the procedure given by the WHO [11].

Salt Iodine Estimation

The children were asked to bring approximately 20 g of salt from their family kitchen in self-sealing polythene bags. The iodine content of the salt was assessed using an iodometric titration method [12].

Assessment of Micro-environmental Factors

Information on the families and subjects regarding the educational status of the parents, the socio-economic status of the family [13], housing and sanitary status, the personal hygiene status of the children [14] and nutrient and goitrogen intake was collected using a pre-tested proforma.

Socio-economic status. Scores were calculated using a number of attributes, namely family size, number of children in the family, income, education, occupation, possession of material goods. Scores were given on the basis of a numbered scale [13], e.g. in the category of material possessions, bicycle, radio and chairs were given one point each, and scooter and television were given two points each. Similarly, points were given for each item in the proforma. The total range of scores was 1–91. On the basis of the scores obtained, the study population was divided into three groups (low, medium, high) by dividing the population into three equal groups after arranging their scores in ascending or descending order. The range of scores obtained was 7–41.

Housing and sanitation. The scores on housing and sanitary conditions were based on general cleanliness, the space available, storage facilities and the disposal of waste.

Personal hygiene. Assessment of the personal hygiene status was based on regular cleaning of teeth, tongue, gums, eyes, hands (particularly after defecation), nails, hair and clothes. The children were divided into the categories of poor, fair and good, depending on the scores obtained.

Dietary intake. Dietary intake was studied using a 24-hour recall and food frequency method. Nutrient intake was calculated from food intake by the 24-hour recall method using table values [15]. The method was validated using a weighment method for 10% of the subjects. The results were found to be comparable.

Classification of Iodine Deficiency and Intervention by Iodine Supplementation

On the basis of urinary iodine excretion, the subjects were divided into cohorts, namely severely, moderately and mildly deficient and non-deficient, having urinary iodine < 2.0, 2.0–4.9, 5.0–9.9 and > 10.0 μg dl⁻¹, respectively [16].
For the intervention study, three groups were formed: (i) experimental group (supplemented deficient children); (ii) control I (non-supplemented deficient children); (iii) control II (non-supplemented non-deficient children). A colloidal solution of iodine was given to randomly selected deficient children (with parental consent) for 10 weeks at the rate of 7 ml week$^{-1}$. Five millilitres of colloidal iodine solution contained 8 mg of iodine. Thus, a total of 112 mg of iodine (1.6 mg iodine ml$^{-1}$ iodine solution) was given during the study.

**Post-intervention Urinary Iodine Estimation**

The urinary iodine of the children from the experimental cohort was measured twice, i.e. after 5 and 10 weeks of iodine supplementation, to study the progressive effect, if any, on the iodine status of the children studied. Urinary iodine was also measured in the children from control cohort I (non-supplemented deficient) and control cohort II (non-supplemented non-deficient) after 10 weeks.

**Statistical Analysis**

The data were analysed for percentage, mean, correlation coefficient and analysis of variance (ANOVA). Simple and multiple regression equations were constructed.

**RESULTS**

**Urinary Iodine Estimation**

Children with a urinary iodine concentration of less than 10 $\mu$g dl$^{-1}$ were classified as deficient, the remaining children were classified as non-deficient. Urinary iodine estimation showed that the total iodine deficiency was 44.7%. Deficiency prevalence was higher in adolescent girls (56.2%) than in boys (34.1%). The mean iodine excretion was 1.18, 3.83, 7.86 and 12.6 $\mu$g dl$^{-1}$ in severely, moderately and mildly deficient and non-deficient cohorts, respectively (Fig. 1).

**Goitre Prevalence**

The total goitre prevalence in the study area was 35.2% (Fig. 2). As per the criterion of the
WHO [10], 32.4% of the children suffered from goitre grade 1 and 2.8% suffered from goitre grade 2.

**Iodine Content of Salt Samples**

Five per cent of the salt samples were crystalline and 95% were powdered. Iodometric titration showed that in the deficient cohort, 84.7% of the salt samples had more than 15 ppm iodine, while 15.3% had less than 15 ppm iodine ($p < 0.05$) (Table 1). In all, 12.7% of the children were consuming salt with an inadequate iodine content.

