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# Perchlorate and Iodide in Dairy and Breast Milk

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Perchlorate inhibits iodide uptake and may impair thyroid and neurodevelopment in infants. Recently, we unambiguously identified the presence of perchlorate in all seven brands of dairy milk randomly purchased from grocery stores in Lubbock, TX. How widespread is perchlorate in milk? Perchlorate in 47 dairy milk samples from 11 states and in 36 human milk samples from 18 states were measured. Iodide was also measured in a number of the samples. Perchlorate was detectable in 81 of 82 samples. The dairy and breast milk means were, respectively, 2.0 and 10.5 $\mu$g/L with the corresponding maximum values of 11 and 92 $\mu$g/L. Perchlorate is present in virtually all milk samples, the average concentration in breast milk is five times higher than in dairy milk. Although the number of available measurements are few at this point, for breast milk samples with a perchlorate content greater than 10 $\mu$g/L, the iodide content is linearly correlated with the inverse of the perchlorate concentration with a $r^2$ of >0.9 ($n = 6$). The presence of perchlorate in the milk lowers the iodide content and may impair thyroid development in infants. On the basis of limited available data, iodide levels in breast milk may be significantly lower than it was two decades ago. Recommended iodine intake by pregnant and lactating women may need to be revised upward.

## Introduction

The occurrence of perchlorate in the aquatic environment has been a subject of discussion as far back as 1986 (*1*). Current concerns began with the discovery of perchlorate in Lake Mead in 1997 (*2*), followed by similar findings in Lake Havasu, Arizona; California Central Valley via the California Aqueduct and independent locations in Utah (*3*). The current picture of known U.S. perchlorate releases is far broader (for a current map, see ref *4*), and the influence may extend far beyond the region of release. The entire lower Colorado is contaminated (*5*), ostensibly from the manufacturing of $NH_4ClO_4$, the preferred oxidant component missile/rocket propellants. Water from the Colorado River irrigates more than 1.8 million acres of land—producing some 15% of the nation's crops and about 13% of its livestock (*6*). Bioconcentration can occur in foods: lettuce and other broadleaf vegetables are particularly susceptible (*7*−9). Citrus fruits have often been leaf-fertilized with Chilean saltpeter spray ($NaNO_3$, known to contain 0.1−0.4% perchlorate (*10*, *11*)). Such products, grown from California to Florida, supply the entire nation. Low levels of natural sources of perchlorate may also exist (*12*, *13*). In 2004, California set a drinking water public health goal (PHG) at 6 $\mu$g/L (*14*). At least six other states have advisory levels ranging from 1 to 18 $\mu$g/L (*15*). The United States Environmental Protection Agency had asked for a regulatory level of 1 $\mu$g/L in drinking water. This was opposed by three other federal agencies. The National Academy of Sciences (NAS) has just issued an opinion and suggested a maximum permissible dose of 0.7 $\mu g\ kg^{-1}\ d^{-1}$ (*16*). If drinking water was the only source of perchlorate, this would translate to a water perchlorate content of ∼23 $\mu$g/L for the average person. Perchlorate displaces iodide from the thyroid gland and is thus utilized in the "perchlorate challenge" test used to assess the efficiency of uptake of iodide by the thyroid gland (*17*).

Perchlorate competitively inhibits iodide uptake; recent experiments on the human sodium iodide symporter (NIS) indicate that perchlorate has a selectivity factor of at least 30 over iodide (*18*). Uptake of perchlorate reduces thyroid hormone (TH) production. From the first trimester of gestation when the fetus depends on maternal TH through the first years of life, adequate TH is essential for proper protein expression, neuronal differentiation, migration, and myelination (*19*−21). Early TH deficiency results in characteristic functional deficits, notably difficulty in processing visual−spatial information, poor sensorimotor coordination, and memory/attention deficits (*22*).

Perchlorate may adversely affect fetal and neonatal development by reducing (a) maternal TH available during gestation, (b) TH production by the fetal thyroid, and (c) the iodide content of breast milk, thus impairing thyroid function and development in the nursing infant (*23*). In rats, perchlorate has been shown to induce changes in brain morphology at dosage levels down to 10 $\mu g\ kg^{-1}\ d^{-1}$ (*24*).

