Selenium Concentration in the Milk of Breast-Feeding Mothers and Its Geographic Distribution

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A total of 905 human milk samples collected in all provinces of Poland, between 12 and 75 days of lactation, were analyzed for selenium concentration. The distribution of Se levels in milk between the provinces was narrow and varied from 8.81 to 11.58 ng/mL, with the mean value (± SD) of 10.24 ± 2.82 ng/mL. The regions with lower levels of Se were in the central and eastern part of Poland; the areas with higher values were in the northern, western, and southern parts of Poland. No significant correlations were found between Se levels in milk and the age of lactating mothers or between Se levels and the postpartum period. The calculated daily Se intakes by breast-fed infants varied from 6.46 to 8.50 µg/day, with the mean value of 7.52 µg/day. This amount does not meet the recommended dietary allowances for infants between 0 and 6 months of age. Based on Se levels in human milk, we present a selenium map of Poland. ***Key words*: human milk, lactation, pregnancy, selenium intake. *Environ Health Perspect* 108:1043–1046(2000). [Online 11 October 2000]**

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Increasing evidence supports the claim that selenium is an essential dietary micronutrient for humans (*1,2*). Selenium is of particular interest in infant nutrition because human milk is the only source of this element during the most rapid period of growth. The composition of human milk is of great importance because breast milk is believed to provide all the nutrients, including trace elements, necessary for normal infant growth (*3,4*). The Se level in human milk depends on where the mother lives (*5–8*). This variation reflects Se content in the soil and, by the same token, the extent of Se accumulation in the cereals consumed in a particular region by animals and humans. It is well known that Se concentration in milk depends on the mother's intake of the element (*8–10*). Milk from women living in countries where the soil content of Se is low, such as New Zealand (*11*), Finland until 1984 (*12,13*), and some other European countries (*13–15*), has lower Se concentration compared with milk obtained from women residing in countries with high soil Se content, such as the United States (*16*), Japan (*6*), or Venezuela (*17*). The Se level in the soil of some parts of Poland is low. The Se intake by the Polish population has not been measured so far. Several authors found strong positive relationships between plasma, serum, or whole blood Se concentrations and Se levels in breast milk (*9,18*).

One of the main factors affecting trace element levels in human milk is the stage of lactation. The concentration of Se mean in breast milk shows a significant decrease in the course of lactation from > 30 ng/mL in the first 2–3 days after parturition to about 10–20 ng/mL in "mature" milk (*8,9*).

In our previous studies (*9,19*), Se concentration in breast milk was measured in one region of Poland. The aim of the present study was to measure Se concentration in mature breast milk in the entire area of Poland, to calculate the dietary Se intake by exclusively breast-fed infants, and to show the distribution of Se in Poland.

Materials and Methods

A total of 905 women from the entire area of Poland (i.e., 49 "old" and now 16 "new" provinces) furnished milk samples for analyses. Breast milk (20–30 mL) was collected manually directly into clean polyethylene containers and was stored at –20°C in the sampling unit up to 1 month. The samples were subsequently transferred in the frozen state to our laboratory and were stored at –80°C until analysis. The mean age of the women donating the milk samples was 29.3 years (17–45 years), and they were in the early stage of lactation (12–75 days postpartum). Most mothers were omnivorous (according to questionnaire), had given natural birth at a maternity clinic, and were healthy at the time of milk donation. Forty-nine percent of the mothers were nulliparous, and 7% had more than four deliveries and had no serious complications with their present or previous pregnancies. Forty-six percent of the women were of low socioeconomic status; 53% were from the middle-income group. Informed consent was obtained from all women enrolled in the study, and the study procedure was approved by the Medical University Ethics Committee on the Use of Human Subjects for Research.

Selenium was measured by the fluorometric method of Watkinson (*20*) with 2,3-diaminonaphthalene (DAN) as a complexing reagent. Milk samples (5 mL) were digested overnight with a mixture of concentrated nitric and perchloric acid and were then reduced with 10% hydrochloric acid. The DAN derivative of selenite formed at pH 2 was extracted into cyclohexane. The fluorescence was measured using a Hitachi F-4010 (Hitachi Ltd., Tokyo, Japan) spectrofluorometer.

The accuracy of the method was verified by using International Union of Pure and Applied Chemistry (IUPAC) certified materials and participation in the interlaboratory comparison trials (*21*). Fairly good agreement of Se levels was obtained between the certified value (33.9 ng/g; range 26.7–37.1 ng/g) and our data (30.05 ± 2.03 ng/g) (± SD) from six analyses of the standard reference material, IAEA A-11 powder milk (International Atomic Energy Agency, Vienna, Austria).

