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Selenium Content of Infant Formulas and Estimated Intake of Infants in Japan and Korea

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Abstract

Selenium contents of infant formulas that were commercially available in Japan and Korea were determined by the method of atomic absorption spectrometry with hydride generation. Total means of selenium contents were 45.2±22.1 ng/g (n=34) in all the Japanese formulas and 58.3±18.9 ng/g (n=22) in all the Korean formulas. Selenium contents of milk-based formulas (54.7±23.2 ng/g in Japan, n=20 and 64.8±12.6 ng/g in Korea, n=18) were significantly higher than those of soy-based formulas (36.8±10.2 ng/g in Japanese brands, n=3 and 26.6±16.2 ng/g in Korean ones, n=3) and special-use fomulas (30.1±11.0 ng/g in Japanese brands, n=11 and 36.4 ng/g in Korean one, n=1). Based on selenium data of these formulas the selenium intakes of infants have been estimated to be about 6.6 μg/day in Japanese and 8.1 μg/day in Korean by milk-based formula feeding.

Key words: selenium content, infant formula, dietary selenium intake

INTRODUCTION

Selenium has been recognized as an essential element for human body; an essential component of glutathione peroxidase (GPx; EC 1.11.1.9), which is an antioxidant enzyme to protect cell membranes from oxidative damage by lipid peroxide and hydrogen peroxide (1). The enzyme activity in plasma as well as serum selenium concentration is lower in newborns than in their mothers and other adults (2,3). There is a good correlation between plasma selenium content and plasma GPx activity (4,5). Supplementation of selenite to infant formula increases plasma selenium and activity of GPx (6). Low selenium intake of formula-fed infants leads to both the very low selenium concentrations and GPx activities in serum and whole blood during the first month of life (3). A low selenium concentration in plasma at birth and a further decrease in plasma selenium during the first month in infants are reported (7). Therefore, the selenium concentration and GPx activity in plasma of infant can depend on human milk and/or formula intake.

We have reported the selenium content of colostrum and transitional milk collected from Japanese women in early lactation (8) and from Korean women during the course of lactation (9,10). In this work we have investigated the selenium content of infant formulas commercially available in Japan and Korea and we have estimated a daily dietary selenium intake for infants fed on formulas.

MATERIAL AND METHODS

Samples

Infant formulas commercially available in Japan and Korea are classified into three groups; cow's milk-based formula, soy-based formula and special-use formulas for allergy, diarrhea and premature infants. The milk-based formulas are divided furthermore into two groups; for infant aged 0 to 5 months or 0 to 12 months and for weaning infants aged more than 5 months. Those formulas were manufactured in 1991, 1993, 1995 and 1997. Formulas brand's, manufactured company's name and a sample number are listed in Table 1.

Cow's milk commercially available in Japan, the same brand of Yukijirushi Co. Ltd. 58 samples, manufactured in 1989 to 1997 were also used for selenium analysis.

Selenium analysis

The selenium content of formula was determined by atomic absorption spectrometry with hydride generation (HG-AAS) with the detection limit of 0.2 ng/ml of selenium, after decomposition of the milk with a mixture of nitric and perchloric acids and then reduction of all the selenium to selenite by boiling with hydrochloric acids, as described by the authors (11-14). Fairly good agreement of selenium determination was obtained between the certified value of 0.11±0.01 μg/g and our data of 0.103±0.006 μg/g (RSD: 6.2%) from six determinations, applying to the standard reference material NBS (National Bureau of Standards, USA) SRM-1549 milk powder. Precision of formula selenium analysis can be considered to be fairly good in trace ppb level analysis, since the relative standard deviation (RSD) of our data was calculated to be 6.2%.