To growing children, milk can be as relevant as water. In a preliminary survey (*25*), we analyzed seven brands of dairy milk samples randomly purchased in Lubbock, TX (U.S. state abbreviations used in this paper can be found in http://www.usps.com/ncsc/lookups/usps_abbreviations.html). All samples contained perchlorate in double-blind measurements by ion chromatography and ion chromatography−mass spectrometry (IC−MS, the latter is considered to be capable of unambiguous identification and quantitation of perchlorate) in two different laboratories. Since that time, milk samples from across California have also been reported to contain perchlorate at comparable or higher levels. How widespread then is the occurrence of perchlorate in dairy milk? Studies with goats indicated that infusion of perchlorate in large doses can cause major reduction of iodide expression in milk (*26*). The World Health Organization identifies iodine deficiency as the dominant preventable cause of mental retardation worldwide (see, for example, ref *27*). The risk may be particularly high for children who are exposed to lead as well, which causes reduced production of transthyretin, the TH carrier protein responsible for TH transport to the developing brain (*28*). To what extent is perchlorate present in human milk? Is there a concomitant reduction of iodide?

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## Experimental Section

**Dairy Milk Survey.** Fifty milk samples from grocery stores were randomly purchased in 11 states. Samples were frozen in their unopened original containers and shipped overnight to Texas Tech University (TTU). On the basis of carton indications, one FL sample was actually produced in AL, and one KS sample originated in WI. Forty-seven samples arrived frozen in physically undamaged condition and were allowed to thaw in a refrigerator at 2 °C. With two exceptions (one 2% fat and one 1% fat), the samples contained 4% fat. One additional sample of soy milk, bought at a local grocery store, was also analyzed.

**Human Milk Survey.** Healthy lactating volunteers, residing in 18 different states, were recruited at random and signed informed consent blank forms in accordance with the policies of the TTU Institutional Review Board. In the fall of 2003, milk was collected by donors in prewashed 50-mL Falcon tubes (Fisher). The tubes were sealed in plastic bags, placed in plastic containers that were then filled with water, frozen in the participants' home freezer, and then shipped overnight to us. Thirty-six of the samples arrived frozen and were analyzed. Several volunteers were still breastfeeding in the spring of 2004, and a second set of samples was collected from them, along with a sample of tap water and a sample of bottled water if they drank bottled water.

**Analytical Methods.** Perchlorate calibration standards were prepared from 100 $\mu$g/mL certified $NaClO_4$ standard (AccuStandard, Inc., New Haven, CT) in distilled, deionized Milli-Q (MQ) water. Recoveries in spiked samples were 95+%. Detailed procedures for the processing of the milk samples prior to analysis have been previously described (*25*). For each milk sample, three separately processed aliquots were pooled together. The pool was subdivided into two; one-half was analyzed by the preconcentration−preelution (PC−PE) suppressed conductometric IC method (*29*). For PC−PE, 2 TAC-LP1 (4 × 35 mm) columns were used. One-milliliter samples were loaded on preconcentrator columns, preeluted with 10 mM NaOH at 0.45 mL/min for 5.8 min, and then switched to main separation columns (AG16, 4 × 50 mm; AS16, 4 × 250 mm) and eluted with 100 mM NaOH at 1.0 mL/min. The limit of detection (LOD, signal-to-noise ratio (S/N) = 3 quoted throughout) of this system was 0.4 $\mu$g/L. Iodide analysis was similarly but separately conducted, using a 0.5-mL sample of 10 mM NaOH at 0.70 mL/min for 1.1 min for preelution and 35 mM NaOH at 0.90 mL/min for elution. The LOD for $I^-$ was 1.0 $\mu$g/L. In both cases, each sample was run minimally in duplicate, typically in triplicate.

The other half of the pooled sample was analyzed in another laboratory by IC-MS. Each laboratory was blind to the result obtained by the other laboratory. The front IC end of the analysis system was essentially identical with the following exceptions. A single TAC-LP1 column was used for PC−PE, the preelution was carried out with 10 mM NaOH for 2.5 min at 0.85 mL/min, and 75 mM NaOH at 1 mL/min was used as an eluent. Following the conductivity detector, the effluent entered the mass spectrometer (AQA, Thermo-Finnigan Inc.) operated in the electrospray ionization mode with probe temperature and electrospray voltage at 350 °C and 3.5 kV, respectively. The fragmentation voltage was −35 V. The selected ion monitoring (SIM) mode was used to monitor $ClO_4^-$ at a mass to charge ratio ($m/z$) of 98.7 and 100.7 (corresponding respectively to the $^{35}$Cl and $^{37}$Cl isotopes). The perchlorate LOD by MS was 1 $\mu$g/L or better at $m/z$ 98.7. All chromatograhic equipment were from Dionex Corporation.

