Cadmium, Copper, Iron, Lead, Manganese, and Zinc
in Evaporated Milk, Infant Products, and Human Milk

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Abstract

Infant formula foods, such as evaporated milk, modified milk, and formulas containing lamb meat and soya flour, were collected quarterly from the Cincinnati, Ohio, market. Human milk from 13 mothers residing in the Cincinnati area was collected during April and May 1968. They were analyzed for Cd, Cu, Fe, Pb, Mn, and Zn by atomic absorption spectrophotometry. Averaged elements in various formulas including evaporated milk and human milk as ppm were: Cd, 0.020 to 0.042; Cu, 0.024 to 1.49; Fe, 0.84 to 19.1; Pb, 0.012 to 0.87; Mn, 0.12 to 2.68; and Zn, 1.34 to 8.60. Human milk and formulas containing milk base had least Cd, Cu, Mn, and Pb; evaporated milk, however, had the most Pb. Formulas containing soya flour and lamb meat products were high in trace elements.

Introduction

The essentiality of some trace elements to the growing young has been established. Trace elements may be essential or they may be detrimental if ingested in high concentrations.

For young infants, mother's milk is considered the best food, provided there is enough and that the mother's diet is adequate during pregnancy and lactation. Cows' milk is considered nearly an ideal food but it is deficient in Fe, Cu, and fluorine. Filled milks or synthetic substitutes for milk, for infant feeding, are available on the market and include such products as modified milk (MM) and those containing soya flour (S) and lamb meat (L). Limited studies (9) have been made of the Cu, Fe, and Pb in evaporated milk (EM) stored in cans for extended periods. When freshly prepared evaporated milk was stored in either electrolytic or hot-dipped plated cans at 37 C or room temperature, the Pb varied from 0.09 to 0.72 with a mean of 0.35 ppm. Similarly, the Cu varied from 0.46 to 1.04 with a mean of 0.68 ppm, and the Fe increased considerably. Samples stored 0 to 50 days had 1.3 to 14.3 ppm Fe with a mean of 6.5 ppm, whereas samples stored up to 340 days had 4.0 to 36.2 ppm Fe with a mean of 16.5 ppm. Large variations of Fe in evaporated milk were attributed to differences in the extent of corrosion in the cans. Tin increased rapidly under all storage conditions (9). The ratio of Pb to Sn in the filling solder affected the Pb uptake by evaporated milk. When the ratio was 60:40 and large amounts of solder were allowed access to milk, Pb uptake was 0.34 to 1.60 ppm, whereas samples not exposed to solder had 0.05 to 0.37 ppm. No significant difference was found in Pb uptake by evaporated milk between a 50:50 filling solder and a 10:90 for internal seams. Presence of solder pellets showed 0.10 to 0.54 ppm Pb (6). Zinc uptake was negligible (1, 6). The Fe in some infant formulas is labeled on the container as: modified milk 2, trace to 12.0 ppm; modified milk 1, 3.0 ppm; and soya flour products, 17.0 ppm; the Cu in modified milk 1 was 0.85 ppm.

Data on Cu, Fe, and Zn in colostrum, transitional, and mature milk from women known to have had adequate diets and from women in the general population are available (15). Composition of human milk (HM) varied widely depending upon environmental factors, the amount and kind of food consumed, lactation, season, etc. (1, 2, 4, 8, 10, 14, 17, 21–23, 25).

Samples of colostrum 2, 5, and 9 days postpartum from 15 mothers of full-term infants and 15 mothers of premature infants, respectively, showed Cu and Mn contents of 0.008 and 0.02, and 0.002 and 0.002% of ash (23). Similarly, milk from 24 women 3, 5, and 7 days postpartum had 0.022 to 0.063 ppm Mn (21). Manganese in 30 samples of transitional milk was 0.107 ± 0.033 ppm (16). A wide range in Cu has been observed, 0.23 to 1.4 ppm (1, 4, 8, 14, 24, 25). The Fe in milk from 101 women ranged from 0.5 to 1.4 ppm, averaging 0.85 ppm (24). Analyses of milk from

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890 women during spring, summer, and autumn, showed means for Mn of 0.1 ppm; Cu, 0.03 ppm; and Zn, 0.6 ppm; Mn and Cu were highest in autumn; Zn was highest in summer (10). A greater spread in Zn of 1.3 to 12.4 with a mean of 4.4 ppm, has been observed (1).

Because data on the trace elements in infant formulas are lacking, the present investigation was undertaken to determine the Cd, Cu, Fe, Pb, Mn, and Zn in some of the infant formulas from the Cincinnati market, and to compare them with those observed in human milk.