**Educational Status of the Parents**

The educational status of the parents revealed that 51% of fathers and 83% of mothers were illiterate. In both the deficient and non-deficient cohorts, the fathers had a better educational status than the mothers.

**Socio-economic Status of the Population**

The socio-economic status scores of the selected population group ranged from 7 to 41 out of a total of 91 points. The study group was divided into three groups based on their socio-economic status scores: lower (7–12), middle (13–21) and higher (22–41). A larger percentage of children (54.1%) came from the middle socio-economic group (Table 2). A higher percentage of iodine-deficient children had a lower socio-economic status. The per capita income of the surveyed families ranged from Rs. 140 to 1000 per month (approximately US $3.3–23.6).

<table>
<thead>
<tr>
<th>ppm of salt iodine</th>
<th>Deficient children</th>
<th>Non-deficient children</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>5.1</td>
<td>2.2</td>
<td>4.2</td>
</tr>
<tr>
<td>1–15</td>
<td>10.2</td>
<td>4.5</td>
<td>8.5</td>
</tr>
<tr>
<td>≥15</td>
<td>84.7</td>
<td>91.0</td>
<td>87.3</td>
</tr>
</tbody>
</table>
TABLE 2. Distribution of families of children on the basis of socio-economic status, sanitary status and personal hygiene

<table>
<thead>
<tr>
<th></th>
<th>Iodine deficient (%)</th>
<th>Non-deficient (%)</th>
<th>Total (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Socio-economic status</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lower</td>
<td>25.5</td>
<td>18.2</td>
<td>23.2</td>
</tr>
<tr>
<td>Middle</td>
<td>54.1</td>
<td>54.5</td>
<td>54.2</td>
</tr>
<tr>
<td>Upper</td>
<td>20.4</td>
<td>27.7</td>
<td>22.5</td>
</tr>
<tr>
<td><strong>Sanitary status</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poor</td>
<td>31.6</td>
<td>9.1</td>
<td>24.6</td>
</tr>
<tr>
<td>Fair</td>
<td>46.9</td>
<td>47.7</td>
<td>47.2</td>
</tr>
<tr>
<td>Good</td>
<td>21.4</td>
<td>43.2</td>
<td>28.2</td>
</tr>
<tr>
<td><strong>Personal hygiene status</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poor</td>
<td>17.3</td>
<td>11.3</td>
<td>15.5</td>
</tr>
<tr>
<td>Fair</td>
<td>79.6</td>
<td>88.6</td>
<td>82.2</td>
</tr>
<tr>
<td>Good</td>
<td>3.1</td>
<td>0.0</td>
<td>2.0</td>
</tr>
</tbody>
</table>

**Housing and Sanitary Conditions of the Families**

The average score gained for housing and sanitary conditions for the non-deficient cohort was 22 out of 30, with the average score being 16 out of 30 for the deficient cohort. Poor housing conditions were prevalent in 24.6% of families. Fair and good housing conditions were prevalent in 47.2 and 28.2% of families, respectively (Table 2). This difference in the two cohorts on housing and sanitary conditions was highly significant ($p < 0.01$). In the present study, only 28.2% of the children’s families had adequate sanitary conditions.

**Personal Hygiene Status of the Children**

All the selected children were studied for their personal hygiene status (Table 2). The majority of children (82.4%) followed fair hygiene practices. Only 2.1% of the children followed good hygiene practices. Significantly ($p < 0.05$) more deficient children followed poor personal hygiene practices.

**Dietary Intake of the Children**

The usual dietary pattern was three meals a day. Wheat and rice were the staple cereals consumed by the children. A large number of children (76.4%) were non-vegetarian; however, the frequency of meat was once a month or less. Potato consumption was high throughout the year as it was consumed at least once every day by 95% of the children. The frequency of consumption of vegetables considered as goitrogenic was high during the winter season. Eighty-two per cent of deficient children consumed goitrogenic foods such as cauliflower, cabbage, mustard leaves and spinach, etc., three times or more in a week during the winter season.

