A Micronutrient Powder with Low Doses of Highly Absorbable Iron and Zinc Reduces Iron and Zinc Deficiency and Improves Weight-For-Age Z-Scores in South African Children[1–4]

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Abstract

Micronutrient powders (MNP) are often added to complementary foods high in inhibitors of iron and zinc absorption. Most MNP therefore include high amounts of iron and zinc, but it is no longer recommended in malarial areas to use untargeted MNP that contain the Reference Nutrient Intake for iron in a single serving. The aim was to test the efficacy of a low-iron and -zinc (each 2.5 mg) MNP containing iron as NaFeEDTA, ascorbic acid (AA), and an exogenous phytase active at gut pH. In a double-blind controlled trial, South African school children with low iron status (n = 200) were randomized to receive either the MNP or the unfortified carrier added just before consumption to a high-phytate maize porridge 5 d/wk for 23 wk; primary outcomes were iron and zinc status and a secondary outcome was somatic growth. Compared with the control, the MNP increased serum ferritin ($P < 0.05$), body iron stores ($P < 0.01$) and weight-for-age Z-scores ($P < 0.05$) and decreased transferrin receptor ($P < 0.05$). The prevalence of iron deficiency fell by 30.6% ($P < 0.01$) and the prevalence of zinc deficiency decreased by 11.8% ($P < 0.05$). Absorption of iron from the MNP was estimated to be 7–8%. Inclusion of an exogenous phytase combined with NaFeEDTA and AA may allow a substantial reduction in the iron dose from existing MNP while still delivering adequate iron and zinc. In addition, the MNP is likely to enhance absorption of the high native iron content of complementary foods based on cereals and/or legumes. J. Nutr. 141: 237–242, 2011.

Introduction

Iron deficiency anemia and zinc deficiency are major public health problems worldwide and infants and children are particularly vulnerable (1,2). Providing additional dietary iron and zinc to infants is difficult, because their needs are often not covered by universal fortification programs. Thus, targeted, in-home fortification of foods with micronutrient powders (MNP),[11] such as Sprinkles, MixMe, or MoniMix, is a promising approach (3).

MNP are often added to cereal-based complementary foods that are high in inhibitors of iron and zinc absorption. Most MNP formulas compensate by increasing the amounts of iron and zinc per serving; e.g., the current Sprinkles sachet contains 12.5 mg iron (4); the original dose was 80 mg iron/sachet (5). However, because untargeted supplements of 12.5 mg iron (with folate) were associated with increased child mortality in a malarial-endemic region of Tanzania (6), the WHO no longer recommends in malarial areas the use of untargeted, in-home MNP that administer the entire infant iron Reference Nutrient Intake in a single dose (7).

Although the mechanism by which iron supplementation increased mortality in the Tanzanian study is unclear (6), MNP containing low levels of iron may be safer than powders with higher iron doses (7). However, low iron (and zinc) doses will have little nutritional impact, unless fractional absorption is high. High levels of phytic acid (myo-inositol-6-phosphate) in many foods strongly reduce the absorption of iron and zinc (8). The reduction of phytic acid in foods improves iron and zinc bioavailability (9,10). Although phytate can be enzymatically degraded in foods before consumption, this approach is not feasible in poor rural settings where foods are not centrally

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[3] This trial was registered at the South African National Clinical Trial Register (http://www.sanctr.gov.za) as DOH-27-0410-2830).

[4] Supplemental Figure 1 is available with the online posting of this paper at jn.nutrition.org.

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[11] Abbreviations used: AA, ascorbic acid; AMA, arm muscle area; BF, body fat; CRP, C-reactive protein; FTU, phytase unit; Hb, hemoglobin; MNP, micronutrient powder; MUAC, mid-upper arm circumference; NTBI, nontransferrin bound iron; SF, serum ferritin; SZn, serum zinc; TfR, transferrin receptor; TSF, triceps skinfold.

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processed (8,10–13). But a phytase added at the point of consumption that remains active at gut pH could be effective in a MNP (14). In addition, NaFeEDTA and ascorbic acid (AA) can enhance iron delivery in high-phytate foods (9,15–17). Iron absorption from a highly inhibitory maize porridge fortified with a new MNP, containing 3 mg iron as NaFeEDTA, 60 mg of AA, and a phytase active at gut pH, was 4 times higher than from ferrous sulfate added to the same meal (14).