**Experimental Procedure**

**Samples.** Human milk was collected in glass stoppered bottles from individual mothers living in the Cincinnati area during April and May 1968. Four different brands of evaporated milks and infant formulas such as modified milk and formulas containing lamb meat and soya flour were collected from the local market quarterly during the year. Each sample represented 3 to 4 cans selected at random, which were mixed before sampling.

**Apparatus.** The atomic absorption spectrophotometer used in these studies was a Jarrel-Ash Model 82-360 equipped with HECTO burner (19).

**Procedure.** Two hundred and fifty grams of sample were ashed at 550°C and 0.5-g portions of the ash were processed for atomic absorption analyses (19).

Cadmium, Cu, Fe, and Zn contents were determined directly on the ash solution by comparison with appropriate standards. For Pb, 0.5 ml of NaCl solution was mixed with 4.5 ml of ash solution to yield 10,000 ppm of Na. Similarly, for Mn, 5.0 ml of the ash solution was pipetted into a 10-ml volumetric flask; NaCl and CaCl₂ solutions were added to yield 10,000 and 500 ppm, respectively; and the mixture was diluted to 10 ml with HNO₃. The presence of NaCl in the analysis of Pb, and NaCl and CaCl₂ in the analysis of Mn was necessary to complex interfering ions and to improve flame characteristics. All standards were made up in 3 HNO₃; in addition the Pb standard contained NaCl, and the Mn standard contained NaCl and CaCl₂.

**Results and Discussion**

Performance of the atomic absorption spectrophotometer was tested by determining the recoveries of Cd, Cu, Fe, Pb, Mn, and Zn, and reproducibility of analyses. Known amounts of Cd, 0.010 mg; Cu, 0.075 mg; Fe, 0.050 mg; Pb, 0.050 mg; Mn, 0.010 mg; and Zn, 0.300 mg were added to 1.0-g portions of milk ash, and the samples were processed. Analyses of eight replicated samples indicated recoveries of 96.4 ± 2.1% Cd, 99.0 ± 0.6% Cu, 83.1 ± 2.0% Fe, 100.1 ± 4.6 Pb, 101.9 ± 2.9% Mn, and 97.9 ± 1.2% Zn.

Eight 1-g portions of the same ash were also analyzed; the reproducibility was 0.0542 ± 0.0020 mg Cd, 0.130 ± 0.007 mg Cu, 1.100 ± 0.120 mg Fe, 0.100 ± 0.006 mg Pb, 0.024 ± 0.004 mg Mn, and 3.97 ± 0.037 mg Zn with a coefficient of variation of 4.1, 5.3, 10.9, 6.0, 14.8, and 9.3%, respectively. These data were assumed satisfactory for amounts of these elements which were analyzed.

Analytical results of samples as purchased are presented in Table 1. Analyses of variance of the data of four brands of evaporated milk showed no significant differences in trace element contents from one brand to another and from one sampling period to another, except that Cd and Mn showed significant variations due to sampling period. Data for all four brands of evaporated milk were pooled based on sampling period for further analysis. Comparison of the Cd, Cu, Fe, Mn, and Zn in evaporated milk with those of market milk (18), assuming that evaporated milk is two-and-one-fourth times more concentrated than market milk, indicated that these cations were within the expected range; however, Pb in evaporated milk was abnormally high (0.74 to 0.87 ppm), probably due to contamination from cans but within the range reported (9).

Information on the trace element content of infant formulas is not available for comparison except in a few cases in which Fe or Cu is reported on the container's label. These data, however, are presumably based on fresh samples analyzed prior to canning or bottling or they may be theoretical fortification values. Modified milk 2 is labeled to contain traces of Fe; the observed Fe was 0.82 ppm. Modified milk 1 was labeled to contain 3.0 ppm Fe and 0.85 ppm Cu; the observed values, 1.88 ± 0.19 ppm Fe and 0.55 ± 0.05 ppm Cu, were somewhat lower. Similarly, soya flour product

1 When this manuscript was ready for publication, a new formula containing soya protein extract and with known amounts of Cu, Fe, and Zn was available on the market. It was too late, however, to include it herein.

2 Mention of commercial products is not to imply endorsement by the Food and Drug Administration, Department of Health, Education, and Welfare.
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was labeled to contain 17.0 ppm Fe and the observed Fe was 19.01 ± 3.99 ppm; consequently, increased Fe must have resulted from uptake by the product from cans.

Based on the amount of dextrimaltose (20 to 25 g per liter) in the formula prepared from evaporated milk the trace elements from this carbohydrate are minimal.

