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Nutrient minerals in drinking water: Implications for the nutrition of infants and young children

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1. INTRODUCTION

The WHO Global Strategy on Infant and Young Child Feeding emphasizes the importance of infant feeding and promotes exclusive breastfeeding in the first six months of life. In infants who cannot be breast-fed or should not receive breast milk, substitutes are required. These should be a formula that complies with the appropriate Codex Alimentarius Standards or, alternatively, a home-prepared formula with micronutrient supplements (WHO 2003). Drinking water is indispensable for the reconstitution of powdered infant formulae and needed for the preparation of other breast-milk substitutes. As a result of the long-term intake of a considerable volume in relation to body weight, the concentrations of nutrient minerals in drinking water may contribute significantly to the total trace element and mineral intake of infants and young children. This is especially applicable to formula-fed infants during the first months of life, who may be the most vulnerable group affected by excessive concentrations of nutrients or contaminants in drinking water.

Defining essential requirements of the composition of infant formulae, the importance of the quality of the water used for their reconstitution has been acknowledged by the Scientific Committee on Food of the European Commission (SCF 2003a). Although it was noted that the mineral content of water may vary widely depending upon its source, the optimal composition remained undefined. Recommendations for the composition of infant formulae refer to total nutrient content as prepared ready for consumption according to manufacturer's instructions. However, these usually inform the consumer about the quantity of powder and drinking water required as well as other technical advice for the reconstitution of the formula, but do not refer to the mineral concentration in drinking water itself.

The use of desalination to provide drinking water may continue to increase all over the world. Remineralization of mineral content in waters that have been treated by demineralization may provide an opportunity to improve compositional choices. Specific aspects of vulnerable groups have to be considered, but the needs of infants and young children, especially if nourished with infant formula instead of human milk, may be of special concern. The question arises whether special nutrient mineral properties of these waters should be considered for use for infants and young children.

2. ASSESSMENT OF MINERAL INTAKE IN INFANT NUTRITION

Public health decisions about the composition of infant foods and the use of drinking water in infancy require awareness of the approaches used in the study methodology applied to nutrition trials in infancy and early childhood. These approaches may be of crucial importance in the interpretation of the results and potential limitations of their significance for the issues raised. Analytical results of infant formulae may only refer to analyses of the powder itself or formulae prepared under standardized laboratory conditions with defined water (Lönnerdal *et al.* 1983). Metabolic studies investigating mineral bioavailability have attempted to exclude or minimize the potential influences of different water supplies (e.g. Schulz-Lell *et al.* 1992). They therefore have been performed either in the clinic, on metabolic wards, or at home using a standardized water supply or ready-to-feed liquid infant formula. On the other hand, recently published epidemiological trials concerning mineral supplementation in infancy neither assess representative mineral concentrations in the drinking water at a household level or the quantitative water intake (Dijkhuizen *et al.* 2001, Lind *et al.* 2003, Penny *et al.* 2004). For example, investigations concerning the effects of copper concentrations in drinking water, analyzed neither the respective nutrition nor representative specimens (Zietz *et al.* 2003). Finally, studies addressing both drinking water and powdered infant formula referred to the concentrations given by the manufacturer, but analysed the reconstituted formula, too. (Pomeranz *et al.* 2002).

3. THE QUANTITATIVE INTAKE OF DRINKING WATER IN INFANCY AND EARLY CHILDHOOD

Health and well-being in early childhood are dependent on an optimal supply of essential nutrients. Nutrient requirements for growth necessitate intake and positive retention of essential trace elements and minerals. The immaturity of homeostatic mechanisms in gastrointestinal and renal functions of resorption and excretion also raises a concern over the susceptibility to an excess or a deficiency of nutrients as well as to toxic substances during this crucial period for mental and motor development. A major factor in the nutrient mineral intake from drinking water is the quantity of water consumed.

3.1. The choice of nutrition – a significant factor of drinking water intake in infancy

In considering the consumption of drinking water by vulnerable populations, a figure of 0.75 litres per day has been used for a 5kg child and a figure of 1 litre per day for a 10kg child (WHO, 1993). Although these figures may be applicable for standard calculations, the range of quantitative water intake observed in populations at that age might be considerable according to the Food and Nutrition Board of the Institute of Medicine (FNB 2003). The choices made in terms of how an infant is fed, especially in the first six months of life, are significant factors in determining the level of nutrient mineral intake from drinking water:

> *Healthy, exclusively breast-fed infants* nourished according to present recommendations (WHO 2003) will not directly consume drinking water in the first six months of life. They might eventually be indirectly affected by a potential passage of (trace) minerals into human milk. Unfortunately, sometimes the early introduction of supplementary feedings of water, tea or other nutrients is practised. After six months, the introduction of complementary foods and breastfeeding for up to two years of age or beyond is recommended. During this period, household drinking water intake will depend on the extent of breastfeeding and on whether complementary foods are prepared at home or bought commercially.
>
> *Healthy infants fed powdered infant formula* consume drinking water from the day they are born owing to the fact that it is used to reconstitute the product. Both may contribute to the mineral intake up until complementary foods are introduced. Different sources of water may be used, including tap water, well water, and natural bottled

mineral water labelled as suitable for infant nutrition. Specific compositional characteristics of water used in a household or the use of stagnant water are very likely to have an effect throughout the entire formula feeding period if parents are not aware of the potential consequences. Infants are likely to be fed formula prepared at home, while older children or adults may consume considerable amounts of drinking water from sources outside the household. Powdered formulae do not necessarily originate from the region in which they are consumed and may be subject to specific directives established by the place of origin. Therefore, different ecological and legal factors may independently affect the two components making up the nutrient mineral composition of infant formula.