In many experiments, especially for quantitating low concentrations with greater accuracy and certainty, we added a 100 $\mu$M solution of 1,12-bis(trimethylammonium) dodecane difluoride ($DQF_2$) flowing at 100 $\mu$L/min postcolumn, just before the MS. This reagent produces large amounts of $DQ^{2+}$ in the MS at a very modest ionization voltage of +2V and thus also produces $DQClO_4^+$, which can be monitored in the positive ion mode at $m/z$ 384.8 and 386.8 for the two respective Cl isotopes. Details of this approach will be published elsewhere; for present purposes, it is sufficient to note that detection at a much larger mass range and in the positive ion mode greatly reduces noise and produces an order of magnitude better LODs than the first method.

Iodide was measured in a subset of the samples in the same chromatographic run at $m/z$ 127 (and at $m/z$ 413 when using $DQF_2$ as a postcolumn reagent). The respective LODs were <3 and 0.7 $\mu$g/L.

## Results and Discussion

**Dairy Milk.** The perchlorate content from a single sample from Maine was below the LOD; all other samples contained measurable levels of perchlorate. The mean perchlorate content was 2.0 $\mu$g/L, with the highest value being 11.0 $\mu$g/L for a sample from California (Table 1). While there are not enough data to elucidate geographical distribution, the three highest concentration samples all came from California; albeit the largest number of samples (10) came from this state as well. Figure 1a shows the frequency of distribution of perchlorate concentration with the sorting bins arranged in a logarithmic scale. The solid line indicates a Gaussian distribution; thus the limited number of data available can be said to loosely fit a log-normal distribution. Iodide concentrations ranged 9.6−382 $\mu$g/L with a mean of 89 $\mu$g/L. The iodide/perchlorate molar ratio ranged from 1.0 to 310 with a mean of 53.3.

**Human Milk.** Perchlorate was detectable in all samples, ranging from 0.6 to 92.2 $\mu$g/L (mean 10.5 $\mu$g/L). Available data are insufficient to elucidate geographical distribution, but high values appear to be widely distributed. Figure 1b shows the frequency distribution, which in this case extends to much higher concentrations than that for dairy milk. Iodide concentrations ranged from 4.5 to 184.5 $\mu$g/L (mean 63.3 $\mu$g/L). The iodide/perchlorate molar ratio ranged from 0.2 to 54 with a mean of 12.3.

**Infant Dosing of Perchlorate from Breast Milk.** Breast milk is the sole source of nourishment and fluid intake for many infants. Currently, 64% of American infants are breastfed in early infancy, 29% and 16% continue to breastfeed at 6 and 12 months of age, respectively (*30*). The Center for Disease Control has a stated goal to increase breastfeeding so that 75%, 50%, and 25% of babies will be breastfed in early infancy and 6 and 12 months of age, respectively (*31*).

A physiologically based pharmacokinetic model for nursing rat pups by Clewell et al. (*23*) predicts that at low levels of maternal exposure (∼10 $\mu$g kg$^{-1}$ d$^{-1}$), up to 50% of the maternal intake is transferred to the infant. Consider an average mother (weight ∼72 kg, C. Olsen, Cornell University, personal communication, 2004) eating a recommended daily diet (∼2800 g, based for example on ref *32*) and drinking a typical amount of water/beverage (∼2000 g) (*33*). If the perchlorate content of food/water averages 12 $\mu$g/kg (2× the California PHG for drinking water, the highest perchlorate content of 18 lettuce samples measured was 121 $\mu$g/kg (*7*)), the intake is ∼60 $\mu$g; <1 $\mu$g kg$^{-1}$ d$^{-1}$, just 30% above the NAS safe dose (*16*) and well below the 2 $\mu$g kg$^{-1}$ d$^{-1}$ safe dose recently recommended for pregnant women (*34*). However, if the rat model of mother → infant transfer is valid, transfer of 30 $\mu$g/d to a newborn (4.1 kg mean weight at 1 month of age (*35*)) will exceed the 6 $\mu$g kg$^{-1}$ d$^{-1}$ safe dose recommended for "children" (*34*) or the NAS safe dose. The same conclusion can be drawn in an alternate manner: A 1-month-old infant consumes a mean of 673 mL/d (the top 99th percentile value 1007 mL/d) breast milk (*36*). This will result in an intake of 0.7−1 $\mu$g d$^{-1}$ ($\mu$g/L of perchlorate)$^{-1}$ in milk. With a mean