Averaged data collected during April and May 1968 from 13 individual mothers are in Table 1. Most of the samples represented normal and late lactation periods.

Comparison of the trace elements of different formulas. Because many of the products must be diluted with water prior to use, all the observed elements were converted to parts per million (milligrams per kilogram) of formula by dilution factors recommended by the manufacturers. (One part of evaporated milk is diluted with 1.5 parts of water, whereas the other formulas are diluted 1:1 with water.) Analyses of variance of the converted data showed that, except for Cd, the averages of all trace elements differed significantly from one sample to another. To determine if these observed differences were due to any one sample, averages for Cd, Cu, Fe, Pb, Mn, and Zn were analyzed by the Duncan's test (5).

The data follow:

Cadmium. The metabolism of Cd follows closely that of Zn. Cadmium is antagonistic to Zn. In relating Cd to Zn, use of molar ratio has been suggested as an indicator of their abundance (22). Calculated molar ratios of Cd to Zn in various products were: Modified milks 1 and 2, 0.0039 and 0.0035; lamb meat product, 0.0014; human milk, 0.0069; evaporated milk, 0.0029; and soya flour product, 0.0029.

Any two averages underscored by the same line are not significant at a = 0.01.

Averaged daily intake of milk or formula by infants was 615 ml (12). Computed Cd intake from various formulas ranged from 0.006 to 0.010 mg, with an average of 0.008 mg per day. Absorption of Cd through the gut, however, is less than 5% (3) because of the antagonistic effect of certain formula constituents. No renal Cd has been detected in infants less than 5 months old. A small amount appeared in a 10-month-old child. Nine out of 24 children over 1 year of age had no detectable Cd in their kidneys, and the mean for the remainder was 0.075 mg per gram.

Table 1. Averaged trace elements in evaporated milk, infant formula, and human milk.a,b

<table>
<thead>
<tr>
<th>Product</th>
<th>Number of samples</th>
<th>Copper (ppm)</th>
<th>Zinc (ppm)</th>
<th>Manganese (ppm)</th>
<th>Lead (ppm)</th>
<th>Iron (ppm)</th>
<th>Cadmium (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evaporated milk (Brand 1)</td>
<td>4</td>
<td>0.17 ± 0.12</td>
<td>0.82 ± 0.45</td>
<td>0.28 ± 0.09</td>
<td>1.09 ± 0.45</td>
<td>0.83 ± 0.06</td>
<td>0.02 ± 0.02</td>
</tr>
<tr>
<td>Evaporated milk (Brand 2)</td>
<td>4</td>
<td>0.14 ± 0.02</td>
<td>0.81 ± 0.46</td>
<td>0.24 ± 0.08</td>
<td>0.92 ± 0.45</td>
<td>0.77 ± 0.04</td>
<td>0.02 ± 0.01</td>
</tr>
<tr>
<td>Evaporated milk (Brand 3)</td>
<td>4</td>
<td>0.16 ± 0.01</td>
<td>0.74 ± 0.31</td>
<td>0.23 ± 0.09</td>
<td>0.83 ± 0.30</td>
<td>0.85 ± 0.02</td>
<td>0.02 ± 0.01</td>
</tr>
<tr>
<td>Formula 1 (MM) 1</td>
<td>4</td>
<td>0.00 ± 0.00</td>
<td>0.83 ± 0.04</td>
<td>0.23 ± 0.01</td>
<td>0.88 ± 0.03</td>
<td>0.80 ± 0.02</td>
<td>0.02 ± 0.01</td>
</tr>
<tr>
<td>Formula 2 (MM) 2</td>
<td>4</td>
<td>0.00 ± 0.00</td>
<td>0.83 ± 0.04</td>
<td>0.23 ± 0.01</td>
<td>0.92 ± 0.03</td>
<td>0.80 ± 0.02</td>
<td>0.02 ± 0.01</td>
</tr>
<tr>
<td>Formula 3 (S)</td>
<td>4</td>
<td>0.00 ± 0.00</td>
<td>0.83 ± 0.04</td>
<td>0.23 ± 0.01</td>
<td>0.92 ± 0.03</td>
<td>0.80 ± 0.02</td>
<td>0.02 ± 0.01</td>
</tr>
<tr>
<td>Human milk</td>
<td>22</td>
<td>0.01 ± 0.01</td>
<td>0.83 ± 0.04</td>
<td>0.23 ± 0.01</td>
<td>0.88 ± 0.03</td>
<td>0.80 ± 0.02</td>
<td>0.02 ± 0.01</td>
</tr>
</tbody>
</table>

- Values are means ± SD of products as originally obtained. S = Soya flour, and L = lamb meat.
- MM 1 L MM 2 S HM EM Avg CdS 0.010 0.010 0.012 0.019 0.019 0.016

Averaged daily intake of milk or formula by infants was 615 ml (12). Computed Cd intake from various formulas ranged from 0.006 to 0.010 mg, with an average of 0.008 mg per day. Absorption of Cd through the gut, however, is less than 5% (3) because of the antagonistic effect of certain formula constituents. No renal Cd has been detected in infants less than 5 months old. A small amount appeared in a 10-month-old child. Nine out of 24 children over 1 year of age had no detectable Cd in their kidneys, and the mean for the remainder was 0.075 mg per gram.