All statistical analyses were carried out using Statgraphics software (Statistical Graphics Corporation, Rockville, MD, USA). The Student's *t*-test was used to calculate statistical significance, which was set at $p < 0.05$.

Results

The overall mean (± SD) Se level in mature human breast milk found in this study, based on the analyses of 905 samples collected from all provinces in Poland, was 10.24 ± 2.82 ng/mL (Table 1). As seen in Table 1, the lowest mean levels of Se in milk were found in the province of Warsaw (8.81 ± 3.12 ng/mL) and the highest in the south (Opole province; 11.35 ± 3.53 ng/mL) and southeast (Rzeszów, Podkarpacie province; 11.58 ± 2.73 mg/mL). The differences between the lowest and highest mean levels of these provinces were statistically significant ($0.0001 < p < 0.002$). Relatively low levels of Se (below 10 ng/mL) were also found in two other provinces of Poland, Bialystok and Lublin. Our data show that in 13 provinces (excluding the three mentioned above) the distribution between mean Se levels in milk

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was uniform and very narrow, ranging from 9.6 to 10.7 ng/mL. The distribution pattern of Se concentrations among the individual milk samples (Table 2) revealed that the majority of the samples (n = 630; 69%) were within the range of 8–12 ng/mL. Only five of all samples studied had the Se level below 5 ng/mL and six had the level above 20 ng/mL. The Se concentrations in the individual milk samples did not correlate with the age of the milk donors (r = 0.019; p = 0.532) or with the period of lactation (r = 0.057; p = 0.082).

A selenium map of Poland, based on our results, is shown in Figure 1. The areas with lower Se levels in milk are located in the mideastern part of Poland, whereas relatively higher levels were found in the northern, western, and southern parts of Poland.

The daily intake of Se by breast-fed infants, calculated based on the milk Se level and the amount of milk consumed (734 mL) by infants up to 60 days of age, was based on Whitehead and Paul's (*22*) guidelines. We used up to 60 days of lactation as the cutoff because the majority of the milk samples (897 samples = 99.0%) were collected from mothers between 12 and 60 days of breast-feeding. The calculated data show that the Se intake in the various provinces in Poland varied from 6.46 to 8.50 µg/day, with the mean value of 7.52 µg (Table 1). The estimated safe and adequate daily dietary Se intake for infants between 0 and 6 months of age is 10 µg/day (*23–25*). Taking this as 100%, the breast-fed infants in Poland consume an amount of Se ranging from 64.6 to 85% of the recommended dose, with a mean value for the whole country of about 75% (Table 1).

Discussion

Selenium concentration in human milk. It is well known that several areas in the world have low Se content in the soil (*26*) and that this is responsible for the low dietary intake of the element (*27*). The level of Se in the soil influences its amount in foodstuffs and thus the dietary Se intake and, consequently, its level in milk (*13,28*). The marked geographic differences in Se levels in human milk are reflected in the differences in dietary Se intake by breast-fed infants (*13,29*). Inadequate Se intake by lactating mothers can be increased by supplementation of inorganic or organic Se (*9,13,19,30*). In Poland the soil has low Se content (0.024 ppm)(*31*). Our data are comparable with the Se levels in milk in some other European countries, such as Austria (*14*), Belgium (*32*), Spain (*33*), Sweden (*10*), and Finland up to the mid-1980s (*30,34*). In some other countries in Europe [Greece, Germany, Estonia, Scotland, Italy, and Finland (after selenium fertilization)], the Se levels in mature milk are much higher (*4,13,35,36*). Although our results show uniform distribution of Se in human milk in different parts of Poland, other authors have shown that Se levels in mature human milk may show considerable geographic variation. For example, Jochum et al. (*37*) found that in Düsseldorf, Germany, the Se level in milk was almost the same as in Poland (i.e., 9.9 ng/mL), whereas Dorner et al. (*38*) showed that in Kiel, Germany, the Se level in human milk ranged from 17.6 to 31.0 ng/mL. Similarly, Brätter et al. (*4*) obtained Se levels in different parts of Germany that varied between 13.5 and 28.3 ng/mL. Comparable variation was found in different parts of the United States (from 13.0 to 28.0 ng/mL)(*5*); in Venezuela, regional differences were much higher and ranged from 50 to 198 ng/mL (*8*). Such great ranges are related to different dietary Se intakes, and these in turn depend mainly on Se content in the soil in the studied region. In the seleniferous region in Venezuela, the daily dietary Se intake by lactating women reaches the value of 776 µg/day.