The aim of this study was to test whether the low-iron/-zinc MNP, when added just before consumption to a highly inhibitory maize porridge and fed to South African children, would improve iron and zinc status (the primary outcomes) and thereby improve somatic growth (the secondary outcome).

Participants and Methods

The study was conducted from April 2009 to November 2009 in 2 primary schools in low socioeconomic areas in Kimberley, Northern Cape, South Africa, a region free of malaria (Supplemental Fig. 1). Ethical approval for the study was given by the Medical Research Council of South Africa and the ETH Zurich, Switzerland. The study was planned and conducted according to general principles of Good Clinical Practice and supervised by an independent safety monitoring board. The baseline screening included all children attending preschool through grade 5 in these 2 schools whose parents had given written informed consent.

Assuming a mean ± SD body iron of 1.25 ± 2.5 mg/kg to detect a difference in body iron of 1.2 mg/kg (14,18) with 80% power, a level of significance of 0.05 and anticipating a 10–15% drop-out rate, we enrolled 100 children in each group. Inclusion criteria were: 1) serum ferritin (SF) ≤ 20 mg/L or serum transferrin receptor (TfR) ≥ 8.2 pg/L; 2) hemoglobin (Hb) ≥ 90 g/L; 3) age between 5 and 11 y; 4) no serious chronic medical problems; and 5) not taking nutritional supplements containing iron. We chose to study school-age children, because the centralized school setting facilitated compliance and health monitoring. We reasoned that if the powder was efficacious at improving iron and zinc status in older, larger children, it would also be beneficial for younger children and infants.

Whole blood was collected by mid-arm venipuncture into EDTA-containing tubes for determination of Hb, SF, TfR, and serum high sensitivity C-reactive protein (CRP) and into a trace-element free tube for serum zinc (SZn). CRP was assessed as an indicator of the acute phase reaction to infection/inflammation. All participating children were dewormed at baseline with a single oral dose of 500 mg mebendazole.

The study was a double-blind, placebo-controlled trial of a MNP powder (composition in Table 1). All children received a daily bowl of 250 g (wet weight) sweetened maize porridge. The treatment group received the MNP; the control group received an identical-appearing powder consisting of the unfortified carrier (dextrose). The MNP contained 2.5 mg iron as NaFeEDTA, 2.5 mg of Zn as zinc oxide, and 60 mg AA, as well as a phytase (DSM Phytase 20000 G, DSM Food Specialties). In our previous absorption study with this phytase, the addition of 190 phytase units (FTU) was effective in improving iron absorption (14). To guarantee this level of phytase activity during storage over the 6-mo study period, a 100% overage was added to the powder dose. However, the phytase was stable during storage; bimonthly analyses confirmed a content of ≥380 FTU (data not shown) over the entire study period. The powder contained AA even though a previous study on a similar meal showed only a small improvement in absorption when combined with NaFeEDTA (14). However, the enhancing effect of AA would complement the effect of EDTA if used in meals containing less phytic acid or in meals high in polyphenols (17). The combination of the 2 enhancers would be effective in a wide range of complementary foods; therefore, they were both included in the mix. To mask a color difference between the fortified powder and the control (difference measured by colorimetry, $\Delta E = 13.5$), equal amounts of a brown food color (Caramel E 150) was added to both. The composition of the 2 powders was analyzed at DSM Nutritional Products; there was no substantial difference in the composition of either of the powders during the study (data not shown).

TABLE 1 Composition of the MNP used in the intervention study

Nutrient	Unit/kg	Overage,[1] %
Retinyl palmitate, g	80	30
Cholecalciferol, mg	1	30
Rac-α-tocopheryl acetate, mg TE	1	10
Thiamine, mg	100	25
Riboflavin, mg	100	25
Pyridoxine, mg	100	25
Folic acid, mg	1.8	25
Niacin, g	1.2	10
Pantothenic acid, mg	400	10
Vitamin B-12, mg	180	25
Vitamin C, g	1.2	20
Iron (as NaFeEDTA), mg	500	5
Calcium, g	4	10
Copper, mg	68	10
Iodine, mg	6	20
Selenium, mg	3.4	10
Zinc, mg	500	10
Phytase, FTU	38,000	100
Carrier[2]	ad 1000	

[1] Overages were added to ensure the required amounts during 6-mo shelf-life.
[2] Ad is used to indicate that the amount of carrier needed to have a total of 1 kg/kg was added.