Home-prepared formulas are more likely to be based on local produce and are affected by local factors such as soil composition, the use of fertilizers or pollution. These may influence, too, the composition of the drinking water in the area. Home-prepared formulae may be prepared with a 1:1 dilution of cow's milk to drinking water with the addition of other components (Kersting 2001). Other concepts are based on a 2:1 dilution of cow's milk (WHO 2000), with a resulting lower quantitative intake of drinking water. After the age of six months, drinking water intake will also be dependent on the choice of complementary foods and beverages and how they are prepared.

The choice of complementary food introduced after six months may vary widely and it influences the evaluation of the nutrient mineral content in drinking water considerably. Inappropriate increases of the mineral intake may be of concern. Use of foods that are naturally rich in trace elements like zinc and iron (e.g. meat) or minerals like calcium (e.g. dairy products) is recommended, but may not be practised because these foods are not available, affordable or acceptable for the family. This may lead to reliance on predominantly plant-based or vegetarian diets of poor nutritional quality (Kersting 2001, FAO and WHO 2001). In these situations, and depending on its composition, drinking water may contribute a considerable part of the dietary mineral intake.

Assumptions about the mineral intake in infants may be influenced by factors not directly linked to the actual product composition. The "standard intake" of drinking water calculated by WHO in early infancy is 750 ml (WHO 1993); the same figure is given by the SCF (2003a) for infant formula. Most standard instructions for infant formulae require 90g water to 100g formula. Therefore, the basic intake assumptions for the quantitative intake of drinking water in formula-fed infants could differ by approximately 10%. Recent recommendations supported a reduction of the upper margins for caloric density in infant formulae and follow-on formulae. As nutrient requirements for powdered infant formulae are given per 100 kcal intake (e.g. SCF 2003a), this results in a reduction of the recommended upper levels of mineral concentrations (-7% or -12%). These examples may only refer to differences of approximately 10%, but they emphasize the need for transparency regarding the factors that influence the final composition of infant formulae.

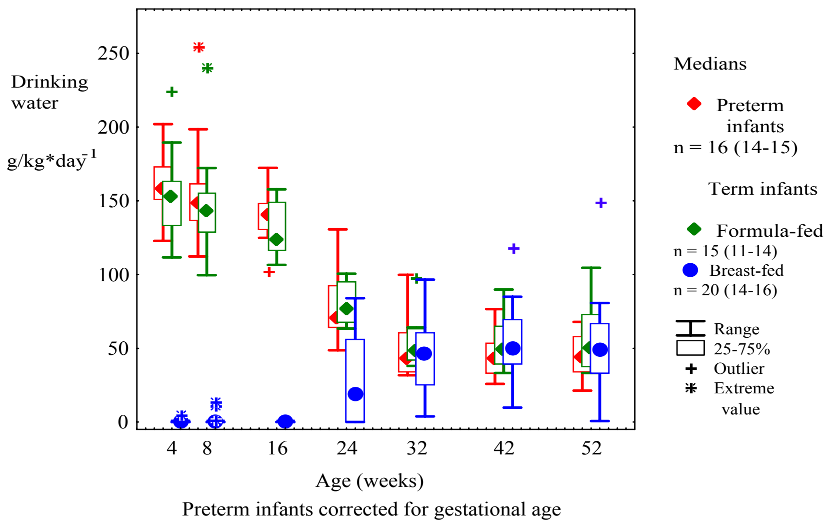

Figure 1: Household drinking water intake of breast-fed term infants and formula-fed term and preterm infants (based on data assessed for Sievers *et al.* 2000, 2001).

3.2. Specific aspects of quantitative intake of drinking water in infancy and childhood

In exclusively breast-fed infants, the mean intake increases from 699g up to 854g at the age of six months (Butte *et al.* 2002). The quantitative milk consumption of formula-fed infants exceeds the intake of breast-fed infants at the age of 2-4 months (Hofvander *et al.* 1982). The potential implications for the quantitative intake of household drinking water (Figure 1) have been calculated by re-evaluating data assessed in a longitudinal trial on nutrient mineral supply in breast-fed and formula-fed infants (Sievers *et al.* 2000, 2001):