Selenium intake by breast-fed infants. In countries where the Se level in milk is around 10 ng/mL (in Poland), the Se intake varies from 5 to 8 µg/day (*8,12,32,36*). Our data show that the Se intake by breast-fed infants in Poland does not meet the recommended daily allowances. Lombeck and Menzel (*39*) calculated that 50% of the breast-fed infants and 90% of the formula-fed infants in many European and overseas countries get < 10 µg Se/day, (i.e., less than is recommended for infants aged 0–6 months). The Se requirements for pregnant and lactating women are increased as a result of Se transport to the fetus via the placenta and to the infant via breast milk (*30,40*). During lactation, a daily loss of 13 µg Se accompanies the secretion of 750 mL of milk. If a dietary absorption of 80% is assumed, an additional 20 µg Se/day is recommended to prevent depletion in the mother (*41*).

Geographic distribution of selenium in Poland. In some countries the geographic distribution of Se has been elaborated into a "selenium map." The most widely known is the Se map of the United States (*5*). Selenium distribution is typically determined based on the Se content in forage crops. Crop plants do not require Se, so their Se levels are directly proportional to the Se available in the soil. Generally, North America is known as a selenium-rich continent. In New Zealand the Se map was elaborated on the incidence of Se-responsive diseases occurring in domestic animals (*42*).

The lowest Se content in the soil has been shown in China, in Keshan County, Heilongjiang Province (*43*). Selenium analyses

Table 2. Distribution of selenium levels in mature human milk in Poland.

Selenium (ng/mL)	No. of samples
3–7	121
8–12	630
13–17	134
18–22	18
> 22	2

Table 1. Selenium concentration in human milk in all Polish provinces and daily dietary selenium intake by exclusively breast-fed infants.

Province	Provincial capital	No. of samples	Age range (years)	Days postpartum (range)	Selenium concentration (ng/mL)		Selenium intake	
					Mean ± SD	Range	µg/day	% of RDA
Zachodnio-Pomorskie	Szczecin	44	16–38	14–45	10.44 ± 2.48	7.3–9.9	7.66 ± 1.82	76.6
Lubuskie	Zielona Góra	38	18–34	15–75	10.74 ± 3.77	6.2–23.4	7.83 ± 2.73	78.3
Wielkopolskie	Poznań	98	18–46	13–61	10.30 ± 2.46	5.4–17.1	7.56 ± 1.80	75.6
Dolnośláskie	Wroclaw	83	19–44	14–64	10.41 ± 2.77	5.0–20.2	7.64 ± 2.03	76.4
Opolskie	Opole	20	21–41	15–73	11.35 ± 3.53	6.0–18.4	8.33 ± 2.59	83.3
Pomorskie	Gdańsk	35	21–41	12–62	10.64 ± 2.39	5.8–16.1	7.81 ± 1.75	78.1
Kujawsko-Pomorskie	Bydgoszcz	59	19–45	14–68	10.59 ± 3.02	3.0–19.7	7.77 ± 2.21	77.7
Warmińsko-Mazurskie	Olsztyn	38	17–40	14–52	10.51 ± 1.77	7.7–14.5	7.71 ± 1.30	77.1
Łódzkie	Łódź	77	20–42	16–62	10.64 ± 3.17	4.7–20.7	7.80 ± 2.32	78.0
Mazowieckie	Warszawa	109	18–41	12–57	8.81 ± 3.12	3.7–21.5	6.46 ± 2.29	64.6
Śląskie	Katowice	50	19–39	12–69	10.04 ± 2.61	5.3–16.1	7.37 ± 1.92	73.7
Świętokrzyskie	Kielce	30	17–39	12–46	10.41 ± 2.50	7.2–17.6	7.65 ± 1.83	76.5
Małopolskie	Kraków	35	19–39	12–75	10.58 ± 3.04	5.9–19.3	7.76 ± 2.23	77.6
Podlaskie	Bialystok	60	18–44	15–69	9.94 ± 2.09	6.5–16.7	7.30 ± 1.53	73.0
Lubuskie	Lublin	77	20–42	13–62	9.58 ± 2.13	4.4–14.0	7.03 ± 1.56	70.3
Podkarpackie	Rzeszów	52	18–42	13–64	11.58 ± 2.73	7.5–21.0	8.50 ± 2.00	85.0
All		905	16–46	12–75	10.24 ± 2.82	3.0–23.4	7.52 ± 2.06	75.2

of blood and hair from local residents and of the local foods were carried out and showed that the Se levels were extremely low (< 20 ng/mL in whole blood). In this region two endemic diseases, Keshan disease (juvenile cardiomyopathy) and Kashin-Beck disease (osteoarthropathy), have been reported. The dietary Se intake was the lowest in the world and consequently the Se level in human milk was only 3 ng/mL (*44*). In contrast, an analysis of Se in human milk collected in the region in China where human selenosis is endemic (Enshi area) showed a level of 283 ng Se/mL milk (*44*).