Statistical analysis

The selenium content of formulas was shown as a mean

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Table 1. Sample descriptions of Japanese and Korean formulas

	Sample no.	Brand name	Dairy products Co. Ltd. manufactured
	Japan infant formula powders		
Milk-based			
0 to 6-12 month	J91-1	Meiji FK-P (0-12m)	Meiji-Nyugyo
	J91-2	Yukijirushi Neo Le (0-12m)	Yukijirushi-Nyugo
	J91-3	Morinaga LK-P (0-12m)	Morinaga-Nyugyo
	J95-4	Soft card F&P-f (0-12m)	Meiji-Nyugyo
	J95-5	L-ai (0-9m)	Yukijirushi-Nyugo
	J95-6	SMA S-26β (0-6m)	Nihon Wyeth
	J97-7	Hohoemi (0-12m)	Meiji-Nyugyo
	J97-8	L-ai (0-9m)	Morinaga-Nyugyo
6 month of more	J97-9	SMA S-26 Baby (0-9m)	Nihon Wyeth
	J91-10	Meiji Step Hi (6-12m)	Meiji-Nyugyo
	J91-11	Morinaga Tirumiru (6-12m)	Meiji-Nyugyo
	J91-12	Yukijirushi Tuyoiko (6-12m)	Yukijirushi-Nyugo
	J95-13	Step (9m-)	Meiji-Nyugyo
	J95-14	Tirumiru Ayumi (6m-)	Morinaga-Nyugyo
	J95-15	Tuyoiko (6m-)	Yukijirushi-Nyugo
	J95-16	SMA Follow 6β (6m-)	Nihon Wyeth
	J97-17	Step (9m-)	Meiji-Nyugyo
	J97-18	Tirumiru Ayumi (9m-)	Morinaga-Nyugyo
	J97-19	Tuyoiko (9m-)	Yukijirushi-Nyugo
	J97-20	SMA New Follow (9m-)	Nihon Wyeth
Soy-based	J95-21S	Soyameal	Meiji-Nyugyo
	J95-22S	Bonlact-i	Wakodo
	J97-23S	Bonlact-i	Wakodo
Special-use	J95-24A (L)	Epitoless 706A (protein hydrolysate)	Meiji-Nyugyo
Allergy	J95-25A (L)	MA-1 (protein hydrolysate)	Morinaga-Nyugyo
	J95-26A (L)	Pepdiett (protein hydrolysate)	Yukijirushi-Nyugo
	J97-27A (L)	Epitoless 706A (protein hydrolysate)	Meiji-Nyugyo
	J97-28A (L)	MA-1 (protein hydrolysate)	Morinaga-Nyugyo
	J95-29A (L)	Elememtal Formula 605Z (amino acid)	Meiji-Nyugyo
Diarrhea	J95-30D (L)	Lactless (protein hydrolysate)	Meiji-Nyugyo
	J95-31D	Akachan-E (protein hydrolysate)	Morinaga-Nyugyo
	J97-32D (L)	Lactless (protein hydrolysate)	Meiji-Nyugyo
	J97-33D	Akachan-E (protein hydrolysate)	Morinaga-Nyugyo
Premature	J95-34P	Neo-milk PM	Yukijirushi-Nyugo
	Korean infant formula powder		
Milk-based			
0 to 5-6 month	K92-1	92 Low-heat 1 (0-6m)	Pasteur
	K92-2	Mamma Omega-1 (0-5m)	Maeil
	K93-3	Maeil Mamma F-1 (0-5m)	Maeil
	K93-4	Imperial-1 (0-5m)	Nam Yang
	K93-5	Nam Yang Formula-1 (0-5m)	Nam Yang
	K93-6	Nam Yang Royal-1 (0-5m)	Nam Yang
	K93-7	Maeil SF-1 (0-6m)	Maeil
(3)5-6 more	K92-8	92 Low-heat 2 (6-12m)	Pasteur
	K92-9	Mamma Omega-2 (5-9m)	Maeil
	K93-10	Maeil Mamma F-2 (5-9m)	Maeil
	K93-11	Imperial-2 (5-9m)	Nam Yang
	K93-12	Nam Yang Formula-2 (5-9m)	Nam Yang
	K93-13	Nam Yang Royal-2 (5-9m)	Nam Yang
	K93-14	Weaning-1 (3-7m)	Pasteur
	K93-15	Weaning-2 (5-12m)	Pasteur
	K93-16	Weaning-3 (7-12m)	Pasteur
	K93-17	Weaning-4 (9-12m)	Pasteur
	K93-18	Weaning-5 (12m-)	Pasteur
Soy-based	K93-19S	Maeil SF-2 (soy)	Maeil
	K93-20S	Nam Yang Hop Alleray (soy)	Nam Yang
	K93-21S	Nam Yang Hop Alleray (soy)	Nam Yang
Special-use			
Diarrhea	K93-22D	Nam Yang Hop Diarrhea	Nam Yang

CHO : Carbohydrate
A : Formula for milk-allergy infant
D : Formula for diarrhea infant
P : Formula for premature infant (milk base formula)
S : Soy base formula (milk-free)
L : Lactose intolerance infant
J : Japanese formulas
K : Korean formulas

of 3 or 4 determinations of the same sample. Data are expressed as means with their standard deviation. Statistical analysis was performed using ANOVA and Student's t-test. Differences were considered to be significant when $p<0.05$.