Exclusive breast-feeding had been recommended for a minimum of four months in infants receiving human milk, the other families were provided with liquid infant-milk formulae. For infants from the age of five months, powdered follow-on formulae, age-specific complementary feeds, powdered cereals and a standard mineral water suitable for infant feeding were supplied. Weighing each meal over a period of 72 hours enabled its nutrient intake to be assessed. Liquid infant formulae were recalculated based on the assumption that the powdered formula and drinking water used corresponded to an equivalent product marketed in Germany. This precept enabled the differences in drinking-water intake between full-term, breast-fed infants and premature or full-term formula-fed infants to be assessed (Figure 1, Table 1). Up until the age of four months, only two breast-fed infants consumed small amounts of drinking water. At the same time, the daily drinking water intake needed for the re-constitution of powdered infant formula decreased from 158 to 140g/kg in premature infants and from 153 to 122.9g/kg in full-term infants. With all families in the study being provided with standardized complementary feeds, it was not until infants reached the age of 32 weeks that comparable intakes of drinking water in all groups (57% of total water intake, Table 1) were attained.

These drinking water intakes exceed those assessed in the DONALD (Dortmund Nutritional and Anthropometrical Longitudinally Designed) Study (Hilbig *et al.* 2002). The authors reported that in formula-fed infants, the daily intake decreased longitudinally from 107 ± 28g/kg at three months to 33 ± 25g/kg at twelve months of age. Comparing specifically the tap-water intake of formula- and breast-fed infants, the mean total daily tap-water intake in breast-fed infants observed throughout the first year was 15 ± 23g/kg and, of formula-fed infants, 49 ± 33g/kg. Between the ages of one and three years, tap-water intake averaged 15 ± 20g/kg. The differences may be explained by several factors: the DONALD study omitted early infancy up until 3 months of age, where higher intakes are observed. Lower intakes of tap drinking water may be indicative of a higher proportion of home-prepared meals. The DONALD study also reported on water intake in school children (Manz *et al.* 2002) and assessed the hydration status of children aged 4 to 10.9 years through the analysis of water intake, urine volume and urine osmolality. Based on their estimates of adequate daily total water intake, the authors confirmed the total water intake of 1.0ml/kcal in children that was recommended earlier (FNB 1989). The mean intake volumes reported for the age groups 4.0-6.9 and 7.0-10.9 were 1495g and 1834g for boys, and 1318g and 1545g for girls. The trends over the 15-year period of the study revealed an increase in total water intake in 2-13-year-old children irrespective of sex, attributable to increased beverage consumption on the one hand, and decreased milk, coffee/tea and soft-drink consumption on the other (Sichert-Hellert *et al.* 2001). The results may be influenced by regional aspects and the high interest in nutrition documented by the longitudinal participation in the trial. Other authors have been rather concerned about consumption of large quantities of squash on the one hand and the low consumption of plain water on the other (Petter *et al.* 1995).

3.3. The contribution of drinking water to nutrient mineral intake in infancy and early childhood

The potential significance of mineral nutrients in infant nutrition, but especially in human milk, has attracted a great deal of attention over the last few decades (Butte *et al.* 2002, FAO and WHO 2001, SCF 2003a). The upperbound acceptable mineral concentrations in WHO Drinking Water Guidelines, mature human milk, and the recent recommendations on the composition of infant formulae and follow-on formulae are compared in Table 2. Age-specific nutrient recommendations from different authorities have been compiled by Olivares (2004). In view of the specific needs of this age group and recent modifications in the assumptions of adequate intakes in infancy, some aspects of current guidelines or directives for drinking water may be reconsidered. The evaluation of adequacy or optimization potential in terms of feeding infants and young children have preferably to be based at household level to enable the assessment of leaching from water pipes or contamination by other sources.

Public health recommendations should take into account that both desalinated water (Cotruvo 2004) and infant formula (Tomita 2000) are manufactured products and offer the potential of influencing the final nutrient mineral supply to the infant. Remineralization of processed waters should aim to achieve concentrations that are acceptable when combined with infant formulae but which are potentially useful in early childhood thereafter. However, the assessment may differ for each mineral under consideration.

3.3.1. Manganese and molybdenum

Manganese and molybdenum concentrations set out in the WHO drinking water guidelines (WHO 1993, 1996) are much higher than those observed in human milk and in the recommendations regarding their respective daily adequate intake (FNB 2001, Table 2).

Table 1: Drinking water intake in infancy (median, range)