**Energy and Nutrient Intake of the Children**

The consumption pattern of energy and nutrients is shown in Table 3. The average energy and protein intake of the non-deficient children was significantly more than that of the iodine-deficient children ($p < 0.05$). The diet without iodized salt provided only 20–23% of the recommended daily allowance (RDA) for iodine. The $\beta$-carotene intake was 14% lower than the RDA in the study population. In the non-deficient cohort, the average intake of $\beta$-carotene was comparable with the RDA. The $\beta$-carotene intake in non-deficient and deficient subjects was statistically different. The interrelationship of the analysis of energy
and nutrient intake and urinary iodine revealed a significant increase in urinary iodine concentration with an increase in calorie and \( \beta \)-carotene intake \((p < 0.01)\).

**Effect of Intervention**

The iodine-deficient cohort was divided into two cohorts, namely the experimental cohort and control cohort I. In the experimental cohort, 11.5, 34.4, 57.1% of the children were suffering from a severe, moderate and mild form of iodine deficiency, respectively. Control cohort I comprised 5.4, 27.0 and 67.6% of children with a severe, moderate and mild form of iodine deficiency, respectively. Control cohort II consisted of non-deficient subjects. The experimental cohort and control cohort I were comparable. The experimental group of children was given an iodine solution. After an intake of 56 mg of iodine over 5 weeks there was a significant \((p < 0.01)\) reduction in severe iodine deficiency. There was also a reduction in the number of moderately deficient children (Fig. 3). One child had reached the normal level, i.e. iodine excretion of more than 10 \( \mu \)g dl\(^{-1}\). After 10 weeks of supplementation, none of the children remained in the severe deficiency cohort and 19.7% had a moderate deficiency. The decline in severe and moderate deficiency was highly significant \((p < 0.01)\). In only 10 weeks, 9.8% of the children had reached the normal level. There was no significant change in the iodine status of the children of control cohort I and control cohort II. This emphasizes that the difference in the experimental cohort was due to supplementation.

**Statistical Analysis**

The following simple regression equations were constructed. These show the definite relationships and effects of all the factors on each other:

(i) \[ Y = 1.34 - 0.083X; \text{ where } Y = \text{ goitre grade}; X = \text{ urinary iodine (} \mu \text{g dl}^{-1} \) \]

(ii) \[ Y_2 = 8.065 + 0.047X_2; \text{ where } Y_2 = \text{ urinary iodine}; X_2 = \text{ salt iodine (ppm)} \]

(iii) \[ Y_3 = 0.16X_3 - 6.48; \text{ where } Y_3 = \text{ goitre grade}; X_3 = \text{ salt iodine (ppm)} \]

To study the combined effect of all the factors studied the following multiple regression equations were constructed:

(iv) \[ Y = 44.23 - 0.233X_1 + 35.15X_2 + 0.238X_3 - 1.02X_4 - 0.35X_5 - 0.4216X_6 - 0.572X_7 \]

Where \( Y = \text{ salt iodine (ppm)}; X_1 = \text{ urinary iodine (} \mu \text{g dl}^{-1} \); X_2 = \text{ goitre grade}; X_3 = \text{ father’s
education; $X_4$ = mother’s education; $X_5$ = socio-economic status score; $X_6$ = sanitary conditions score; $X_7$ = personal hygiene status score.

(v) $A = 2.3 - 4.12B_1 + 0.135B_2 + 0.0071B_3 - 0.051B_4 + 0.0961B_5 + 0.151B_6 + 0.168B_7$

Where $A$ = urinary iodine (μg dl$^{-1}$); $B_1$ = goitre grade; $B_2$ = salt iodine (ppm); $B_3$ = father’s education; $B_4$ = mother’s education; $B_5$ = socio-economic status score; $B_6$ = sanitary conditions score; $B_7$ = personal hygiene status score.

