

Zinc Absorption and Exchangeable Zinc Pool Sizes in Breast-Fed Infants Fed Meat or Cereal as First Complementary Food

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ABSTRACT

Background: The aims of this study were to compare the absorption efficiency of zinc from rice cereal and meat, with and without human milk, in 7-month-old breast-fed infants and to compare the size of exchangeable zinc pools in the infants according to the assigned complementary food.

Methods: Fractional absorption of zinc was measured in male infants using extrinsic labeling with a stable isotope of zinc in a test meal of either pureed beef (n = 9) or iron-fortified infant rice cereal (n = 9). The effect on fractional absorption of the addition of human milk to each complementary food was measured in each infant with a second oral zinc isotope. Fractional absorption was measured using fecal monitoring of isotope excretion, and exchangeable zinc pool size was calculated from isotopic enrichment in urine.

Results: Fractional absorption of zinc did not statistically differ between the beef (0.41 ± 0.11) and cereal (0.36 ± 0.05) test meals, although the trend showed that beef had higher frac-

tional absorption than cereal. The higher intake of zinc from the beef versus cereal test meal resulted in a 16-fold greater amount of absorbed zinc ($P = 0.0002$). The addition of human milk caused significant decreases in fractional absorption of zinc (0.07 ± 0.02 , $P = 0.01$) and absorbed zinc (0.04 ± 0.01 mg, $P < 0.0001$). The size of the exchangeable zinc pool did not differ according to group but was strongly correlated with mean daily zinc intake ($r = 0.72$, $P = 0.003$).

Conclusions: These results confirm that meat as a complementary food for breast-fed infants can provide a rich source of dietary zinc that is well absorbed. The significant positive correlation between zinc intake and exchangeable zinc pool size suggests that increasing zinc intake positively affects metabolically available zinc. *JPGN* 34:35–41, 2002. **Key Words:** Zinc absorption—Zinc intake—Breast-fed infants—Complementary foods—Meat—Exchangeable zinc pool. © 2002 Lippincott Williams & Wilkins, Inc.

The importance of zinc for normal infant growth and development has long been recognized, as has the superior bioavailability of zinc in human milk. In recent years, however, the adequacy of zinc from human milk to maintain normal zinc status in the infant after approximately 6 months of age has been questioned (1–4). There

is a sharp physiologic decrease in zinc concentrations in human milk during the first 6 months postpartum (5). During the first 2 to 3 months of life, exclusively breast-fed infants can maintain positive net absorption through a combination of relatively high zinc concentrations in milk, efficient fractional absorption, conservation of intestinal endogenous zinc, and possibly by using zinc stores present at birth (5–7). At 4 to 5 months of age, however, mean net absorption is modestly positive and perhaps marginally adequate to meet requirements for growth and to replace losses in urine and integument as estimated by factorial calculations (6,7). Beyond 6 months of age, as zinc concentrations in human milk continue to gradually decrease, additional sources of dietary zinc are likely to become important for the infant to meet zinc requirements to sustain normal growth (4).

The aim of this study was to compare the fractional absorption of zinc from iron-fortified infant rice cereal and meat in 7-month-old breast-fed infants. Rice cereal is often recommended as the first complementary food, and

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it provides an important source of dietary iron but is very low in zinc. Pureed beef was selected as a rich source of highly bioavailable zinc, iron, and other essential nutrients. We tested three hypotheses: 1) that exclusively breast-fed infants who were randomly assigned to receive beef as their first complementary food would have significantly greater zinc intake and higher zinc fractional absorption at 7 months compared with those who were given iron-fortified infant rice cereal as the first complementary food; 2) that fractional absorption of zinc from complementary foods would be enhanced by adding human milk to the complementary food; 3) and that the infants assigned to the beef group would have significantly larger exchangeable zinc pool (EZP) size. These studies of zinc absorption and the size of the EZP were undertaken in a group of infants who were part of a larger longitudinal study that examined the effects of the intervention on growth, iron and zinc status, and cognitive development (8).