Age, ±2 weeks	4	8	16	24	32	42	52
	Total water intake, g x kg^{-1} x d^{-1}						
FF-PT	158.3 (128.1-201.9)	148.0 (123.2-254.2)	140.1 (102.2-172.4)	90.2 (52.9-130.6)	78.5 (58.0-116.2)	77.9 (65.1-110.9)	81.3 (56.9-116.6)
FF-T	152.7 (111.8-224.1)	142.6 (99.6-240.0)	122.9 (106.5-157.8)	94.5 (81.9-117.8)	87.9 (69.3-139.6)	83.7 (53.8-135.3)	77.7 (63.4-149.9)
BF-T	132.7 (81.7–147.7)	111.4 (75.6-153.0)	97.8 (50.1-144.2)	98.8 (66.9-132.2)	84.9 (71.4-140.3)	82.9 (60.0-165.3)	93.7 (49.2-192.2)
	Drinking water intake, g x kg^{-1} x d^{-1}						
FF-PT	158.3 (122.8-201.9)	148.0 (112.3-254.2)	140.1 (102.2-172.4)	70.3 (48.6-130.6)	43.1 (31.7-99.9)	42.9 (25.9-76.6)	43.9 (21.3-67.9)
FF-T	152.7 (111.8-224.1)	142.6 (99.6-240.0)	122.9 (106.5-157.8)	76.5 (63.4-100.6)	47.8 (38.0-97.8)	48.7 (33.3-89.9)	50.0 (33.2-104.6)
BF-T	0.0 (0.0-4.7)	0.0 (0.0-14.0)	0.0	18.6 (0.0-83.9)	46.6 (3.8-96.5)	49.5 (9.8-118.1)	48.9 (0.8-148.8)
	Drinking water intake, % of total water intake						
FF-PT	100.0 (95.8-100.0)	100.0 (91.1-100.0)	100.0 (98.9-100.0)	88.2 (65.4-100.0)	57.7 (41.4-85.9)	53.3 (39.6-73.5)	55.2 (37.4-71.9)
FF-T	100.0	100.0 (99.9-100.2)	100.0	81.7 (67.8-100.0)	57.7 (48.1-70.1)	58.2 (54.8-75.1)	58.9 (44.8-70.4)
BF-T	0.0 (0.0. to 3.6)	0.0 (0.0-11.4)	-	16.8 (0.0-84.3)	57.0 (4.6-71.6)	63.8 (12.2-77.3)	66.3 (0.9-81.3)

FF-PT: Premature, formula-fed infants, investigated in parallel with term infant groups, gestational age at birth 29 (25 – 32) weeks; fed cow's-milk-protein-based infant formula at least up until the age of 16 weeks, corrected for gestational age; n= 16 (14-15) infants

FF-T: Term, formula-fed infants, fed cow's-milk-protein-based infant formula at least up until the age of 16 weeks; n=15 (11-14) infants

BF-T: Term, exclusively or predominantly breast-fed infants up until the age of 16 weeks; n = 20 (14-16) infants

Manganese is an essential nutrient in the formation of bone, amino acids, cholesterol and carbohydrate metabolism and present in the metalloenzymes arginase, glutamine synthetase, and manganese superoxide dismutase. The recommended adequate intake (AI) is based on the intake from human milk and set at 0.003mg/day in the first six months (preceding recommendation: 0.3-0.6 mg; FNB 1989). Thereafter, an increased intake of 0.6mg/day (7-12 months) and 1.2mg/day for children aged 1-3 years (FNB 2001) has been recommended. During the last decade other recommendations and directives have also decreased considerably: In Germany, infant formulae for special medical purposes had to provide 0.5 to 2mg manganese per day, equivalent to 0.66 to 2.67mg/L (BMJFFS 1988), but actual requirements are set at 0.325 to 1.3 mg/L (EC 1999). Analytical results of formulae ranged from 0.0 to 7.8mg Mn/L (Lönnerdal *et al.* 1983), with high concentrations observed in soy-protein-based formulae and formulae for special medical purposes. Subsequently considerably lower results were assessed (0.44 and 0.53mg Mn/L; Krachler *et al.* 1998). Recommendations for infant milk formulae yielded a range of 1-100µg/100kcal (SCF 2003a), equivalent to 0.007 to 0.65mg Mn/L. Therefore, regardless of any change in drinking water composition or respective regulations, the potential significance of the contribution of drinking water supply to infant nutrition has increased considerably.

A WHO guideline value has been set at 0.5mg/L based upon aesthetics for manganese in drinking water (WHO 1996). Powdered infant formula with the mean recommended manganese concentration (0.325mg/L) would exceed the suggested maximum (SCF 2003a) if prepared with drinking water in the upper range of WHO guideline values. Animal studies (Keen *et al.* 1986, Tran *et al.* 2002) indicate that neonatal manganese metabolism may be of special concern. Balance studies in infants confirmed substantial quantitative manganese retention in infants fed special diets as a result of metabolic disease or in premature infants fed routine mineral supplements and containing manganese by contamination (Sievers *et al.* 1990, 1991). Recommendations concerning drinking water for the reconstitution of infant formulae should take into consideration the low concentration in human milk and concerns about the safety of high manganese intakes. In situations where high manganese concentrations in drinking water cannot be avoided, the potential combination with formulae of high manganese content with high manganese water should be discouraged.