DISCUSSION

Iodine, an essential micronutrient, is necessary for physical and mental well-being. An adequate intake of iodine is of immense importance to global development. Iodine deficiency at its present magnitude means that investment in economic development and education cannot achieve their potential unless this problem is adequately addressed [17]. Urinary iodine estimation showed that 41.8% of children suffered from iodine deficiency. The iodine level in urine reflects the subject’s intake. Girls had a poorer iodine status as compared with boys, which is reflected in a higher prevalence of goitre and lower urinary iodine excretion in girls. The age of 10–12 years is the time of the puberty growth spurt in girls; it arrives later in boys. The physiological needs for thyroxin are increased to sustain growth. In the absence of additional intake, urinary iodine excretion is diminished to meet the body’s needs. Hence, the higher prevalence of goitre in girls. The total goitre prevalence in girls was 38.2%.

Urinary iodine content correlated significantly ($r = -0.763, p < 0.01$) with goitre grade. In Table 4, all the parameters studied are classified on the basis of urinary iodine excretion. It was found that as urinary iodine excretion increased, goitre grade decreased.

Urinary iodine excretion and goitre grade in the four cohorts was statistically different ($F = 195.44; p < 0.01$). The consumption of iodine was not different in the mild and moderate cohorts, but there was a significant difference in severely deficient and non-deficient subjects ($F = 33.48; p < 0.05$). Of the total salt samples, 12.67% had an iodine content below the minimum recommended level of 15 ppm. Urinary iodine content correlated positively with salt iodine content ($r = 0.134, p < 0.05$). Between 10 and 15 g of salt is consumed daily by an individual on a regular basis. To meet the present recommended requirement of iodine, i.e. 150 μg day$^{-1}$, the salt is fortified with iodine at the level.
TABLE 4. Classification of variables on the basis of urinary iodine excretion

<table>
<thead>
<tr>
<th>UIE classification</th>
<th>UIE of children</th>
<th>GG</th>
<th>SES</th>
<th>SS</th>
<th>PH</th>
<th>Intake of goitrigen</th>
<th>β-carotene intake</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;2</td>
<td>1.12 ± 0.76</td>
<td>1.50</td>
<td>10.8</td>
<td>12.0</td>
<td>18.0</td>
<td>3.0 ± 0.0</td>
<td>2010.4 ± 827.27</td>
</tr>
<tr>
<td>2–4.9</td>
<td>3.53 ± 1.23</td>
<td>1.04</td>
<td>15.63</td>
<td>14.32</td>
<td>18.68</td>
<td>2.88 ± 0.53</td>
<td>2263.4 ± 629.4</td>
</tr>
<tr>
<td>5–9.9</td>
<td>6.76 ± 2.49</td>
<td>0.67</td>
<td>15.99</td>
<td>20.97</td>
<td>18.32</td>
<td>2.46 ± 0.86</td>
<td>2349.7 ± 368.1</td>
</tr>
<tr>
<td>≥ 10</td>
<td>14.73 ± 5.26</td>
<td>0.02</td>
<td>17.02</td>
<td>22.84</td>
<td>19.69</td>
<td>2.02 ± 0.50</td>
<td>2494.1 ± 329.4</td>
</tr>
<tr>
<td>F-value</td>
<td>136.1**</td>
<td>195.54**</td>
<td>6.8**</td>
<td>5.69**</td>
<td>1.84</td>
<td>12.12**</td>
<td>6.43**</td>
</tr>
</tbody>
</table>

**p < 0.01.

UIE, urinary iodine excretion; GG, goitre grade; SES, socio-economic status; SS, sanitary status; PH, personal hygiene.
of 15 ppm [18]. In the present study, although the subjects were consuming adequate levels of iodine through fortified salt at the level of 15 ppm, they still suffered from iodine deficiency. This leads to the conclusion that 15 ppm iodine fortification of salt is not sufficient to meet the daily requirements in the region, hence causing iodine deficiency.

The education of the parents did not have any influence because most of the parents were illiterate. The socio-economic status of the family was significantly different in the severely deficient and non-deficient subjects ($F = 6.8, p < 0.01$). The socio-economic status of the family correlated positively with the urinary iodine excretion of the children and negatively with goitre grade. Socio-economic status, sanitation status, and intake of goitrogens, iodine and β-carotene affected urinary iodine excretion and goitre grade. Intake of β-carotene was less in severely deficient cohorts.