METHODS

Study Design

This study was a cross-sectional comparison of zinc absorption from two complementary foods: iron-fortified infant rice cereal ("cereal") or pureed beef ("beef"), with and without human milk. Healthy, exclusively breast-fed male infants were randomly assigned to one of the complementary food groups, the initiation of which was at the parents' discretion between 5 and 6 months of age. Beef or cereal alone as the test meal was extrinsically labeled with a zinc stable isotope on day 1, and the assigned complementary food mixed with human milk was similarly labeled with a second zinc stable isotope on day 2. Fractional absorption of zinc was determined using fecal monitoring of isotope excretion, and EZP was calculated from urine isotopic enrichment on days 4 through 8 (6,9). The study was conducted in the subjects' homes after carefully training the parents to make metabolic collections.

Subjects

Twenty healthy male infants were studied at 7 months (± 2 weeks) of age. The fecal collections for two infants were incomplete and unusable; therefore, data from 18 infants are presented. All infants were born at term, and birth weights were appropriate for gestational age. The infants were recruited from advertisements in clinics and hospitals and by word of mouth. The Colorado Multiple Institutional Review Board approved the study design, procedures, and consent form. After receiving explanation of the purpose and requirements of the study, parents of all subjects in the study gave signed consent.

Diets

All infants were exclusively breast-fed until 5 to 6 months of age, at which time the assigned complementary food, either commercial pureed beef ("Beef and Beef Gravy," Second Foods®) or iron-fortified infant rice cereal (First Foods®) was

introduced. Gerber Products Company (Fremont, MI, U.S.A.) supplied both products. Zinc content of both complementary foods was analyzed in our laboratory (see Laboratory Analyses). Results showed good agreement with the manufacturer data: 25.5 $\mu\text{g Zn/g}$ for the beef and 15.2 $\mu\text{g Zn/g}$ for the dry cereal. Other complementary foods low in zinc, iron, and protein, such as pureed fruits, were also gradually introduced during ensuing weeks before the absorption study. Parents were encouraged to feed the complementary foods ad libitum, without specific guidelines with respect to amounts. Infants assigned to the beef group were not allowed cereal until after completion of studies at 7 months, and vice versa. None of the subjects received infant formula before or during the study. Three-day diet records were completed twice monthly after introduction of complementary foods, including one record within the week before isotope administration. Mean daily intakes of energy, protein, zinc, and iron were calculated using Nutritionist IV (First Data Bank; San Bruno, CA, U.S.A.).

Isotope Preparation and Administration

^{70}Zn -enriched zinc oxide powder (99.72 atom %) and ^{67}Zn -enriched zinc oxide powder (89.55 atom %) were obtained from Oak Ridge National Laboratories (Oak Ridge, TN, U.S.A.). Accurately weighed quantities of the isotopes were dissolved in 1 N H_2SO_4 , diluted in triply deionized water, titrated to pH 5 with metal-free ammonium hydroxide, and the solutions were filtered through micropore filters. The concentration of zinc in the isotope preparations was determined in triplicate using atomic absorption spectrophotometry, with corrections made for the higher atomic weight of the enriched zinc preparations.

Complementary food (beef or cereal) on day 1 and complementary food mixed with expressed milk from the infant's mother on day 2 were extrinsically labeled with an accurately weighed dose of either ^{70}Zn or ^{67}Zn solution. Doses were initially approximately 50 μg and were increased to approximately 100 μg for the last seven subjects: three in the beef group and four in the cereal group. The dose size was increased to obtain higher enrichment in the urine, and it was predicted on the basis of previous studies in our lab that the absolute amount of the higher dose was small enough to avoid an effect on fractional absorption (10). The dose sizes between day 1 and 2 were within 10% of each other for all subjects. The order of isotopes used for day 1 and day 2 was alternated among subjects. For the beef test meal, isotope was added to 1 g to 2 g of puree. For the cereal, deionized water was added to cereal flakes to make it edible, and then isotope was added to 1 g to 2 g of the wet cereal mixture. Complementary food and isotope solution were mixed thoroughly by injecting isotope into the food mixture from a weighed syringe and stirring with a metal-free plastic laboratory utensil. To quantify amounts of isotope added, both the syringe and the container with food and isotope were weighed on a balance accurate to 0.1 mg before and after addition of the isotope solution. The mixture was then allowed to equilibrate for at least 4 hours before administration. On day 2, the beef puree was diluted approximately 1:1 with human milk, and human milk was substituted for water mixed with the rice cereal. Aliquots of unlabeled and labeled complementary food and of expressed mother's milk were reserved for later total zinc and isotopic enrichment analyses.