3 Any two averages underscored by the same line are not significant at a = 0.01.
This suggests dietary exposure is important in Cd accumulation (22).

**Copper.** Averaged Cu in milks, in formulas and in human milk varied from 0.049 to 0.744 ppm. Copper in the soya flour product was significantly different from modified milks 1 and 2, evaporated and human milks, and lamb meat product. Similarly, Cu in modified 2 and evaporated milk was significantly different from Cu in human and modified milk 1, and lamb meat product.

<table>
<thead>
<tr>
<th>MM2</th>
<th>EM</th>
<th>HM</th>
<th>MM1</th>
<th>L</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avg Cu</td>
<td>0.049</td>
<td>0.074</td>
<td>0.24</td>
<td>0.276</td>
<td>0.391</td>
</tr>
</tbody>
</table>

Copper in cows' milk produced in the United States varied from 0.039 to 0.150 ppm, with a mean of 0.089 ppm (18), and that for evaporated milk was within the expected range. Modified milk samples contain powdered milk. Based on milk values, Cu in modified milk 2 appeared reasonable, but Cu in modified milk 1 was lower than the 0.042 ppm listed.

The daily requirement of Cu for infants is 0.08 mg per kilogram body weight (7). Based on an average daily consumption of 615 ml of formula, they would receive 0.030 to 0.458 mg of Cu.

**Iron.** Averaged Fe in milks and formulas varied from 0.413 to 9.50 ppm.

<table>
<thead>
<tr>
<th>MM2</th>
<th>EM</th>
<th>HM</th>
<th>MM1</th>
<th>L</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avg Fe</td>
<td>0.413</td>
<td>0.469</td>
<td>0.841</td>
<td>0.938</td>
<td>7.26</td>
</tr>
</tbody>
</table>

Iron in modified milks 1 and 2, evaporated and human milks did not differ significantly but were different from those of lamb meat and soya flour products. The Fe contents of lamb meat and soya flour products were significantly different. The Fe in cow's milk produced in the United States varied from 0.29 to 1.53 ppm, with an average of 0.64 ppm (18). Iron is poorly absorbed in the body; its metabolic requirement for infants is about 1.5 mg per kilogram per day (7). Based on an average daily consumption of 615 ml of formula, infants would receive 0.030 to 0.458 mg of Cu.

**Zinc.** Averaged Zn in milks and formulas varied from 1.34 to 3.99 ppm. Zinc in human and modified milks 1 and 2 did not differ significantly among themselves, but were different from those of the other samples; Zn in evaporated milk, soya flour and lamb meat products did not differ significantly.

<table>
<thead>
<tr>
<th>HM</th>
<th>MM1</th>
<th>MM2</th>
<th>EM</th>
<th>S</th>
<th>L</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avg Zn</td>
<td>1.34</td>
<td>1.47</td>
<td>1.92</td>
<td>3.14</td>
<td>3.71</td>
</tr>
</tbody>
</table>

Zinc in market milk produced in the United States varied from 2.35 to 5.05 ppm, averaging 3.27 ppm (18). Based on an average daily consumption of 615 ml of milk or formula, Zn intake by infants is 0.824 to 2.45 mg. For humans, an average intake of 10 to 15 mg of Zn per day is adequate. Results of a balanced study in young school children has shown a dietary requirement of 6 mg of Zn per day is adequate. Results of a balanced study in young school children has shown a dietary requirement of 6 mg of Zn per day is adequate. Results of a balanced study in young school children has shown a dietary requirement of 6 mg of Zn per day is adequate. Results of a balanced study in young school children has shown a dietary requirement of 6 mg of Zn per day is adequate. However, Zn requirement for infants has not been well established. A mixed diet containing recommended amounts of animal protein is expected to supply needed amounts of Zn (7).

In conclusion, our data indicate wide variations in trace elements in the formulas analyzed.
There is some uptake of trace elements (Fe, Pb) by the product from cans, especially if they are made of metal; the amount of this uptake depends on the length of time the product is stored.

Acknowledgments

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References