**TABLE 1. Perchlorate and Iodide in Dairy and Breast Milk Samples[a]**

| dairy milk | | | breast milk | | |
|---|---|---|---|---|---|
| sample ID[b] | perchlorate ($\mu$g/L) | iodide ($\mu$g/L) | sample ID | perchlorate ($\mu$g/L) | iodide ($\mu$g/L) |
| AK1 | 0.9 ± 0.0 | | CA11 | 20.7 ± 1.9 | 19.7 ± 0.0 |
| AK2 | 1.1 ± 0.5 | 134 ± 2 | CA13 | 3.2 ± 0.6 | 18.0 ± 0.9 |
| AK3 | 1.0 ± 0.1 | 53.7 ± 1.7 | CA19 | 5.5 ± 0.3 | 56.3 ± 1.3 |
| AK4 | 1.4 ± 0.7 | 48.2 ± 0.2 | CA27 | 1.4 ± 0.5 | |
| AK5 | 1.3 ± 0.2 | | CA44 | 2.2 ± 0.8 | |
| AK6 | 1.6 ± 0.8 | 127±2 | CT21 | 1.4 ± 0.4 | 8.2 ± 0.3 |
| AK7 | 1.0 ± 0.4 | 19.4 ± 0.9 | FL12 | 1.9 ± 0.4 | 131 ± 2 |
| AZ1 | 1.1 ± 0.2 | 85.1 ± 0.2 | GA18 | 2.6 ± 1.0 | |
| AZ2 | 0.9 ± 0.4 | 114 ± 0.0 | GA57 | 1.9 ± 0.6 | 11.0 ± 1.0 |
| AZ3 | 1.7 ± 0.4 | 76.5 ± 0.8 | GA65 | 1.9 ± 0.6 | 91.7 ± 0.4 |
| AZ4 | 0.8 ± 0.1 | 123 ± 0.4 | HI16 | 1.6 ± 0.4 | 4.5 ± 0.3 |
| CA1 | 1.0 ± 0.1 | 94.0 ± 1.3 | *HU | 3.3 ± 0.2 | |
| CA2 | 11.0 ± 0.6 | 13.5 ± 1.3 | MD51 | 4.1 ± 0.8 | 47.4 ± 0.10 |
| CA3 | 5.8 ± 0.2 | 15.4 ± 0.8 | ME69 | 2.3 ± 0.5 | 30.6 ± 0.4 |
| CA4 | 5.8 ± 0.3 | 23.2 ± 0.6 | MI10 | 4.7 ± 0.6 | |
| CA5 | 1.3 ± 0.5 | | MO54 | 31.6 ± 2.0 | 7.7 ± 3.0 |
| CA6 | 1.6 ± 0.3 | 9.6 ± 0.6 | NC101 | 3.8 ± 0.1 | 144.8 ±1.1 |
| CA7 | 4.2 ± 1.1 | 15.6 ± 2.3 | NE52 | 31.5 ± 0.9 | |
| CA8 | 0.8 ± 0.2 | | NJ2 | 50.7 ± 2.2 | |
| CA9 | 1.2 ± 0.2 | 10.2 ± 1.1 | NJ23 | 92.2 ± 5.8 | |
| CA10 | 2.5 ± 0.6 | 22.1 ± 0.2 | NJ43 | 3.2 ± 0.3 | 162 ± 2.1 |
| FL1 | 1.1 ± 0.5 | 135.1 ± 2.7 | NM59 | 37.6 ± 1.3 | 12.3 ± 0.0 |
| FL2 | 1.4 ± 0.4 | 119 ± 0.0 | NY55 | 3.8 ± 1.0 | |
| FL3 | 2.0 ± 0.2 | 26.9 ± 0.0 | TX100 | 11.8 ± 1.2 | |
| HI1 | 1.0 ± 0.2 | 83.7 ± 1.0 | TX20 | 2.1 ± 0.6 | 21.2 ± 1.7 |
| HI2 | 1.0 ± 0.4 | 85.5 ± 0.6 | TX26 | 1.4 ± 0.2 | |
| HI3 | 1.4 ± 0.4 | 76.4 ± 1.0 | TX30 | 2.0 ± 0.6 | 31.5 ± 1.4 |
| HI4 | 5.7 ± 0.8 | 291 ± 3 | TX56 | 1.4 ± 0.3 | 33.5 ± 1.2 |
| KS1 | 2.0 ± 0.1 | 66.8 ± 0.4 | TX7 | 3.5 ± 0.6 | 57.4 ± 1.3 |
| KS2 | 0.6 ± 0.1 | 128 ± 3 | TX76 | 11.3 ± 2.1 | 183.3 ± 1.2 |
| KS3 | 2.6 ± 1.1 | 61.1 ± 1.1 | TX78 | 12.7 ± 0.5 | 184.5 ± 1.0 |
| KS4 | 1.2 ± 0.5 | | TX83 | 5.1 ± 0.5 | 175.7 ± 2.0 |
| KS5 | 1.2 ± 0.4 | 147 ± 1 | TX90 | 1.9 ± 0.9 | |
| ME1 | 0.4 ± 0.1 | 28.0 ± 0.6 | VA 48 | 3.3 ± 0.3 | 10.7 ± 2.9 |
| ME2 | nd | 52.3 ± 0.2 | WA 4 | 2.3 ± 0.4 | |
| ME3 | 0.6 ± 0.0 | 28.6 ± 0.2 | WV103 | 2.3 ± 0.0 | 40.8 ± 0.2 |
| ME4 | 0.4 ± 0.0 | 16.3 ± 0.1 | | | |
| NH1 | 4.7 ± 0.4 | 51.9 ± 0.4 | | | |
| NM1 | 2.0 ± 0.4 | | | | |
| NM2 | 0.8 ± 0.2 | | | | |
| NM3 | 0.7 ± 0.3 | | | | |
| NY1 | 4.4 ± 0.3 | 382 ± 3 | | | |
| PA1 | 1.0 ± 0.0 | 33.0 ± 2.0 | | | |
| PA2 | 0.8 ± 0.0 | 303 ± 0 | | | |
| PA3 | 2.8 ± 0.4 | 247 ± 3 | | | |
| PA4 | 1.0 ± 0.2 | 15.4 ± 2.0 | | | |
| PA5 | 2.2 ± 0.2 | 114 ± 3 | | | |
| average | 2.0 | 89.2 | average | 10.5 | 63.3 |
| max | 11.0 | 382 | max | 92.2 | 162 |
| min | 0.0 | 9.6 | min | 1.4 | 4.5 |
| | | | soy milk Lubbock, TX | 0.7 ± 0.1 | 8.5 ± 0.1 |