The isotopically labeled feeds were all administered by one of the investigators (S.J. or M.S.). A small zinc-free syringe was used to slowly and quantitatively administer the labeled complementary food, which was followed by an additional ~1 tablespoon (~15 g) of unlabeled complementary food given by spoon. The syringe containing the labeled feed was weighed before and after administration of the test meal on a balance accurate to 0.01 g. Any matter drooled during the test meal administration or subsequent regurgitation was collected on ashless filter papers and saved for determination of total zinc and isotopic enrichment; dose was adjusted accordingly. Subjects did not nurse or ingest any complementary foods for approximately 2 hours before or after the dose was given.

Fecal and Urine Collections

All fecal samples were collected from the time of the first isotopically labeled feed on day 1 through at least day 8, or until a minimum of 8 fecal samples were passed and collected (6). A baseline fecal sample was obtained before administration of the label. Feces were collected primarily in a zinc-free plastic bag, which was secured to the infant's bottom. A net panty was used to hold a zinc-free cotton cloth to prevent the urine from getting into the fecal bag during the days that urine was not collected for analysis. Any "losses" of feces were dabbed up on ashless filter papers for analysis with the remainder of the sample. Samples were stored in well-labeled individual plastic bags in coolers provided to each subject for the study. The mothers, all of whom had been trained before the beginning of the study, quantified actual losses, which were uncommon. All stools and notations regarding the collections were recorded by the mother on a daily log sheet, which was verified by the member of research team who made regular visits to the house.

Urine was collected during the last 3 days of the study using a zinc-free urine bag (U-Bag, Hollister, Inc.; Libertyville, IL, U.S.A.) attached to the scrotum with an adhesive spray. The bags were drained frequently into a zinc-free specimen cup. Collections were made three times daily over approximately 4- to 5-hour intervals. The actual collection interval was dependent on the time required to obtain ~100 mL for each collection period. The starting and ending times for each period were noted on the specimen cup and the log sheets. Fecal and urine specimens were frozen at -20°C until analysis.

Laboratory Analyses

The filter papers with regurgitations from the days of isotope administration and individual fecal samples were ashed at 450°C (6). The ashed samples were quantitatively dissolved in 6 N HCl, and total zinc was determined with duplicate diluted aliquots using an atomic absorption spectrophotometer fitted with a deuterium arc background correction lamp (Perkin-Elmer; Norwalk, CT, U.S.A.). Other inorganic elements were removed from reconstituted ashed samples using ion exchange chromatography (Bio-Rad Laboratories; Richmond, CA, U.S.A.). Isotopic enrichment was determined by measuring isotope ratios with fast atom bombardment induced secondary ion mass spectrometry on a double-focusing mass spectrometer (model VG 7070 E HF: Fisons-VG Analytical; Manchester, UK) equipped with an atom gun (Ion Tech, London, UK). The mass spectrometer was operated at low resolution, and ion

counting detection and peak switching were used to measure $^{70}\text{Zn}/^{66}\text{Zn}$ and $^{67}\text{Zn}/^{66}\text{Zn}$ ratios. Fecal samples containing 1 μg to 2 μg zinc were analyzed; the precision of the measured ratios was 0.5% to 1.0% relative standard deviation. Enrichment, defined as all zinc in a sample from an isotopically enriched source divided by total zinc in the sample, was calculated from the measured ratios using a standard curve (11).

Individual urine samples were dried in a drying oven at 80°C to 90°C. Dried samples were then ashed in muffle furnace as described above for fecal samples. Reconstituted ash was placed on ion exchange columns and isotopic enrichment determined as described above for the fecal specimens (6,12).

Complementary food and complementary food with isotope (dose) were analyzed for total zinc and zinc isotope enrichment with the same procedure used for fecal samples.