Molybdenum is a co-factor in the enzymes sulphite oxidase, xanthine oxidase and aldehyde oxidase (Turnlund 2002). The adequate intake in infants and young children has been set for the age of 0-6 months at 2µg/day, derived from the intake by human milk (preceding recommendation: 15-30µg/day; FNB

1989). In contrast to manganese, however, the AI for the age 7-12 months has been derived from the likely intake with human milk as a sole source (3μg/day) and not from the estimated intake with a mixed diet (FNB 2001). This value will be greatly exceeded by formula-fed infants and by infants nourished with the recommended complementary feeds (Anke *et al.* 1993). The uncertainty over molybdenum requirements is also reflected in the tolerable upper intake (UL) level defined for adults with 0.01mg/kg body weight (SCF 2000a) or, alternatively, 0.03mg/kg body weight (FNB 2001). Both were based on the same trial (Fungwe *et al.* 1990), but differed in the assessment of the uncertainty factors. Despite concern about the infant's capacity to deal with excess amounts of Mo, no UL has been set for infancy.

Table 2: Trace minerals in human milk and in drinking water guidelines

Mineral	Mature human milk (Lawrence and Lawrence 1999)	Drinking water guidelines (WHO 1996)	SCF 2003a (Recommended energy content: 60-70kcal/dl; based on 65kcal/dl, cow's-milk- protein-based formula)
	mg/L	Mg/L	mg/L
Calcium (mg/L)	280	n.g.	325-910 (Ca:P=1-2)
Iron (mg/L)	0.40	0.3**	1.95-8.45
Zinc (mg/L)	1.2	3.0**	3.25-9.75
Copper (mg/L)	0.25	1.0**; 2.0*(P)	0.228-0.65
Selenium (μg/L)	20	10*	20-59
Fluoride (mg/L)	0.016	1.5 (P)	≤ 0.65
Magnesium (mg/L)	30	n.g.	33-98
Sodium (mg/L)	180	200**	130-390
Sulphate (mg/L)	140 (sulphur)	250**	n.g.
Chloride (mg/L)	420 (chlorine)	250 **	325-1040
Manganese (μg/L)	6	100**; 500* (P)	6.5-650
Molybdenum (μg/L)	2μg/d (2)	70*	n.g.

* Health-based guideline value, (P): provisional; **Parameters in drinking water that may give rise to complaints from consumers (2) FNB 2001

The upper level of Mo intake has been set at 10μg/100kcal for nutrients for special dietary purposes in infancy (EC 1999). An infant formula prepared in accordance with this directive may result in a daily Mo uptake > 10μg/kg. In addition, an upper guideline value of 70μg/L has been set for drinking water (WHO 1993). The maximum Mo intake by water used for powdered formula preparation exceeds 10μg/kg at an intake of 150ml/kg or more. This volume, however, is quite common in premature and young full-term infants (Figure 1) and unsupplemented infant formulae repeatedly contained > 100µg/L (Sievers 2003). The threshold for long-term safe molybdenum intake in infancy may need to be reconsidered and re-evaluated by studies in areas with naturally longterm high molybdenum intakes by drinking water before present WHO guidelines are extended on other processed waters.

3.3.2.Copper

Both copper deficiency and excess are of clinical importance: *copper deficiency* has been described in premature infants and is characterized by oedema, anaemia, leucopoenia, neutropenia and osteoporosis (Sutton *et al.* 1985). On the other hand, concerns have been raised after the description of Non-Indian Childhood Cirrhosis associated with excessive copper concentrations in well waters with a low pH and copper pipes (Dieter 1999). Examinations in a subgroup of infants from households with copper concentrations exceeding 0.8mg/L yielded no indication of a hazard resulting from copper pipes connected to public water supplies (Zietz *et al.* 2003). The safety of the WHO guideline value (2mg/L) for copper in drinking water during infancy has been supported (Olivares *et al.* 1998). Leaching from copper pipes and other potential problems of infant formula preparation have raised concern and have been addressed in respective recommendations (Committee on Nutrition 2004).

Differences in the quality of water available from the tap or directly drawn at the water plant may be important in terms of its suitability in infancy and early childhood. The problems of the use of well water have to be considered in both developed and developing countries, though the proportion of public water supply and the use of home wells may vary considerably. In Germany, in 1998, only 2.5% of the drinking water supply was derived from well supplies. However, more than 58% of the [adult] study population consumed first-draw drinking water for their personal consumption (Becker *et al.* 2001). Concerns arise that common awareness of problems caused by the application of this practice to formula preparation cannot be assumed.

The FNB (2001) recommendations in the first year for adequate copper intake, based on intake by human milk and adequate complementary feeds thereafter, were set for the first 6 months at 200µg/day and, in the 7-12 months thereafter, at 220µg/day. For young children of 1-3 years, the intake was set at 340µg/day. Regulations for both components of infant formulae - the powdered formula and the water - have declined considerably during the last few years: In the past, national directives for copper intake by foods for medical purposes in infancy were set at 0.5 to 2mg Cu per day, equivalent to 0.670 to 2.7mg/L formula (BMJFFS 1988). This has been reduced to 0.130 to 0.780mg Cu/L formula (EC 1999), slightly lower values are recommended in infant formulae (SCF 2003a). At the same time, the WHO Guideline value of 2mg/L (WHO 1996) has been transferred into present regulations on drinking water, which formerly set a cut-off value of 3mg/L (BMJFG 1990, BMG 2001). These changes result in a reduction of the upper margin of daily copper intake from > 4 mg/d to 2 mg/d at an intake of 750 ml/d.