[a] $n = 4-6$ for each sample. [b] The first two letters indicate the state of origin. An asterisk (*) indicates that the subject was unwilling to reveal the state.

perchlorate content 10.5 $\mu$g/L to a high value over 92 $\mu$g/L, it is obvious that the NAS safe dose of 0.7 $\mu$g kg$^{-1}$ d$^{-1}$ will be exceeded for the majority of infants, and some will also exceed the 10 $\mu$g kg$^{-1}$ d$^{-1}$ dose at which brain morphology changes were observed in nursing rat pups (*24*).

**Perchlorate and Iodide.** In Figures 2 and 3 (respectively dairy and breast milk), we examine if increasing levels of perchlorate reduces iodide expression. In each plot, we divide iodide levels in two groups, those above 60 $\mu$g/L and those below, this being the iodide content for many infant feed formulas (see, for example, ref *37*). We similarly divide perchlorate content in two groups, high and low, in this case arbitrarily dividing the span of the observed perchlorate range in two equal halves. We have thus four quadrants. It will be appreciated that there can be causes other than perchlorate for low iodide levels, (e.g., due to low iodide intake). It is remarkable that not a single datum fell within the high perchlorate−high iodide quadrant for either bovine or human milk samples.

At this point with limited resources, we have been able to analyze only a few samples. With this caveat in place, we note the following. Perchlorate in breast milk does not appear to be well-correlated with the water the respective mothers are consuming (Table 2). Ongoing goat studies by us (A.B.K., E.E.S.) indicate that perchlorate is expressed in milk within a short time after perchlorate dosing through food/water and also is cleared fairly rapidly following cessation of dosing. This suggests that perchlorate in breast milk is likely to be