Calculations

Zinc intake from the test meal was calculated for each subject by adding total zinc (isotopic and natural) in labeled complementary food and natural zinc from unlabeled complementary food that was consumed along with the labeled feed. To calculate fractional absorption, the quantity of isotope tracer (as a fraction of administered dose) present in each fecal sample was calculated by multiplying the total zinc in the sample by its enrichment, and the cumulative values of these data were plotted against time from isotope tracer administration. Correction for absorbed isotope that was subsequently secreted into the intestinal lumen and excreted in the feces was made by extrapolating to time zero a linear regression line through the final points of the cumulative fecal excretion plot, after excretion of unabsorbed isotope was apparently complete (6,9). The corrected cumulative fractional fecal excretion was subtracted from 1 to determine fractional absorption of zinc. Multiplication of fractional absorption by zinc in the test meal determined total absorbed zinc from the test meal.

The EZP is defined as the estimate of the total size of the combined pools of zinc that exchange with zinc in plasma within approximately 2 to 3 days. The EZP was calculated by dividing the mass of isotope absorbed (fractional absorption \times dose) by the enrichment value at the y-intercept of the linear regression of a semilog plot of urine enrichment data from days 4 to 8 after isotope administration. The validity of substituting urine for plasma enrichment and using an orally instead of intravenously administered isotope has been examined in adult studies (9,13).

Statistical Analysis

To test the effects of food and human milk on the outcomes of fractional absorption and absorbed zinc, we used a linear mixed regression model with a random subject effect (14). The strength of this model is its proper attribution of variability within and between subjects. To control for the possible confounding effects of different doses among subjects, we included a dichotomized term for dose (high, low). Hypotheses were tested using linear contrasts. A simple linear regression model and correlations were used to explore the effect of dietary zinc intake on EZP. Statistical analyses were performed on Graph Pad Prism 2.01 (GraphPad Software, Inc., San Diego, CA, U.S.A.) and SAS (SAS Institute, Inc., Cary, NC U.S.A.) pro-

grams. Data are presented as mean \pm SD for subject dietary summaries and mean \pm SE for test results. Statistical significance was considered to be $P < 0.05$.

RESULTS

The mean weight of the infants was $7.9 \text{ kg} \pm 0.82 \text{ kg}$, with no difference between the beef and cereal groups. Mean daily intakes of energy, protein, zinc, and iron from all complementary foods, calculated from 3-day diet records are shown in Table 1. The contribution for each of the nutrients from the assigned complementary food is also shown. The mean zinc intakes relative to body weight were $0.20 \text{ mg} \cdot \text{kg}^{-1} \cdot \text{d}^{-1} \pm 0.15 \text{ mg} \cdot \text{kg}^{-1} \cdot \text{d}^{-1}$ for the beef group and $0.09 \text{ mg} \cdot \text{kg}^{-1} \cdot \text{d}^{-1} \pm 0.05 \text{ mg} \cdot \text{kg}^{-1} \cdot \text{d}^{-1}$ for the cereal group ($P = 0.08$).

Results of the zinc absorption studies are summarized in Table 2. As expected, the zinc intake from the test meals for day 1 (no human milk) was significantly greater in the beef group. Fractional absorption tended to be higher from beef, but the difference was not statistically significant. Nevertheless, because of the much higher zinc content of the zinc meal, absorbed zinc was significantly higher from beef than from cereal ($P < 0.001$). The addition of human milk led to an average decrease of fractional zinc absorption (-0.07 ± 0.02 , $P = 0.01$) from both the beef and the cereal. Figure 1 presents results for individual infants. Fractional zinc absorption decreased in 15 infants after the addition of human milk and increased in only 3. Absorbed zinc also decreased significantly ($P < 0.001$) with the addition of human milk to the test meal.

Mean EZP was $15.5 \text{ mg} \pm 4.4 \text{ mg}$ ($1.6 \pm 0.4 \text{ mg/kg}$) in the beef group ($n = 9$) and $11.2 \text{ mg} \pm 2.2 \text{ mg}$ ($1.4 \pm 0.3 \text{ mg/kg}$) in the cereal group ($n = 7$); means were not significantly different between groups. Simple linear regression was performed on EZP as a function of dietary zinc intake. The slope estimate was 8.46 ± 1.72 ($P = 0.0003$), indicating that an increase of 1 mg/d in dietary zinc intake resulted in an increase of 8.5 mg in the EZP. The Spear-

man correlation coefficient was 0.72 ($P = 0.003$; Fig. 2). The relation with zinc intake was essentially the same for EZP relative to body weight (mg/kg; ($r = 0.71$, $P = 0.003$). There was no correlation between EZP and fractional absorption ($r = -0.04$).