3.3.3. Iron and zinc

Iron and zinc drinking guideline values are only set at levels that may give rise to complaints from consumers (WHO 1996). Recommendations for both elements in infant food other than human milk have to take into consideration the importance of bioavailability (FAO/WHO 2001). Other than for manganese, molybdenum and copper, these are within the concentrations observed in mature (iron) human milk or colostrum and transitional human milk (zinc), Table 2.

The low iron intake recommended in the first six months of life by the FNB 2001 (0.27mg Fe/d) is based on the highly bioavailable intake with human milk. Thereafter, however, increased intakes are needed to cover the demands of growth, especially the increase in blood volume (7-12 months: 11mg/d; 1-3 years: 7mg/d). The American Academy of Pediatrics (AAP 1999) advocated an iron supplementation of 4-12mg/L of infant formulae. The SCF (2003a) of the European Commission regarded 2-8mg/L as suitable for cow's-milk-based infant formula and 6-15mg/L for soy-based follow-on formula. 2mg/L in drinking water were not considered to present a hazard to health, but it has been assumed that acceptability would usually be affected above 0.3mg Fe/L because of the staining of laundry and plumbing fixtures (WHO 1996). Therefore, in infants fed iron supplemented formulae, the contribution of drinking water to the iron intake may be of minor importance.

This assessment may be different in infants fed home-prepared, non-supplemented formulae or complementary feeds. In Bangladesh, children drinking water containing > 1mg Fe/L were significantly taller than those drinking < 1mg Fe/L (Briend *et al.* 1990). The higher iron concentrations were caused by soil characteristics and high concentrations occurred in clusters of tube wells. However, other minerals present in the soil along with iron may have promoted linear growth too. The effects of other trace elements (e.g. zinc, copper) have not been reported in a trial investigating the fortification of drinking water with iron for pre-school children attending day-care community institutions in Brazil. A reduction of anaemia in preschool children in a day care centre and in families with a low socio-economic status (Dutra de Oliveira *et al.* 1994, 2002) was assessed.

Zinc in colostrum may exceed 10mg/L, declining continuously down to a level of about 1.2mg/L at 4 months (Dorea 2000). Despite the high bioavailability of zinc in human milk, it may be difficult to satisfy needs adequately after a period of four to six months (Butte *et al.* 2002). In view of different bioavailability depending on the nutritional source, intake recommendations range from 1.1 to 6.6mg/day during the first six months of life, and 2.5 to 6.4mg/day thereafter (FAO and WHO 2001). The FNB (2001) recommended 2 and 3mg respectively, based on the zinc concentration in human milk as the basic source. Recommendations for infant and follow-on formulae (SCF 2003a) in accordance with the current infant formulae EC directive, yield 3.3–10mg/L or, if based on soy protein, 4.9–15.6mg/L. The upper level of tolerable zinc intake for children aged 1-3 years (SCF 2003b) has been set at 7mg/day. Water yielding a zinc concentration within the upper range of WHO guideline values (3mg/L, Table 2) might contribute considerably to the zinc intake in infancy.

3.3.4. Calcium and magnesium

The calcium and magnesium concentrations in cow's milk far exceed those present in human milk (Lawrence and Lawrence 1999) and have to be modified e.g. during the manufacturing of infant formulae based on cow's milk protein. The adequate intake (AI) for calcium has been set at 210mg (formula-fed infants: 315mg/d), 270mg and 500mg, respectively, for ages 0-6 and 7-12 months and 1-3 years. The AI for magnesium was set at 30mg (formula-fed infants: 35mg) and 75mg (0-6 and 7-12 months) and for ages 1-3 years the RDA was set at 80mg (FNB 2003). The ranges recommended for infant formulae by the SCF (2003a) were 325-910mg/L Ca and 33-88mg/L Mg (SCF 2003a) respectively. Lesser absorption from infant milk formula compared to human milk has been considered, therefore the minimum requirements are set above that found in human milk.

High mineral concentrations in water increase the renal solute load and, therefore, are of concern in infancy. For natural mineral water labelled as "suitable for the feeding of infants", the Committee on Nutrition of the German Society of Paediatrics (1991) advocated, amongst others, concentrations of < 20mg Na/L and < 200mg/L sulphate. The Committee assessed that, at that time, the cut-off value for sulphate (200mg/L) in mineral waters with a sodium concentration < 20mg/L led to a natural limitation of the calcium and magnesium concentration. In view of this finding, no cut-off value for calcium and magnesium was set. In Switzerland, however, a cut-off value has been set for calcium < 200mg/L and magnesium < 40mg/L (Committee on Nutrition 1990). Public drinking water in Germany yielded a mean concentration of 66.4 (0-555.9) mg/L calcium and 11.8 (0-555.9) mg/L magnesium (Schimantschek 2003). Transparency should be provided for the consumer with respect to Ca and Mg concentrations in public drinking water, this may not be achieved by referring to “water hardness”. Older infants fed mainly plant-based complementary foods and young children on vegetarian nutrition may benefit from drinking water contributing to calcium and / or magnesium intake.