RESULTS AND DISCUSSION

Selenium content of cow's milk

We have investigated the concentration of selenium in Japanese commercial cow's milk. Fig. 1 shows the longitudinal change in selenium content of the same brand of cow's milk manufactured in 1989 to 1997. There was little change in the milk selenium content (19.5±2.3 ng/g, n=58 samples) for nine years. In addition there was also little change in the selenium content of 17 lots of different brands of cow's milk manufactured in different parts of Japan from Hokkaido in the north to Miyazaki in the south of Japan, regardless of the milk-fat content, resulting in an almost constant value as an average of 18.2±3.9 ng/g, n=17 samples, which was reported by the authors (8). These similar results of 19.5±2.3 ng/g and 18.2±3.9 ng/g seem to depend on almost identical routine-feed at Japanese dairy farm.

Selenium content of formulas

Analytical results of selenium are listed in Table 2 for all the formula samples with other nutrient amounts labelled. A lots of nutrients, that is, carbohydrate, protein, fat and ash in proximate composition, and Ca, P, Mg, Na, Cl and K in macromineral, and Fe, Cu, Zn, Mn and I in micromineral were labelled by brands but Se was not labelled. Table 3 summarizes an average selenium content of formulas classified into three groups; cow's milk based, soy-based and special-use formulas. All data between Japanese and Korean formulas are not statistically different. But selenium contents in milk-based formulas (54.7±23.2 ng/g, n=20 in Japan; 64.8±12.6 ng/g, n=18 in Korea) were significantly higher than in soy-based formulas (36.8±10.2 ng/g, n=3 in Japan; 26.6±16.2 ng/g, n=3 in Korea) and special-use fomulas (30.1±11.0 ng/g in Japanese brands, n=11 and 36.4 ng/g in Korean one, n=1) ($p<0.05$). The selenium contents between the milk-based formulas for infants aged 0 to 5 months or 0 to 12 months (49.1±19.0 ng/g, in Japan, n=9; 55.8±12.1 ng/g, in Korea, n=7) and for weaning infants aged more than 5 months (59.3±26.1 ng/g, in Japan, n=11; 70.6±9.5 ng/g, in Korea, n=11) were not statistically different. The selenium contents between special-use and soy-based formulas were not statistically different, either.

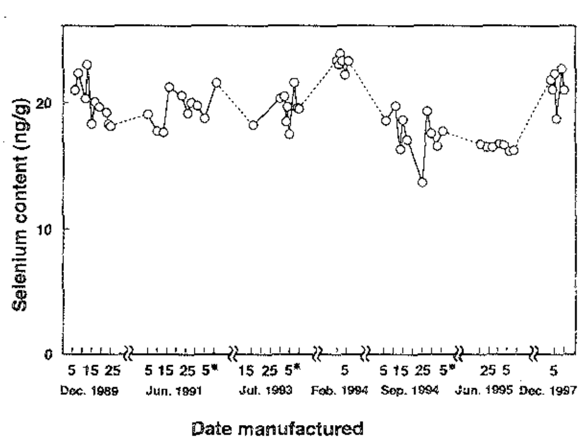

Fig. 1. The logitudinal change in selenium content of same brand of cow's milk commercially available in Japan (Yukijirushi 3.5). Average selenium content of all the 58 samples (Yukijirushi 3.5) from 1989 to 1997 was to be 19.5±2.3 ng/g (n=58).
*Date of the next month.