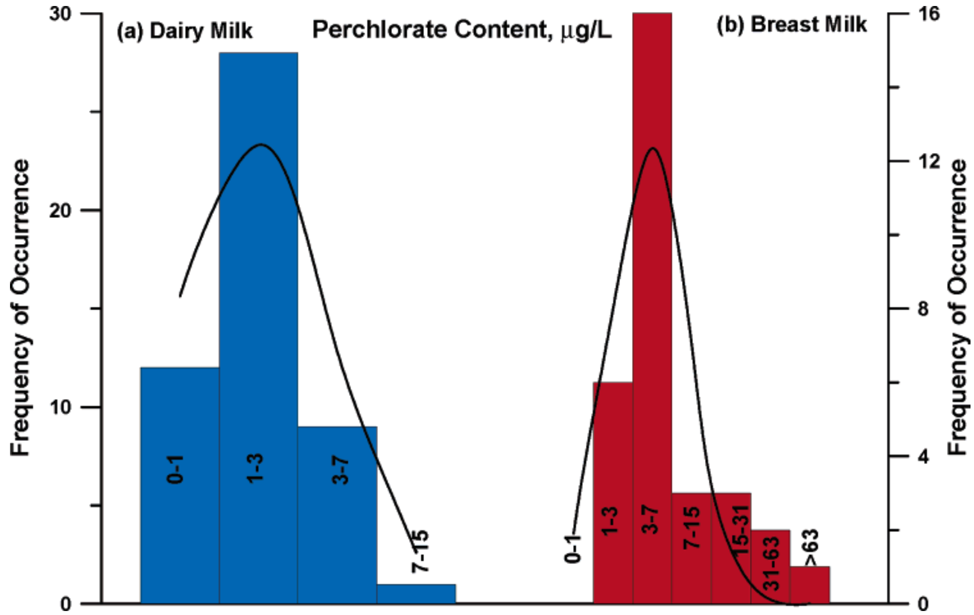


**FIGURE 1. Frequency distribution of perchlorate content of (a) dairy and (b) breast milk samples. The bins successively span perchlorate concentration differentials of 1, 2, 4, 8 $\mu$g/L, etc., in a logarithmically increasing order.**