3.3.5. Sodium

Children, the elderly, and persons with compromised renal systems are more susceptible than healthy adults to harmful effects of high sodium intake. The FNB (2001) set the adequate intake (AI) at 120mg, derived from the intake of breast-fed infants. In accordance with respective regulations in the USA, the regulation for infant milk formulae in Europe supports an intake of 20-60mg/100kcal (EEC 1991), equivalent to 127-292.5mg Na/d. Mineral quantities have been calculated and incorporated into baby formula by the manufacturers in accordance with current directives.

Actual data on sodium metabolism in infants fed modern infant milk formulae, however, are scarce and the interpretation has to take into account specific information: longitudinal sodium balance studies in infancy compared ready-to-feed liquid infant milk formula-fed (269mg Na/L) infants with breast-fed (138mg Na/L) infants (Schulz-Lell *et al.* 1992). The daily retentions observed were 11.5mg/kg and 9.2mg/kg, respectively. The actual composition of this brand marketed as powdered infant formula has a sodium content of 120mg Na/100g powder. In Germany, a mean sodium drinking water concentration of 12.4 (<1.0-210) mg/L has been observed (Wolter 1989), concentrations exceeding 150mg/L are the rare exception. The upper level of the Drinking Water Ordinance is 200mg/L (BMG 2001), equivalent to respective WHO guidelines. Prepared according to current recommendations for the preparation of infant feeds/formula in the first months of life (Kersting 2001, Committee on Nutrition 2004), these factors may theoretically result in a considerable range of sodium intake:

> Up to 186mg/L (formula + bottled mineral water labelled as suitable for the preparation of infant formula, containing ≤ 20mg/L).
>
> Up to 366mg/L (formula + drinking water with the upper limit of 200mg/L).
>
> Up to 310 or 490mg/L, respectively, through the components drinking water (as used in 1) or 2)) and cow’s milk (580mg/L, Lawrence and

Lawrence 1999) if parents insist on the use of home-prepared formula and prepare it according to Kersting (2001).

These examples also highlight potential hazards; drinking water with high sodium concentrations may elevate the sodium concentration of infant formulae considerably. Cow's-milk-based infant formulae with low sodium content may be either not available, not affordable or inadequately prepared owing to regional or social constraints. The home-prepared replacement formula recipe described by WHO/UNICEF/UNAIDS (WHO 2000) comprises a 2:1 dilution of cow's milk with drinking water and added sugar. Cow's milk contains more sodium than human milk; the sodium concentrations to be expected will range from slightly less than 406mg/L up to 586mg/L or above (based on the recommendation of ≤ 20mg/L for bottled drinking water for infant use to ≤ 200mg/L for drinking water). Other minerals may potentially increase the renal solute load, too, necessitating higher quantities of water available to form urine in view of the reduced ability of infants to concentrate urine. This may reduce the margin of safety, especially under conditions of stress, such as infections accompanied by fever.

Where definite problems exist with drinking water (e.g. excessive nitrate content), packaged mineral water should be considered as an alternative to drinking water from the public supply. The infant formula industry does try to lower the higher mineral concentration of cow's milk compared to human milk, but with the addition of mineral waters this content may be increased again. Considerable ranges for sodium in packaged mineral waters have been observed in Europe (26.6 (1.3-1723.0) Na, Misund *et al.* 1999). This necessitates transparency as to whether a product is suitable for the use in infant nutrition or not. Paediatric recommendations for the suitable composition of packaged waters for use in infant feeding were set at <20mg Na/L (Committee on Nutrition 1991, 2004). A certain contradiction arises in view of the previously mentioned cut-off value for public drinking water (200mg/L). However, these differences may scarcely be of practical relevance for public drinking water in Germany. In other regions, where sodium concentrations exceeding 180mg/L have been repeatedly described in drinking water (Alam and Sadiq 1989, Pomeranz *et al.* 2002), the assessment may differ considerably and preferable choices should be considered if processed water yields options.

Concern has been raised due to higher blood pressure in infants fed infant formulas with a higher sodium content due to the concentration in the drinking water (Pomeranz *et al.* 2002). In addition, an association between formula feeding and blood pressure later in life has been found and attributed in part to the difference in sodium content between human milk and infant formula (Martin *et al.* 2003). There is a need for epidemiological studies that focus on the potential health effects of different concentrations of sodium and other [trace] mineral supply by drinking water on infants and young children. These should be conducted in regions where "natural experiments" render exposures close to the upper margins of current recommendations and necessitate these evaluations in view of potential consequences for the use of drinking water.

Especially in infancy, fluid consumption may serve nutritional purposes including caloric requirements but it also plays an important role in hydration. This is obvious in cases of diarrhoea, where increased fluid intake is necessary for rehydration and ORS (oral rehydration solution) recommended. A reduction in morbidity has been achieved by lowering the sodium concentration of the former standard solution from 90 to 75 mmol/L (2070mg/L to 1725 mg/L) (WHO and UNICEF 2001). Oral rehydration solutions containing 60mmol/L (1380 mg/L) have been recommended in Europe in view of the concern over hypernatraemia or the osmotically-driven increase in stool output, especially in infants and young children (ESPGAN 1992).