The porridge was prepared by trained field workers each morning with partially degermed, unfortified maize flour (SASKO GRAIN, Klerksdorp Mill, Pioneer Foods), water, and a small amount of sucrose. Before adding the powder, the porridge temperature was checked and the powder added only if the temperature was ≤40°C. Because children would not be able to eat the porridge if it was served at a higher temperature, this temperature (or cooler) is likely to be the one at which the porridge would be consumed under uncontrolled circumstances. A standard meal temperature was chosen to minimize potential variation in phytase activity during meal distribution and to avoid potential deactivation of the phytase at higher temperatures; the phytase remains active up to 60°C and actually has its temperature optimum between 50°C and 60°C.

The native iron, zinc, and phytic acid content of a serving of the porridge was 0.5 mg, 0.7 mg, and 0.3 g, respectively. The cooked porridge was dished up in color-coded bowls and, just before serving, 5 g of the powder was mixed into the porridge. A triangle test (19) conducted with 23 children from grade 5 who were not study participants found no detectable difference between the 2 powders in the porridge ($P \leq 0.05$). A run-in period of 3 wk demonstrated that the portion size was not too large and the porridge was well liked.

Both schools had an existing lunch feeding program and the porridge was given in addition to this lunch meal. To ensure sufficient time before the mid-day meal, the children received their portion between 0800 and 0900 h in the morning. The meal was eaten under direct supervision and nothing else was consumed with the meal. The total duration of the feeding was 23 wk, 5 d/wk, for a total of 113 feeding d. Each day, absences were recorded and any leftovers were individually weighed and noted in each child's compliance sheet by trained fieldworkers. At the end of the study, all baseline anthropometric and biochemical measures were repeated. Children who remained iron deficient at the end of the study were treated with oral iron supplements per WHO protocol (20). The children continued to receive porridge for 3 wk after the endpoint sampling until the end of the school term.

Laboratory analyses. Hb was measured in whole blood on the day of the blood draw at the Department of Hematology of the National Health

Laboratory Services at the Kimberley hospital (Kimberley, South Africa) using a Sysmex 32 2000i (Roche Diagnostics). The remaining blood was centrifuged on the day of collection (500 3 g, 10 min, room temperature). Serum and plasma were separated into aliquots and frozen at 2208C until analysis. SF and CRP were measured on an IMMULITE automatic system (DPC Bühlmann). TfR was measured using enzyme immunoassays (Ramco Laboratories). Using the SF and TfR, the amount of body iron was calculated according to the equation developed by Cook et al. (21,22). SZn was measured by atomic absorption spectrophotometry (SpektrAA 240 FS, Varian). Phytic acid in the maize flour was measured using a modification of the Makower method (23). For iron and zinc analysis, the maize flour was digested with nitric acid and hydrogen peroxide and measured by graphite furnace and flame atomic absorption spectrophotometry (SpektrAA 240 Z and FS, respectively; Varian) respectively. Heavy metals were measured at Swiss Quality Testing Service (Dietikon) using atomic absorption spectrometry (AAnalyst 600, Perkin Elmer).

Anthropometric measurements. Height was measured without shoes to the nearest 0.1 cm using a rigid stadiometer and weight was measured in light clothing to the nearest 0.01 kg on an electronic scale (Masskot, UC-300 Precision Health Scale; A&D Co); these were calibrated using a fixed weight and steel tape, respectively. Skinfold thickness was measured at the triceps (TSF) and subscapular site to the nearest 0.1 mm with Harpenden skinfold caliper (Baty International) with constant spring pressure of 10 g/mm^2. For the TSF, the midpoint of the back of the upper arm between the tips of the radial and acromial processes was determined by measuring with the arm flexed at 908. With the arm hanging freely at the side, the caliper was applied vertically above the olecranon at the marked level. At the subscapular site, the skinfold thickness was picked up just below the inferior angle of the scapula at 458 to the vertical along the natural cleavage lines of the skin. Mid-upper arm circumference (MUAC) was measured to the nearest 0.1 cm with a Lufkin steel measuring tape (Cooper Tools, Apex). These anthropometric measures were done in duplicate by the same team of 3 experienced examiners at baseline and endpoint.