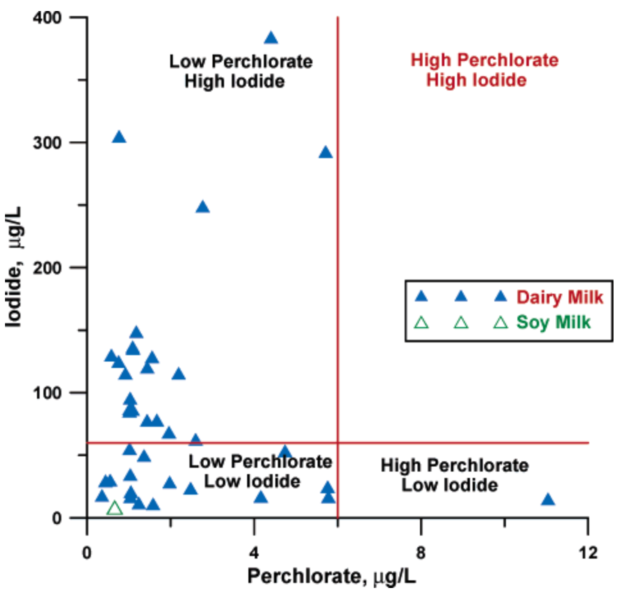


**FIGURE 2. Iodide as a function of perchlorate concentration in dairy milk.**

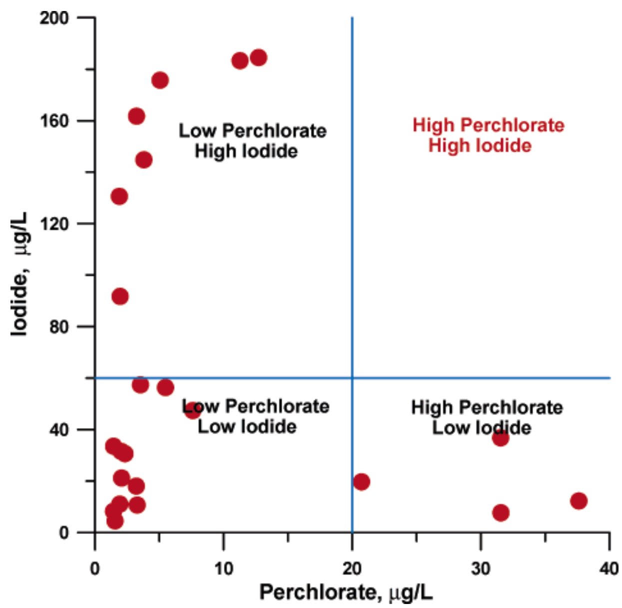


**FIGURE 3. Iodide as a function of perchlorate concentration in human milk.**

highly variable with time and may depend on immediate dietary history. Accordingly, at least in one case (WV103), marked variation is seen between the fall and spring samples. If we take all the available data, there is no meaningful correlation between the perchlorate and iodide levels in breast milk. On the other hand, for breast milk that contained $\geq 10\,\mu$g/L perchlorate, the iodide concentration expressed in milk is linearly related to the reciprocal of perchlorate concentration (Figure 4). Although the number of data points *are* very limited and the observed results may be entirely fortuitous, this correlation is very high given the variability of real biological samples. If the NIS behaves as an ion exchange membrane, the concentration in the membrane phase (to which we assume the receiver phase concentrations will be directly related) will be governed by (*38*):

$$[I^-]_m/[ClO_4^-]_m = [I^-]_{df}/[[ClO_4^-]_{df} \ldots \qquad (1)$$

where the subscripts m and df, respectively, indicate the membrane and the donor fluid. If the iodide concentration in the donor fluid was more or less constant, a relationship like that observed in Figure 4 will indeed be expected.

The present recommended daily allowance (RDA) for iodine ranges from 110 (0–6 month), 130 (7–12 month), 150 (>14 yr), 220 (pregnant women), to 290 (lactating women) $\mu$g (*39*, *40*). Even without the recognition that perchlorate has become generally pervasive and the present RDA's were formulated without consideration of perchlorate inhibition of iodide transport, concerns have been expressed recently that the level of iodine consumption in the U.S. population, especially among women of childbearing age, represents mild iodine deficiency (*40*). Among 100 healthy pregnant women, 49% were found to have urinary iodine levels below what would be expected for subjects consuming the applicable RDA (*41*). It is also apparent that the perchlorate–iodide situation is much worse in human milk, relative to cow's milk. Dairy cattle have been bred to optimize the milk output

**TABLE 2. Perchlorate in Milk versus Perchlorate in Water Consumed**[a]

| sample ID | perchlorate in milk ($\mu$g/L) fall 2003 | perchlorate in milk ($\mu$g/L) spring 2004 | perchlorate in tap water ($\mu$g/L) spring 2004 | perchlorate in bottled water ($\mu$g/L) spring 2004 |
|---|---|---|---|---|
| CA13 | 3.2 | na | 1.0 | <0.5 |
| CA19 | 5.5 | 6.6 | <0.5 | 2.0 |
| CA27 | 1.4 | na | <0.5 | <0.5 |
| FL12 | 1.9 | 7.6 | <0.5 | 1.0 |
| GA65 | 1.9 | 4.9 | <0.5 | <0.5 |
| HI16 | 1.6 | 5.0 | na | na |
| ME69 | 2.3 | 1.0 | na | na |
| MI10 | 4.7 | na | 1.0 | <0.5 |
| NC101 | 3.8 | na | 3.0 | <0.5 |
| NJ43 | 3.2 | 7.6 | 1.0 | 1.0 |
| NY55 | 3.8 | na | <0.5 | <0.5 |
| TX20 | 2.1 | na | <0.5 | <0.5 |
| TX30 | 2.0 | na | <0.5 | <0.5 |
| TX83 | 5.1 | na | na | <0.5 |
| VA48 | 3.3 | na | <0.5 | <0.5 |
| WA4 | 2.3 | na | <0.5 | <0.5 |
| WV103 | 2.3 | 19.2 | <0.5 | <0.5 |

[a] Perchlorate in bottled water is given only for those subjects that reported drinking bottled water.

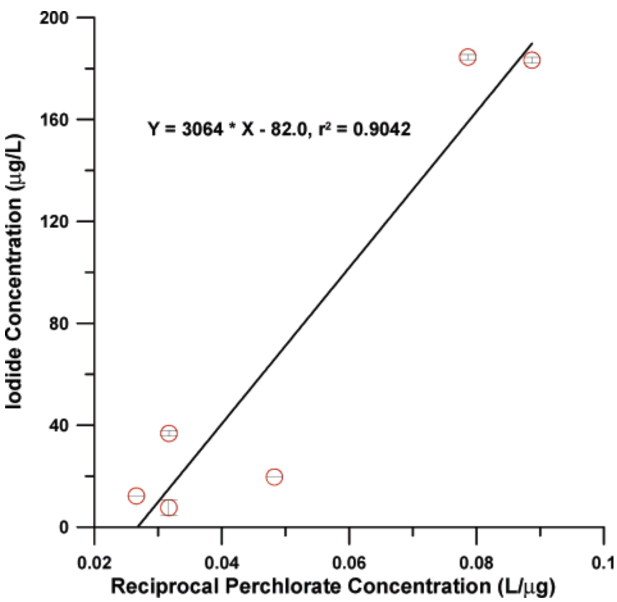


**FIGURE 4. Iodide versus reciprocal perchlorate concentrations in breast milk samples that contained more than 10 $\mu$g/L perchlorate.**