DISCUSSION

Introduction of meat as a complementary food for breast-fed infants has been recommended as a means to meet infant iron needs (15), and the effectiveness of increased meat intake to improve iron status and iron absorption in late infancy has been examined (16). To our knowledge, this is the first report to examine the effect of meat (beef) as a complementary food on zinc intake and absorption in breast-fed infants. The total daily zinc intake from complementary foods for the beef group was more than twofold that of the cereal group, although energy intakes were not significantly different between groups. The mean daily zinc intake for the cereal group was quite comparable to intakes from complementary foods reported in two other studies in breast-fed infants of similar age, for whom selection of complementary foods was not specifically manipulated (1,17). The contribution of human milk to the daily zinc intake was estimated at approximately 0.5 mg/d, based on test weigh data from a large group of breast-fed infants at 7 months of age (1). The mean daily zinc intake from the pureed beef represents approximately 60 g puree/day, and provided approximately 45% of daily energy intake from complementary foods.

The lack of significant difference in fractional absorption between the beef and cereal test meals was unexpected, because studies in adults have shown higher fractional absorption in foods with increased protein, including from animal products, compared with cereals (18). Factors that may have contributed to the findings in these infants include, especially, the very small amount of zinc in the cereal test meal, which may have counterbalanced absorption-inhibiting properties of the cereal; the unanticipated degree of variability in fractional absorption; and the potential limitations of the extrinsic label method for measuring fractional absorption (9,18,19).

The phytate:zinc molar ratio of the cereal was calculated to be approximately 25, based on phytate data from the manufacturer and laboratory analysis of the zinc content of the cereal. Despite this relatively high ratio, the fractional absorption was inversely related to the amount of zinc in the test meal, suggesting that this effect may have been stronger in this study design than the potential interference by phytate binding in the intestinal lumen.

The variability in fractional absorption was considerably higher than that reported by our research group in infants either exclusively on human milk or on formula (6,20), but was close to that observed in breast-fed infants who were consuming beikost when studied (17). The degree of variability in this study was probably

TABLE 1. Mean calculated daily intakes from all complementary foods and from assigned complementary food

	Beef group	Cereal group	P value
Energy (kJ/d)	605 \pm 420* (270 \pm 210)†	835 \pm 375 (230 \pm 145)	NS
Protein (g/d)	9.3 \pm 6.7 (8.2 \pm 6.3)	4.1 \pm 1.8 (1.0 \pm 0.7)	0.05
Iron (mg/d)	1.3 \pm 0.9 (0.9 \pm 0.7)	6.3 \pm 3.7 (5.0 \pm 3.3)	0.001
Zinc (mg/d)	1.6 \pm 1.2 (1.5 \pm 1.1)	0.7 \pm 0.4 (0.2 \pm 0.2)	0.04

NS, not significant.

* Mean \pm SD

† Numbers in parentheses represent mean intakes provided by the assigned complementary food.

TABLE 2. Fractional absorption, absorbed zinc, and zinc intake (mg) from test meal, with and without addition of human milk (HM), in the two study groups

	Beef only (day 1)	Beef + HM (day 2)	Cereal only (day 1)	Cereal + HM (day 2)
n	9	9	9	9
Zn intake (mg)	0.41 ± 0.04	0.28 ± 0.09	0.03 ± 0.003	0.04 ± 0.003
Fractional absorption	0.41 ± 0.05*	0.36 ± 0.05*	0.36 ± 0.05*	0.27 ± 0.05*
Absorbed zinc (mg)	0.17 ± 0.02†	0.08 ± 0.02‡	0.01 ± 0.02†	0.007 ± 0.02‡

* Day 2 versus day 1, within subject; $P < 0.0001$.

† Beef versus cereal; $P < 0.0001$.

‡ Beef + HM versus cereal + HM; $P = 0.02$.

Data are presented as mean ± SE and are adjusted for dose.

in part because of the effect of the increased isotope dose administered to some of the subjects. Therefore, although there may have been an overall food effect (i.e., beef vs. cereal) on fractional absorption, our sample size may not have been large enough to capture this difference.