Age- and sex-specific criteria from the WHO were used to calculate height- and weight-for-age Z-scores. MUAC-for-height Z-scores were used as an additional indicator for undernutrition (24). To take into account effects of ethnicity, gender, and differences in physical maturity, percent body fat (BF) was calculated according to the equations developed by Slaughter et al. (25). MUAC and TSF were used to calculate arm muscle area (AMA) according to the equation proposed by Frisancho and Garn (26,27).

Statistical analyses. Data processing and statistical analyses were done using PASW (formerly SPSS) software (version 18.0: SPSS) and Excel (Microsoft Office 2003; Microsoft). The normality of the data were assessed before analysis using a Shapiro-Wilk test and graphically by evaluating histograms and Q-Q plots. Normally distributed data were expressed as mean 6 SD. When data were not normally distributed, they were expressed as medians with a bootstrapped 95% CI using 1000 resamplings (28,29). These variables were transformed for comparison. To obtain optimal normalization, square root transformation was used for body iron and logarithmical transformation for Hb, SF, TfR, SZn, height, weight, MUAC, BF, and AMA. Two-factor repeated-measures ANOVA was done to compare effects of time by group interaction for continuous data. Normality of residuals was tested using P-P plots of regression for standardized residuals. For prevalence data, a Generalized Estimation Equation model adjusted for binominal distribution was used. The data were tested for baseline differences between the groups using t tests. Time 3 treatment analysis was adjusted for existing baseline differences where applicable.

Results

Randomization at baseline between the treatment and the control group was effective, because the 2 groups did not differ at baseline, with the exception of the gender ratio ($P < 0.05$) (Tables 2 and 3). Therefore, models using gender as a covariate were tested. Of the 200 children enrolled in the study, 8 (4%, 5 in the treatment and 3 in the control group) did not complete the study (Supplemental Fig. 1). Reasons for this were migration ($n = 3$), preexisting health problems not reported at enrollment ($n = 2$), and not wanting to continue because they were the only participants in their class ($n = 2$). One child was absent for the endpoint measurements. No serious adverse health events occurred related to the study.

Feeding was interrupted by holidays for 3 wk in July and for 1 wk in September. Overall compliance, taking into account absenteeism and leftovers, was 88% in the treatment and 91% in the control group. Total iron intakes were 298 and 51 mg and total zinc intakes were 318 and 72 mg in the treatment and the control groups, respectively. Lead, cadmium, and mercury content of the maize flour were below their detection limit (, 0.05 mg/kg) (data not shown).

TABLE 2 Iron and zinc status indices and CRP concentrations in children who received maize porridge fortified with a MNP containing an exogenous phytase or control, by group, at baseline, and after 6 mo[1]

	Treatment group	Control group
n	95	97
Age,[2] y	8.1 (7.9–8.6)	8.0 (7.7–8.8)
Male:female, n	61: 39[a]	50: 50
Height,[3] cm	121 6 10	122 6 9
Weight, kg	22.6 6 6.8	22.5 6 4.9
Hb, g/L		
Baseline	125 (123–127)	126 (123–128)
6 mo	125 (123–126)	125 (123–126)
Anemia prevalence,[3] %		
Baseline	6.3	8.2
6 mo	5.3	12.4
SF, mg/L		
Baseline	18.5 (17.1–21.1)	19.4 (18.6–21.8)
6 mo	21.6 (18.6–21.8)[b]	20.8 (17.0–23.7)
TfR, pg/L		
Baseline	8.6 (8.3–8.8)	8.5 (8.3–8.8)
6 mo	6.2 (5.7–6.5)[b]	6.8 (6.4–7.1)
Iron deficiency,[4] %		
Baseline	75.0	74.0
6 mo	18.9[b]	48.5
Body iron,[5] mg/kg body weight		
Baseline	1.8 (1.4–2.3)	2.0 (1.9–2.2)
6 mo	3.6 (3.0–3.9)[b]	2.8 (2.1–3.1)
SZn, mg/L		
Baseline	6.58 (6.41–6.71)	6.40 (5.96–6.76)
6 mo	6.89 (6.66–7.31)[c]	6.59 (6.44–7.00)[c]
Zinc deficiency,[6] %		
Baseline	47.4	52.5
6 mo	30.5[b]	47.4
Serum CRP . 10 mg/L, %		
Baseline	0.0	1.0
6 mo	1.1	4.1