This suggests that the studied parameters which form the micro-environment for the children have an influence on the children’s iodine status, leading to the conclusion that all these factors should be taken into account when assessing an individual’s iodine status. Studies have reported that iodine is not the only factor in the causation of deficiency. Various environmental factors, such as socio-economic status, sanitation status, intake of goitrogens, also adversely affect the condition [19–21]. Improvement in personal hygiene, sanitary conditions and socio-economic status positively influenced the iodine status of the study population.

Equation (i) will help to deduce the urinary iodine excretion of this population where goitre grade is known. From equation (ii) it can be calculated that to have urinary iodine excretion of $10 \mu g \text{ dl}^{-1}$, the salt consumed should have 41.2 ppm iodine. Equation (iii) shows that to have goitre grade 0, the salt should have an iodine content of 38.6 ppm. It can be inferred that in the study area more iodine in the salt is required than the current recommended level of fortification. Although most of the salt samples (97%) had an iodine content of more than 15 ppm, iodine deficiency was still prevalent, which can be attributed to cooking losses. The loss of iodine occurs because of Indian culinary practices, which include adding salt before or while cooking. In this process iodine loss is 20–70% [21].

The combined effects of various factors on salt iodine content and urinary iodine [equations (iv) and (v)] were studied and the salt iodine requirement was calculated. The results showed that, in order to have urinary iodine excretion of $10 \mu g \text{ dl}^{-1}$ (no deficiency), children of 10–12 years of age of lower and middle socio-economic status with goitre grade 0 would require 20–25 ppm iodine in salt, i.e. they would require 200–250 µg iodine in their daily diet. The children with goitre grade 1 of middle and lower socio-economic status would require 55–60 ppm iodine in salt. This suggests that the recommended iodine content of 15 ppm at household level is not enough to meet the requirements of these children living in poor environmental conditions. Children with goitre should be given therapeutic doses of iodine or iodine supplementation in order to eliminate iodine deficiency disorders. This equation also reveals that urinary iodine is not only affected by goitre grade and salt iodine content; other factors also play a role.

Table 5 shows that in the low socio-economic group, if the salt consumed has 15 ppm iodine, the non-goitrous children will have urinary iodine excretion of less than $10 \mu g \text{ dl}^{-1}$ and will suffer from mild iodine deficiency, but salt with 15 ppm iodine is adequate for non-goitrous children of the middle and upper classes. However, goitrous children will suffer from mild iodine deficiency even if they consume salt with 30 ppm iodine. This equation reveals that with an improvement in sanitary conditions and personal hygiene, urinary iodine excretion would increase.

The formulated equations reveal that to improve the iodine status of children of lower and middle socio-economic cohorts (living in the same environmental set-up), salt should have an iodine content of 60 ppm at consumption level and that iodine deficiency is not the only causative factor for the low status of children in the study area; there is also an interplay of other factors which make the condition worse, emphasizing the need for intervention for an improvement in environmental factors.
### TABLE 5. Effect of different variables on urinary iodine excretion

<table>
<thead>
<tr>
<th>Socio-economic status</th>
<th>Salt iodine content (ppm)</th>
<th>Goitre grade 0</th>
<th>Goitre grade I</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower</td>
<td>15</td>
<td>9.2</td>
<td>5.07</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>11.2</td>
<td>7.09</td>
</tr>
<tr>
<td>Middle</td>
<td>15</td>
<td>11.3</td>
<td>7.27</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>13.39</td>
<td>9.27</td>
</tr>
<tr>
<td>Upper</td>
<td>15</td>
<td>13.78</td>
<td>9.66</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>15.81</td>
<td>11.69</td>
</tr>
</tbody>
</table>

* $Y = 44.23 - 0.233X_1 + 35.15X_2 + 0.238X_3$. See text for details.

Intervention in the form of supplementation of colloidal iodine solution proved beneficial and improved the iodine status of the children (Fig. 3). Severe deficiency was totally eliminated in the experimental cohort. The larger number of children in the mild cohort shows that these children improved their status from severe and moderate to mild. They still require more iodine to achieve the normal state.

The study provides information to support a case to improve household and micro-environmental factors along with adequate nutrients to achieve sustainable health improvement of children.

### REFERENCES