The extrinsic label method for measuring zinc absorption also is based on the assumption of equal mixing of tracer with the intrinsic zinc (9,19). The equilibration period allowed after mixing of the isotope with the test meal food may not have resulted in such equivalence with the natural zinc. The degree of exchange also may have differed between the beef and cereal test meals (19). For example, the phytate-bound native zinc in the cereal may not have been solubilized and equally exchanged with the extrinsic label. However, when isotope is given in aqueous solution alone, absorption is typically greater than 60% (21). This suggests that the food matrix had some impact on the isotope absorption.

The lower zinc intake in the infants in the cereal group might be hypothesized to result in more marginal zinc status and thus lead to higher fractional absorption. However, chronic low zinc intake in adults has not been shown to enhance fractional absorption (22,23). The lack of correlation between EZP and fractional absorption also suggests that luminal factors, including the amount of zinc available for absorption, may be more important in determining fractional absorption than the host's zinc status (24).

The lower fractional absorption in the test meal with the added human milk was also unexpected, particularly for the cereal group. The normally low concentration of zinc in human milk at this stage of lactation (5) resulted in minimal added zinc to the test meal from the human milk. For the beef group, addition of milk led to substantially lower zinc in the test meal, which might be predicted to enhance fractional absorption. The figures for fractional absorption from the complementary food mixed with human milk were somewhat lower than those obtained by Abrams et al. (17). In their study, extrinsically labeled human milk was consumed with several meals throughout the day, and fractional absorption was approximately 0.5, similar to what has been observed with exclusive human milk feeding (6).

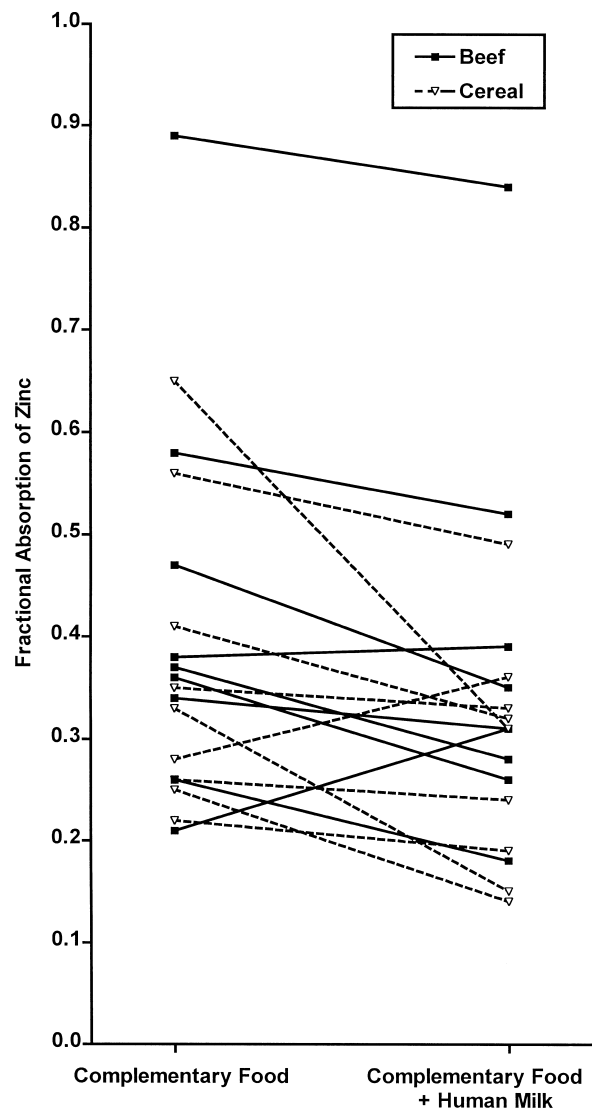


FIG. 1. Fractional absorption of zinc from test meal with complementary food alone (day 1) or from complementary food plus human milk (day 2). $P = 0.01$ by paired comparison t test and by general linear model.