Other hazards concerning sodium in infancy may arise from inadequate feeding practices. Hyponatremic seizures resulting from water intoxication have been associated with bottled drinking water used as an inexpensive "supplement" to cow's-milk-based infant formula (CDC 1994). The labelling had been misinterpreted to indicate that the product had been produced specifically for infants and contained nutrients adequate for use as a feeding supplement. Inadequate dilution of infant foods may result in nutritionally insufficient feeding. Misjudgement, inexperience or poverty may lead to the use of bottled water products marketed specifically for infants as an affordable and appropriate feeding supplement. These aspects underline the importance of adequate labelling and instructions for the parent or carer.

4. CONCLUSIONS

Public heath recommendations on infant nutrition should consider the complete process that includes all the stages involved in the source of the nutrients. This refers to the choice of the base ingredients used for the production of manufactured or home-prepared products well as to the provision of adequate instructions for the reconstitution and the feeding to the infant. Water companies should comply with existing guidelines and legislation, however the quality of water available from the tap may differ from that at the water plant and additional water treatment is possible at household level. Transparency in terms of a water's suitability for infant and child nutrition is essential for the consumer to make an informed choice. Depending on region and social status, consumers may have a choice of water (tap, mineral, bottled water) or have to accept what is available. Social inequalities and lack of information may result in non-recommended practices of infant feeding that can cause inadequate mineral intake.

Guidelines that are to be effective in terms of trace element intake in infants and young children have to consider age-specific trace element requirements. It is essential that they take into account the combined effects of general recommendations on infant feeding on a comparable organizational level. For example:

The WHO global strategy on infant and young child feeding and specific recommendations for trace mineral and mineral intakes in infancy;

The Standards of the Codex Alimentarius for infant formulae;

The WHO/UNAIDS/UNICEF recommended (and other) recipes for home-prepared replacement milks for infants of HIV-infected mothers, and

The WHO Guidelines for Drinking Water Quality.

The awareness of potential variations and analysis of the water used by a population is important for epidemiological assessments of the trace element supply in infancy. Intervention studies in communities in the intention of changing water sources or treatment could facilitate the evaluations of the implications of different mineral intakes in infancy and early childhood. The natural occurrence of concentrations in drinking water within the upper range of WHO drinking water guidelines may support the assessment of the safety for some minerals (e.g. molybdenum). In view of the consequences for public health recommendations and potential consequences for infant morbidity on the one hand, and potential economic consequences for governments and households on the other, there is a need for further scientific evidence of the optimal mineral concentrations in drinking water in early childhood.

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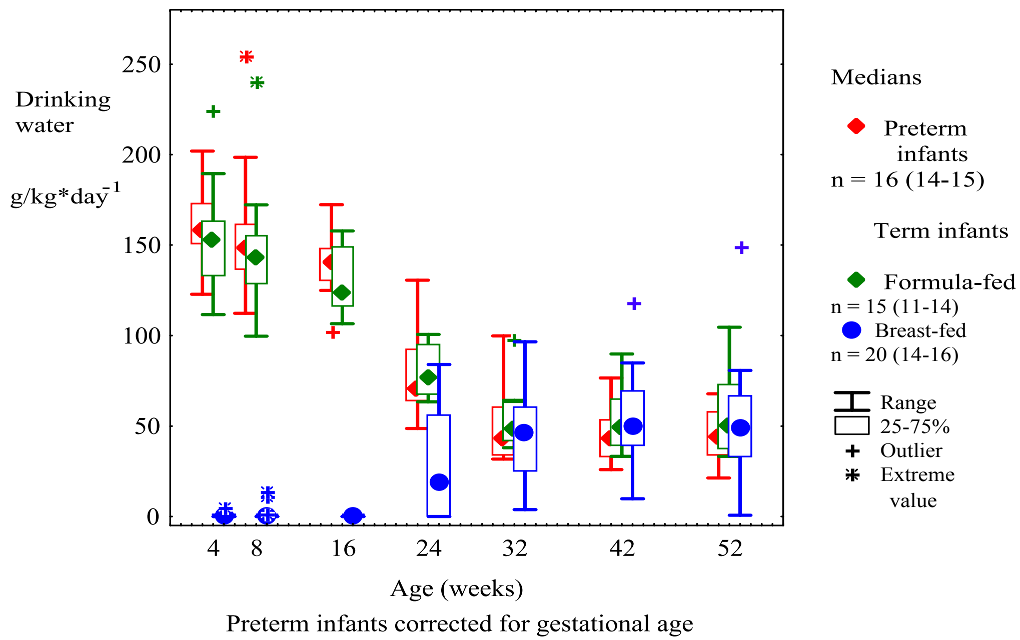

Figure 1: Household drinking water intake of breast-fed term infants and formula-fed term and preterm infants (based on mineral nutrition studies: Sievers *et al.* 2000, 2001)