The protein sources of these special-use formulas are from protein hydrolysate (Table 1). Accordingly this lower selenium content (30.1±11.0 ng/g, n=11) may be due to the loss of selenium in the protein hydrolysis treatment. The lowest selenium content (4.1 ng/g) is found in the formula for milk-allergy [J95-25A (L)], which is elemental formula composed of amino acids as nitrogen sources. Since highest selenium content (161 and 162 ng/g) is found in two lots of Japanese skim milk powder for cuisine (8), from which the milk-fat has been removed, amounts of intrinsic selenium in infant formulas are probably associated with protein ingredients such as casein derived from milk or isolated soy protein.

It has been known that dietary selenium is normally associated with proteins; the greatest contribution of intrinsic selenium comes from the protein ingredients, eg., whey, casein, or isolated soy protein (15). The selenium and protein content in breast milk are positively correlated, which may be explained by the occurrence of seleno-amino acids in proteins (16). Most selenium occurs in tissues as seleno amino acids in proteins, either in specific selenoproteins or as a result of unspecific incorporation along with sulphur amino acids (17).

Milner et al. (18) has reported that most selenium in human milk is protein bound and at least nine selenoproteins are detected in dialyzed milk samples by the molecular sieve (Sephadex) chromatography and that glutathione peroxidase accounted for 15~30% of selenium found in milk.

Comparison with human milk

The selenium concentrations of formulas for lactation are calculated to be 7.7 and 9.4 ng/ml for the Japanese and Korean milk-based formulas, respectively, and 5.2 and 3.7 ng/ml for those soy-based formulas, since infant formula powder is generally used for dissolving with warm water to be 14 to 15% solution. There are other data on infant formulas; in the United States the selenium concentrations were 5 to 24 in two lots of different brands of milk-based formulas (15) and 7 to 14 ng/ml in four lots of soy-based formulas (15); study in Finland showed the selenium concentrations of a locally produced milk-based infant formula to be as low as 3 to 5 ng/ml (3). The selenium content of infant formulas varies as a result of differences