[1] Values are means 6 SD, medians (bootstrapped 95% CI), or percentages. Letters indicate differences ($P < 0.05$): [a] vs. control; [b] vs. baseline and control; [c] vs. baseline.
[2] Groups did not differ at baseline, $P \geq 0.05$.
[3] Defined as Hb concentration , 115 g/L (30).
[4] Defined as SF , 15 mg/L or TfR . 8.2 pg/L (30,31).
[5] To convert body iron to mmol/kg, multiply by 0.0171; to convert SZn to mmol/L, multiply by 0.0153.
[6] Defined as SZn , 6.5 mg/L (32).

TABLE 3 Anthropometric measures in South African primary school children who received maize porridge fortified with a MNP containing an exogenous phytase or control, by group, at baseline, and after 6 mo[1,2]

	Treatment group	Control group
n	95	97
Weight-for-age Z-scores		
Baseline[2]	21.5 (21.9, 21.2)	21.4 (21.6, 21.1)
6 mo	20.9 (21.4, 20.7)[a]	21.0 (21.1, 20.7)
Height-for-age Z-scores		
Baseline	21.6 (22.0, 21.4)	21.4 (21.6, 21.2)
6 mo	21.0 (21.6, 21.2)[b]	20.9 (21.0, 20.6)[b]
MUAC-for-height Z-scores		
Baseline	21.3 (21.5, 21.0)	21.2 (21.4, 20.9)
6 mo	21.0 (21.4, 20.8)[b]	21.1 (21.2, 20.7)[b]
BF, %		
Baseline	9.6 (8.9, 10.6)	10.3 (8.8, 10.7)
6 mo	9.8 (9.6, 11.4)[b]	10.3 (9.2, 11.6)[b]
AMA, cm^2		
Baseline	17.0 (16.3, 17.7)	17.5 (16.6, 18.1)
6 mo	18.4 (17.4, 19.9)	19.7 (18.1, 20.5)

[1] Values are medians (bootstrapped 95% CI). Letters indicate differences ($P < 0.05$): [a] vs. baseline and control; [b] vs. corresponding baseline.
[2] Groups did not differ at baseline, n = 192.

There was no between-group difference in the prevalence of elevated serum CRP concentrations at either time point. Because of the very low prevalence of elevated CRP, children with an elevated value were included in the analysis, because it had no substantial effect on the result. Time × treatment interactions were significant for SF ($P < 0.01$; $h^2 = 0.035$), TfR ($P < 0.05$; $h^2 = 0.032$), body iron stores ($P < 0.01$; $h^2 = 0.046$), and the prevalence of iron ($P < 0.01$) and zinc deficiency ($P < 0.05$) (Table 3). Adjusting for baseline gender differences did not substantially change the levels of significance for SF, body iron, zinc deficiency, Hb, TfR, or SZn. For SZn, there was a time effect ($P < 0.001$; $h^2 = 0.066$). Hb concentration and the prevalence of iron deficiency anemia were not changed during the intervention ($P > 0.05$). If the difference in ingested iron between the groups (247 mg) led to a mean incremental increase in body iron of 23 mg, bioavailability was ;9%.

The Z-scores for weight-for-age showed a time × treatment effect after adjusting for gender ($P < 0.05$; $h^2 = 0.023$), and height-for-age, MUAC-for-height, and AMA changed over time ($P < 0.001$; $h^2 = 0.535$, 0.085, and 0.274, respectively) but not with treatment ($P > 0.05$), even after adjusting for baseline gender differences (Table 3).