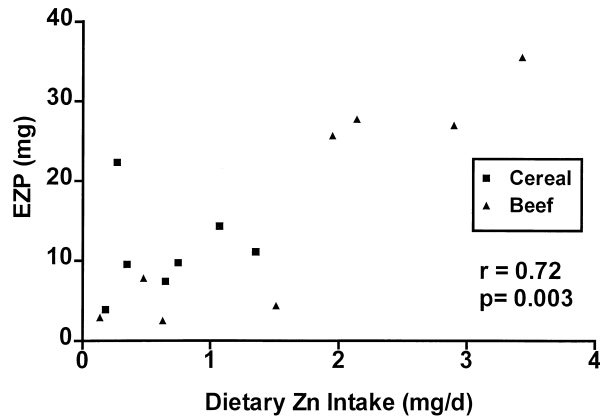


FIG. 2. Plot of dietary zinc intake and size of exchangeable zinc pool (EZP) in breast-fed infants according to assigned complementary food.

Despite the lack of a clear significant difference in fractional absorption between the beef and cereal groups, the large difference in zinc intake combined with the tendency for higher fractional absorption resulted in a much greater amount of absorbed zinc from the test meal for the beef group. Because the dose was given with a single test meal, it is impossible to extrapolate to the entire day's absorbed zinc. Given the high percentage of total daily zinc intake provided by the beef for the infants in that group, it seems likely that their overall daily absorbed zinc would also have been higher. Similarly, without information on total daily zinc intake, including that from human milk, or on endogenous fecal zinc or daily urine zinc losses, net absorption cannot be compared between groups.

The EZP is thought to represent metabolically active zinc, which in adults represents approximately 10% of total body zinc (13,25). The remainder of the mass of zinc resides in more slowly exchanging pools, especially those in muscle and bone (25). Whether the relation between total body zinc and EZP is similar for infants is unknown. The strong correlation between dietary zinc intake and EZP has been observed in other studies (13,22). The size of the EZP relative to body weight in the current study was very low compared with those of 2- to 5-month-old exclusively breast-fed infants, in whom EZP sizes were 4 mg/kg to 6 mg/kg (9). The relation between EZP and zinc status is not yet well understood, and the consequences of such a relatively low EZP are unknown. The data presented in Figure 2 suggest that an increase in zinc intake would result in an increase in the size of the EZP, although the effect of an increase in EZP in relation to functional outcomes has not been adequately explored. We speculate that the relatively low EZP size in the infants in this study supports a need by this age for a source of zinc intake in addition to that from human milk.

The results of this study are relevant to current recommendations for choice of complementary foods for

breast-fed infants. Zinc has been identified as a "problem nutrient," along with iron, calcium, and vitamin A, for the older breast-fed infant because of the discrepancy between its content in complementary foods and the amount required by the infant for normal growth (4). A daily intake of 2.2 mg of zinc from complementary foods has been recommended, a figure derived in part from an assumed fractional absorption of 0.30 (4). Although the average zinc intake by subjects in the beef group was slightly lower than this, intake of subjects in the cereal group was only approximately one third this figure, and none of the individuals in the cereal group achieved such an average intake (Fig. 2). In developed countries, most breast-fed infants will have access to and gradually increase their intake of complementary foods that are rich in zinc, such as meats. For those in whom this does not occur, the risk of developing at least mild zinc deficiency will probably increase. In developing countries, the limited access to animal products as complementary foods is more problematic for maintaining adequate zinc status in the older infant (4,26). The data presented in Figure 2 also suggest that an increase in zinc intake would result in increased EZP size. Zinc deficiency has been identified in breast-fed infants between 6 and 12 months of age who live in impoverished conditions (27). The prevalence of mild-to-moderate zinc deficiency in other settings is unknown and probably depends on types and amounts of complementary foods, as well as on burden of infection (7).

In summary, the introduction of beef as a complementary food to approximately 7-month-old breast-fed infants resulted in a significantly greater zinc intake compared with those receiving infant rice cereal. There was a trend for greater fractional absorption of zinc in the beef group; the higher zinc content of the test meal resulted in significantly greater absorbed zinc for those infants receiving beef. The addition of human milk to either the beef or the cereal resulted in slightly lower fractional absorption and no advantage in the amount of zinc absorbed. The strong positive relation between the size of the EZP and zinc intake from either source suggests that increasing zinc intake in the older breast-fed infant will positively affect metabolically available zinc.

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