Table 2. Nutrients composition of Japanese and Korean formulas

	Sample no.	Protein	C.H.	Fat	Ash	Water	Ca	Mg	Na	K	P	Fe	Cu	Zn	Cl	Mn	I	Se
				(%)								(μg/g)						(ng/g)
Milk-based																		
0 to 6-12 month	J91-1	12.2	57.8	25.0	2.8	2.8	3800	400	1400	4900	2200	60	3.2	28	3200	1.0		44.2
	J91-2	13.5	54.0	27.8	2.2	2.5	3500	370	1500	5000	2000	60	3.1	26	3100	0.30		41.0
	J91-3	12.6	55.5	27.0	2.2	2.7	3600	450	1600	5400	2000	60	3.2	27	3300	0.30		32.1
	J95-4	12.2	57.8	25.0	2.2	2.8	3800	400	1400	4900	2200	60	3.2	28	3200	0.70		29.8
	J95-5	13.0	54.2	27.8	2.2	2.8	3500	370	1500	5000	2000	60	3.1	26	3100	0.30		45.5
	J95-6	12.0	55.9	28.0	2.1	2.0	3500	370	1200	4500	2200	71	3.7	29	3100			60.3
	J97-7	11.7	58.3	25.0	2.2	2.8	3800	400	1400	4900	2100	60	3.2	28	3100	0.70		51.0
	J97-8	13.0	54.2	27.8	2.2	2.8	3500	370	1500	5000	2000	60	3.1	26	3100	0.30		44.7
	J97-9	12.0	55.9	28.0	2.1	2.0	3500	370	1200	4500	2200	71	3.7	29	3100			93.6
6 month or more	J91-10	18.5	53.5	21.0	4.2	2.8	8100		2300	8100	3900	75						42.7
	J91-11	16.5	56.8	20.0	3.7	3.0	5600	550	2300	7600	3000	70						39.7
	J91-12	17.2	56.6	20.0	3.7	2.5	5000		2500	8000	3500	70						57.9
	J95-13	18.5	56.5	18.0	4.2	2.8	7000	700	2300	8100	3900	75						31.0
	J95-14	15.4	57.9	20.0	3.7	3.0	5600	700	2300	7600	3000	75			5400			39.1
	J95-15	15.7	57.2	21.0	3.3	2.8	5000	500	2000	7000	3000	70			5000			65.7
	J95-16	16.2	56.1	21.7	3.5	2.5	6300	500	2000	6250	3500	83			4650			98.2
	J97-17	17.0	58.1	18.0	4.1	2.8	6800	680	2200	7900	3800	80			5200			50.3
	J97-18	15.4	59.9	18.0	3.7	3.0	5600	700	2300	7600	3000	75			5400			37.2
	J97-19	15.7	57.2	21.0	3.3	2.8	5000	500	2000	7000	3000	70			5000			83.0
	J97-20	16.2	56.1	21.7	3.5	2.5	6250	500	2000	6250	3500	83			4600			107
Soy-based	J95-21S	13.4	61.5	20.0	2.6	2.5	4700	420	1500	5250	3000	65	3.2	28	3200		0.35	44.2
	J95-22S	14.5	60.2	20.0	2.8	2.5	4500	400	2000	6600	2700	70	3.6	36	3300		1.0	25.2
	J97-23S	14.5	60.2	20.0	2.8	2.5	4500	400	2000	6600	2700	70	3.6	36	3300		1.0	41.1
Special-use	J95-24A (L)	14.5	60.0	20.0	2.5	3.0	4000	420	1500	5250	2300	65	3.2	28	3200			28.9
Allergy	J95-25A (L)	11.7	78.6	2.5	2.3	3.0	3800	420	1500	4500	2200	65	3.2	28	3200			4.1
	J95-26A (L)	15.7	60.5	18.0	2.8	3.0	4000	450	1800	5800	2700	60	3.2	27	3600			35.0
	J95-27A	14.5	59.4	20.6	2.7	2.8	4000	370	1600	5300	2300	60	3.1	26	3100			25.9
	J97-28A (L)	14.5	60.0	20.0	2.5	3.0	4000	420	1500	5250	2300	65	3.2	28	3200			39.3
	J97-29A (L)	15.7	60.5	18.0	2.8	3.0	4000	450	1800	5800	2700	60	3.2	27	3600			28.9
Diarrhea	J95-30D (L)	14.0	61.0	20.0	2.5	2.5	4000	420	1500	5250	2600	65	3.2	28	3200			22.2
	J95-31D	12.6	55.5	27.0	2.2	2.7	3600	450	1600	5400	2000	60	3.2	27	3300	0.30		27.1
	J97-32D (L)	14.0	61.0	20.0	2.5	2.5	4000	420	1500	5250	2600	65	3.2	28	3200			35.1
	J97-33D	12.6	55.5	27.0	2.2	2.7	3600	450	1600	5400	2000	60	3.2	27	3300	0.30		40.8
Premature	J95-34P	15.2	59.9	19.6	2.8	2.5	4250	480	2000	6000	2300	100	3.1	26	4080			43.7

Table 2. Continued

	Sample no.	Protein	C.H.	Fat	Ash	Water	Ca	Mg	Na	K	P	Fe	Cu	Zn	Cl	Mn	I	Se
				(%)								(μg/g)						(ng/g)
Milk-based																		
0 to 5-6 month	K92-1	13.2	55.2	27.8	1.8	2.0	3800	380	1300	4500	2350	60	3.0	31	3200			47.5
	K93-2	12.6	55.5	27.2	2.2	2.5	3600	450	1400	4600	2100	60	3.2	28	3100			41.9
	K93-3	13.5	54.8	27.0	2.2	2.5	3600				2300	60	3.2	27				57.5
	K93-4	12.6	55.8	27.0	2.1	2.5	3600				2000	60	3.2	26				47.8
	K92-5	13.5	55.0	27.3	2.0	2.2	3700				2600	60	3.2	26				53.7
	K93-6	12.6	55.4	27.3	2.2	2.5	3600				2000	60	3.2	26				65.1
	K93-7	17.5	67.6	8.4	3.5	3.0	5000	500	2800	6900	3500				3500			77.2
(3)5-6 month	K92-8	16.5	55.5	23.2	2.8	2.0	6000	500	2350	6300	3500	70	3.0	31	4000			49.4
or more	K93-9	16.0	53.3	24.0	3.2	2.5	5600				3000	70	3.2	27				66.4
	K93-10	16.0	53.3	25.0	3.2	2.5	5600				3000	70	3.2	27				60.1
	K93-11	16.0	54.8	24.0	3.2	2.5	5000				3000	65	3.2	26				76.5
	K93-12	16.0	53.0	25.3	3.2	2.5	5000				3000	85	3.2	26				73.5
	K93-13	16.0	53.0	25.3	3.2	2.5	5000				3000	85	3.2	26				74.0
	K93-14						8900	380	2200	5900	6400	60	3.0	31				72.6
	K93-15						7500	380	1700	5700	6400	60	3.0	31				67.4
	K93-16						7700	500	1600	4800	6600	60	3.0	31				82.5
	K93-17						6900	500	1700	4100	6100	60	3.0	31				81.4
	K93-18						5800	500	870	2100	520	60	3.0	31				72.4
Soy based	K93-19S	14.5	51.8	27.0	3.2	3.5	4500	450	1900		3000	93		39			0.50	14.6
	K93-20S	16.0	53.3	25.0	3.2	2.5	4600	400	1900	5200	3000	89		37			0.50	20.2
	K93-21S	17.0	50.0	26.0	3.0	4.0	6000	235	2500	5000	3000	100		46	3000		0.45	45.1
Special-use																		
Diarrhea	K93-22D	15.5	68.5	10.0	2.5	3.5	2900		1100	3000	1400							36.4