to food input ratio; the large output dilutes the expressed perchlorate. We hypothesize that perchlorate consumption comes primarily from food rather than from water or beverages. The recent finding of Jackson et al. (*42*) support this contention: they report bioconcentration factors of ∼200, for example, for a staple crop like wheat, relative to the water used to irrigate them. The ratio of daily milk output to food input for the average U.S. mother is 0.25 (0.7 kg/2.8 kg). For dairy cattle, this averages 1.6 (1.3−1.8, depending on the stage of lactation; see, for example, ref *43*). It may not be entirely coincidental that this ∼6× dilution factor is comparable to the 5.2× lower average perchlorate concentration that we observe in dairy milk versus breast milk. Epidemiologic studies conducted in Chile reportedly show that there are no differences in thyroid or other associated disorders with drinking water containing in excess of 100 $\mu$g/L perchlorate in one city versus another in which perchlorate in tap water was below detectable levels (*44*). It is often disregarded that the same studies also show that the iodide content of the same high perchlorate-laden drinking water is also very high, in fact more than the perchlorate content and for an average person can more than meet the U.S. RDA for iodine just from the water. Any consideration of the effects of perchlorate intake is necessarily incomplete without consideration of the iodine intake.

**Should the Present Iodine RDA for Pregnant and Lactating Women Be Increased?** Perchlorate has largely been considered as an isolated contaminant in water, affecting a limited local population. One epidemiologic study has concluded that the abnormal thyroid functions of newborns in Arizona is related to the ammonium perchlorate contamination of the lower Colorado River (*45*). Another study has concluded that decreased thyroid function in a population of newborn infants in California is associated with gestational exposure to perchlorate (*46*). Other studies have largely concluded that perchlorate exposure has no effects compared to control populations (*47*−49). We feel compelled to note that water *may* not be the principal direct vector for perchlorate exposure and a comparable control population with no perchlorate exposure may be mythical. Studies must be made where total perchlorate exposure is taken into account.

The U.S. median urinary iodine excretion in 1988−1994 was 14.5 $\mu$g/dL versus 32 $\mu$g/dL in 1971−1974, suggesting a ∼50% reduction in dietary iodine intake (*41*). The most recent study from 2000 shows only a marginal increase of urinary iodine to 16.1 $\mu$g/dL (see ref *50*). The last focused study on iodide content of breast milk was in the early 1980s: the results ($n = 37$) were significantly correlated with the intake of iodized salt and spanned 29−490 $\mu$g/L with an average of 178 $\mu$g/L (*51*), some 3× higher than the average of the present study. It is tempting to attribute this substantial and marked decrease to reduced dietary iodine intake (processed food no longer uses iodized salt; many prenatal vitamin supplements do not even contain iodine (*40*)) and the increased presence of perchlorate. But some caveats are in order. Ionic iodide ($I^-$) is the form of iodine that is transported by the NIS and should be the most relevant to measure in this context. Our method measures $I^-$, the report from the 1980s also ostensibly measured $I^-$ only. However, they report that their $I^-$ values represent ∼84% of the total iodine found in parallel measurements. Early chromatographic measurements have indicated that $I^-$ does not constitute the majority of the iodine present (*52*) although more recent work contradicts this (*53*). Obviously, modern methods of iodine speciation in milk will be of value. The need for better iodine speciation in milk has been recognized by others as well (*54*).

Regardless, breast milk iodide levels measured here are sufficiently low to be of concern. Our results do suggest that perchlorate may play an active role in the observed decrease in milk iodide levels when the perchlorate levels are high. Low-level perchlorate contamination seems to be widespread. Although much activity and research on remediation are presently underway, it will likely be years before concentrations actually decrease. Perchlorate is unique among many environmental threats. Its sole effect is in inhibiting iodide transport. This can be counteracted by increasing iodide intake. For iodine, the range between the RDA and the maximum safe dose (2 mg/d) is an order of magnitude. An increase in the RDA for the susceptible population could be the most prudent course.

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