In Finland human whole blood and serum was used to determine the Se levels of different parts of the country (*45*). Finland is known as having the lowest content of Se in the soil in Europe. Gissel-Nielsen (*46*) prepared a Se map of some European countries, and the data were based on Se content in fodder crops published by various researchers. According to the map, in most countries the Se content in soils (except Scandinavia) is adequate. Parts of the United Kingdom (especially Ireland) have toxic amounts of Se. According to this map, 75% of Poland has adequate Se content.

Studies performed in 1990 by Debski (*47*), based on Se content in cow's milk and partly on Se content in grass and in livers of hares, showed that 75% of Poland is Se deficient and only 25% is adequate. He showed that in central and southwestern Poland, cow's milk contains 7.9–10.3 ng Se/mL, and in the northeast < 5.5 ng/mL. Our data on the distribution of Se in human milk in Poland (this study) are mostly in accord with those of Debski. However, taking Se intake of 10 μg/day to be the lowest adequate value, the mean amount of Se consumed by breast-fed infants equals 75% of the recommended dose. Our general conclusion, then, is that Polish mothers have a suboptimal level of Se in human milk.

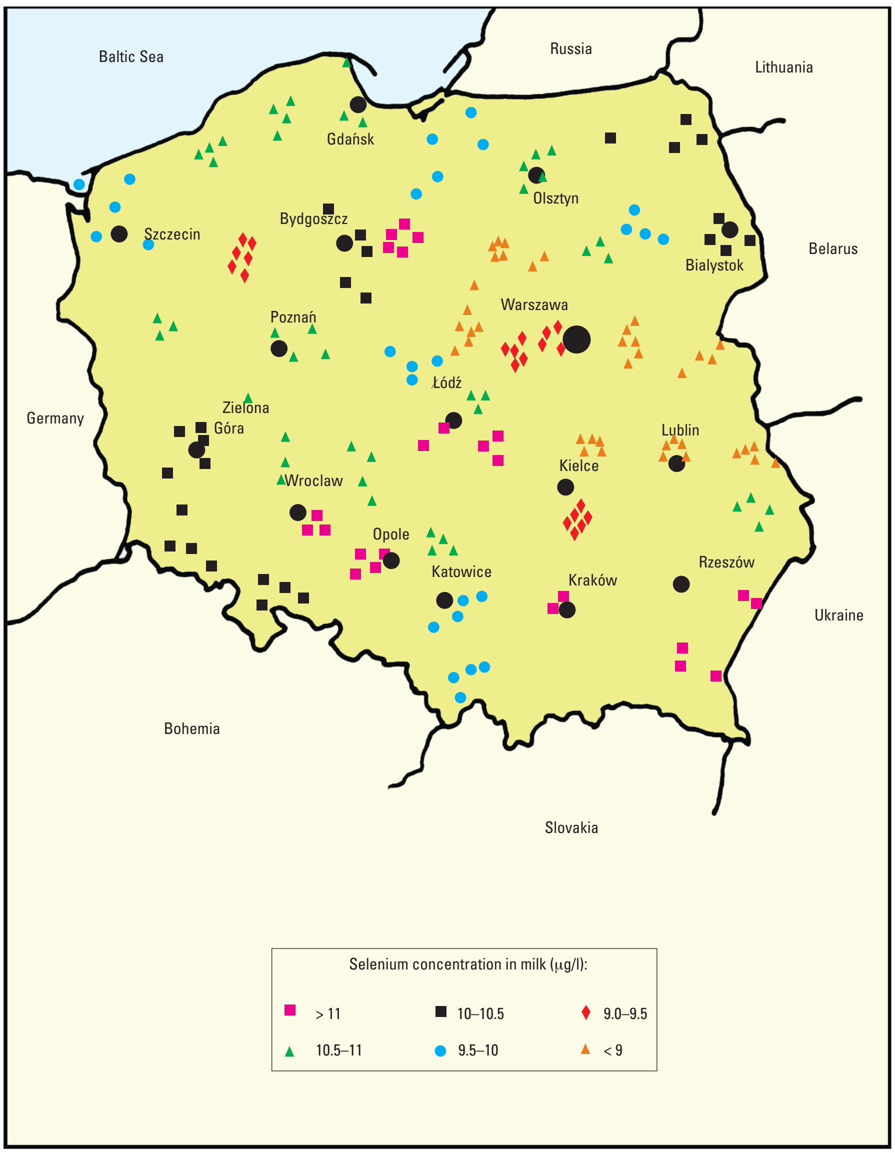

Figure 1. Selenium concentration in the milk of breast-feeding mothers in different provinces in Poland. The black circles designate the capitals of the provinces (see Table 1). Other symbols denote the Se concentration in the particular province, as presented in the figure key.

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