CHO : Carbohydrate
A : Formula for milk-allergy infant
D : Formula for diarrhea infant
P : Formula for premature infant (milk base formula)
All nutrients except selenium are to have been labelled and Se was analyzed.

S : Soy base formula (milk-free)
L : Lactose intolerance infant
J : Japanese formulas
K : Korean formulas

Table 3. Selenium content (ng/g) of Japanese and Korean formulas

Infant formula	Japanese formulas	Korean formulas
Milk-based (average)	54.7±23.2 (n=20)[a]	64.8±12.6 (n=18)[a]
0 to 5-12 month	49.1±19.0 (n=9)	55.8±12.1 (n=7)
5 month or more (weaning)	59.3±26.1 (n=11)	70.6± 9.5 (n=11)
Soy-based	36.8±10.2 (n=3)[b]	26.6±16.2 (n=3)[b]
Special-use (average)	30.1±11.0 (n=11)[b]	36.4 (n=1)[b]
Allergy	27.0±12.2 (n=6)	-
Diarrhea	31.3± 8.3 (n=4)	36.4 (n=1)
Premature	43.7 (n=1)	-
Total mean	45.2±22.1 (n=34)	58.3±18.9(n=22)

Mean±SD. All data between Japanese and Korean formulas are not statistically different. [a,b]The same letters in the column are not significantly different at 5% level.

in the amounts of intrinsic seleniunm in the ingredients.

Selenium content of worldwide mature human milk has been summarized as an overall mean of 18 ng/ml ranged 7 to 33 ng/ml with 99% of the 241 subjects from 17 states in the United States (19); 10 ng/ml (8) and 18 ng/ml (8,15) in Japan; 12 ng/ml in Korea (9,20); 15 ng/ml in Greece (15); 17.6 to 31.0 ng/ml in Germany (21); 10 to 100 ng/ml for low and high selenium area in China (22); 5.7 to 10.7 ng/ml in Finland (1,8); 2.6 ng/ml for the Keshan disease area in China (22); and 10 to 20 ng/ml as a general value (1).

In conclusion, selenium concentrations in Japanese and Korean milk-based formulas are considered to be almost equal to human milk selenium, whereas those soy based formulas seem to be somewhat lower than in human mature milk but not in the level of 2.6 ng/ml for the Keshan disease area.

Estimated selenium intake of infants

In this work the dietary selenium intake was calculated to be 6.6 and 8.1 μg/day for Japanese and Korean infants fed on milk-based formulas and to be 4.5 to 3.2 μg/day for those infants fed on soy-based formulas, respectively, based on a formula milk consumption of a mean 860 ml per day (23). It is indicated that the selenium intakes of Japanese and Korean infants fed on these milk-based formula are almost equal to 6.98~8.38 μg/day estimated from the infants fed on human milk of our previous data (9).

Recommendations of selenium requirements for infants and children have been extrapolated from adult values on the basis of body weight, resulting in 10 and 15 μg/day for the first and second 6 months of infants by N.R.C. in 1989 (24). Other recommended dietary allowance as reference nutrient intake for 0 to 3 month infant and 4 to 6 month infant in England is estimated to be 10 and 13 μg/day, respectively (25).

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