Discussion

Despite its low dose (2.5 mg) of iron and zinc, this MNP was clearly efficacious: it decreased iron deficiency by 75% compared with 35% in the control group and zinc deficiency by 36% compared with 9%. A recent meta-analysis also concluded that MNP are just as effective as drops in reducing anemia prevalence but did not find an effect on zinc status (33). Body iron doubled from 1.8 to 3.6 mg/kg in the treatment group and increased from 2.0 to 2.8 mg/kg in the control group. Therefore, the increment in body iron due to MNP was 1.0 mg/kg or 22.6 mg based on mean body weight, corresponding to a bioavailability of the additional 247 mg iron of 9%. Because fortification iron and native food iron are absorbed from a common pool (15,34–36), an increase in native iron absorption from the maize porridge due to the EDTA, AA, and phytase likely contributed to the increase in body iron in the treatment group; thus, the bioavailability of the iron fortificant in the MNP may have been closer to 7–8%. This estimate is consistent with a previous stable isotope-labeled test meal study in healthy Swiss women, where iron absorption from this MNP in a comparable maize porridge was 7.4% (14). Fractional iron absorption is inversely related to iron stores (37) and the Swiss women had higher SF than the children in the present study. Thus, we might have expected a higher absorption rate in the children. But the effect of absorption enhancers on iron bioavailability is often greater in single meal studies than when they are consumed over the long term (38). The comparable estimate of iron absorption from the MNP demonstrates it is feasible to extrapolate from single meal studies in healthy young adults when planning efficacy studies in iron-deficient children in developing countries.

Most previous efficacy studies of NaFeEDTA used higher doses (5–10 mg/d) and mainly included anemic participants (39–43). In a previous study in South African children using similar low-dose NaFeEDTA (2.4 mg/d iron) to fortify brown bread, iron status did not improve despite a longer (34 wk) intervention (44). The efficacy of our low dose is likely to have been partially due to the phytase as well as the AA in the MNP. This highlights the importance of phytate reduction to enhance iron absorption from cereal-based foods (8,45). Commercially produced weaning foods reach only a small proportion of infants and children in the developing world (46). Dephytinization at the point of consumption, e.g., by adding phytase during meal preparation, involves waiting periods that could increase risk of food contamination (47). This study is the first to our knowledge to demonstrate the potential value of an exogenous phytase added just before consumption to ensure adequate iron absorption from an inhibitory meal. The phytase remains active at gastric pH and degrades phytic acid while the food is in transit through the stomach and upper duodenum. The phytase is derived from a genetically modified (self-cloned) Aspergillus niger that is Self-Affirmed Generally Recognized as Safe. This enzyme is identical to the one produced by nongenetically modified Aspergillus spp.

Because of the potential safety concerns of providing an iron-fortified MNP to infants in a malarial area (7), and also because we wanted to test the phytase first in older children to judge its safety, we studied school children in an area free of malaria. A school-based intervention also facilitated meal preparation, distribution, and monitoring of consumption. Also, although MNP are typically used to fortify infant foods, they are increasingly being used for older age groups (33). We reasoned that if the low iron and zinc dose in the MNP was effective in older children with greater body weight and higher iron and zinc requirements, it would also likely be beneficial for infants. However, because infants may have less mature regulation of iron absorption and/or utilization (48), extrapolation from older to younger children should be done cautiously.

The improvement in iron status in the control group was likely due to a combination of factors: 1) the additional native iron (0.5 mg/serving) and/or the additional energy and protein provided by the nonfortified porridge; 2) more attention to the child's diet/health at home due the parents' awareness of the child's iron deficiency; and/or 3) the mebendazole treatment. Although we did not measure helminth burden, it is possible that the deworming reduced blood loss due to hookworm infection in this population (49). Given the close supervision, the high acceptability of the porridge and the consistent color-coding, it is very unlikely that meals were switched or shared.

One-half of the children in the study were mildly zinc deficient at baseline and provision of the MNP significantly reduced the prevalence of zinc deficiency by 66%. The efficacy of the low dose of zinc was likely due to reduction of phytic acid by the phytase and the presence of NaFeEDTA; both can increase zinc absorption (9,50–52). Zinc, and possibly iron, fortification is thought to have affect undernutrition measured as weight-for-age (53–55) and undernutrition in the study was widespread: weight-for-age Z-scores were −1.5. The increased energy and protein intake from the maize porridge had a beneficial effect on the children's physical development; in both groups, all growth indicators except for arm muscle mass markedly improved. Even though most of the children in this study were only mildly zinc (and iron) deficient at baseline, there was a bigger improvement in the weight-for-age Z-score in the group receiving the MNP. It is possible that a potential small impact of the MNP on indicators other than weight-for-age Z-score was obscured by the robust overall improvement in both groups, given that the study was of short duration and was underpowered to detect growth outcomes.

The absorbed iron requirement for weaning infants and preschool children is ~500–700 mg/d (56). Our low-dose MNP, if absorbed at 7–8%, could provide 25–50% of this requirement. Moreover, this MNP will also likely enhance absorption of the high native iron and zinc content of complementary foods based on cereals and legumes; traditional complementary foods may provide 2.5–12.0 mg/d iron as well as 1.0–10.4 mg/d zinc (57).

Untargeted iron supplementation may increase 5-y-old child morbidity and mortality from malaria in the absence of monitoring and treatment programs (6,58–60). Several potential mechanisms may explain this increase in mortality. An oral bolus of iron may generate nontransferrin bound iron (NTBI) which is potentially toxic (7). It is unclear if NTBI generation is simply a reflection of the total absorbed iron dose. If it is, even though our MNP contains a low dose of iron, it is highly bioavailable, and the absorbed iron dose will likely be comparable to that from a higher dose that is less well absorbed. We are currently studying whether generation of NTBI is dependent on dose and/or iron compound. Alternatively, it is possible that unabsorbed dietary iron may induce adverse changes in the gut microflora (7). Recent findings from our group indicate that unabsorbed fortification iron modifies the colonic microflora in African children toward a potentially more pathogenic profile (61); this may at least partially explain the increased risk for diarrhea reported in previous iron interventions (6,59,62). If this is true, then reducing the dose of fortification iron in an MNP while maximizing its absorption could be important in areas where diarrheal disease burden is high, such as in sub-Saharan Africa, where diarrhea contributes to 1 in 6 young child deaths (63).

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ERRATUM

Troesch B, van Stujivenberg ME, Smuts CM, Kruger HS, Biebinger R, Hurrell RF, Baumgartner J, Zimmermann MB (2011). A micronutrient powder with low doses of highly absorbable iron and zinc reduces iron and zinc deficiency and improves weight-for-age Z scores in South African children. J Nutr. 141:237–42.

The name of one of the authors was misspelled as Martha E. van Stujivenberg instead of Martha E. van Stuijvenberg. Therefore, the authors are as follows:

Barbara Troesch, Martha E. van Stuijvenberg, Cornelius M. Smuts, H. Salomè Kruger, Ralf Biebinger, Richard F. Hurrell, Jeannine Baumgartner, and Michael B. Zimmermann.

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In the above-mentioned article, some values in Table 1 were incorrect and are given correctly in the table below. We apologize for any confusion this error may have caused.

TABLE 1 Composition of the micronutrient powder used in the intervention study

Nutrient	Unit/kg	Overage,[1] %
Vitamin A, mg RAE[2]	80	30
Vitamin D-3, mg	1	30
Vitamin E, g TE[3]	1	10
Thiamine, mg	100	25
Riboflavin, mg	100	25
Pyridoxine, mg	100	25
Folic Acid, mg	18	25
Niacin, g	1.2	10
Pantothenic acid, mg	400	10
Vitamin B-12, mg	180	25
Vitamin C, g	12	20
Iron (as NaFeEDTA), mg	500	5
Calcium, g	40	10
Copper, mg	68	10
Iodine, mg	6	20
Selenium, mg	3.4	10
Zinc, mg	500	10
Phytase, FTU	38,000	100
Carrier[4]	ad 1000 g	

[1] Overages were added to ensure the required amounts during 6-mo shelf-life.
[2] Retinyl actetate equivalents.
[3] Tocopherol equivalents.
[4] Ad is used to indicate that the amount of carrier needed to have a total of 1 kg/kg was added.