original communications

The retention of calcium, iron, phosphorus, and magnesium during pregnancy: the adequacy of prenatal diets with and without supplementation[1,2]

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ABSTRACT Vitamin and mineral supplementation is often prescribed by physicians to meet the additional nutrient requirements of pregnancy. In order to partially ascertain the effectiveness of these prenatal supplements, the retention of calcium and iron was determined in pregnant women consuming supplemented or unsupplemented self-selected diets. The retention of phosphorus and magnesium, minerals not included in the prenatal supplements, was also determined. Seven-day metabolic balance experiments spaced periodically throughout the pregnancy were conducted on 10 healthy pregnant white women. The retention of calcium by the supplemented group was comparable to that of the unsupplemented group, while the retention of iron was more dependent on the magnitude of the iron intake than on its source. Although no supplement contained phosphate, the intake of phosphorus met the recommended allowances for this mineral. Significantly related to the intake of dietary calcium, the adequate phosphorus intakes reflected diets providing adequate calcium. The mean magnesium intake was only 60% of the recently established recommended dietary allowance. Although the calcium and iron salts provided by the prenatal supplements were well utilized, the intakes of phosphorus and magnesium indicate that the reliance on the effectiveness of mineral supplements should not lessen the emphasis by the physician on the importance of a good prenatal diet. *Am. J. Clin. Nutr.* 32: 286–291, 1979.

The elevated nutritional requirements of pregnancy appear to be accompanied by an increased efficiency in the utilization of some nutrients (1–4). Despite this adaptation, additional daily allowances of nutrients are recommended by the Food and Nutrition Board of the National Research Council (5). Vitamin and mineral supplements are often prescribed to meet these requirements. Otherwise, the importance of a good prenatal diet may be neglected.

The utilization of calcium and iron salts, two minerals generally provided by a prenatal supplement, has been variable. Comparative studies using men, nonpregnant women and children show that the effectiveness of minerals provided through ordinary food depends on the mineral salt used, the nutritional needs of the subject, and other components in the diet (6–10). Phosphorus and magnesium are generally not provided by a prenatal supplement. Specific dietary allowances for these minerals were recommended by the National Research Council for the first time in 1968 (11).

The purpose of this investigation was 2-fold: *1*) to ascertain the effectiveness of cer-

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tain prenatal supplements in meeting the calcium and iron requirements of pregnancy; and *2*) to determine the retention of phosphorus and magnesium. The investigation was conducted with the purpose of determining the retention of these minerals in prenatal diets representative of the diets the subjects normally consumed. As a further indication of the general adequacy of the diet, nitrogen retention was investigated also.

Methods

The retention of calcium, iron, phosphorus, magnesium, and nitrogen was studied in ten healthy, pregnant white women eating self-selected diets with or without supplementation. Metabolic balance experiments were spaced periodically throughout the pregnancy. A maximum of six 7-day balance periods were completed on each subject, two balance periods per trimester of pregnancy, in order to determine changes in mineral retention related to the progression of pregnancy (Table 1).

The purpose and procedure of the balance study was discussed with two private practice obstetricians who agreed to refer patients to the study. Understanding that the accuracy of the study depended on the ability and reliability of the subjects in collecting specimens and keeping records, care was taken in the selection of women referred to the study. Upon referral, the woman was visited in her home with the husband present, if possible.

TABLE 1
Distribution of the 7-day balance periods and dietary supplementation of subjects during these periods

Subject	Estimated week of gestation					
	First trimester		Second trimester		Third trimester	
	1	2	3	4	5	6
1			20[a]	24[a]	29[a, b]	36[a, b]
2	8	13	19[c]	25	30	36
3			16[d]	22[d]	29[d]	35[d]
4		10	16[d]	22[d]	29[d]	35[d]
5			16[d]	22[d]	29[d]	35[d]
6		9	16[e]	22[e]	29[e]	35[e]
7	6	12[f]	16[f]	22[g]	27[g]	35[g]
8[h]	5	9[d]	16[d]	21[d]		
9		11	16	22	29	35
10		11	16	22	29	34

[a] Filibon F. A., Lederle Laboratories, Pearl River, N.Y. [b] Ferro-Sequels, Lederle Laboratories, Pearl River, N.Y. [c] Fero-Folic-500, Abbott Laboratories, North Chicago, Ill. [d] Natalins, Mead Johnson Laboratories, Evansville, Ind. [e] Fero-Gradumet, Abbott Laboratories, North Chicago, Ill. [f] Pramilet F. A. (121), Ross Laboratories, Columbus, Ohio. [g] Pramet F. A. (147), Ross Laboratories, Columbus, Ohio. [h] Subject moved from area and balance experiments could not be continued.

The purpose of the study, the responsibilities of the subject, and possible inconveniences and difficulties were discussed with each participant.

The subjects included three graduate and two undergraduate students at the University of Tennessee, the wife of a student, a registered nurse, two secretaries, and a former elementary school teacher. All ten subjects were nulliparous. The average age of the expectant mothers was 24 years with ages ranging from 19 to 29 years. Records of weight gain throughout pregnancy and the hematocrits determined in early pregnancy were provided by the obstetricians.

The diets of the subjects were self-selected. Food was prepared, eaten, and all samples collected by the subjects in their homes. The women were encouraged to continue the same dietary and work routines during the balance weeks that were practiced during the weeks between balance periods. The purpose was to determine mineral intakes as occurred under ordinary home conditions. Multiple vitamin, mineral supplements were taken if prescribed by the obstetrician. The iron and calcium content of these supplements is presented in Table 2.

Subjects were instructed in the weighing, recording, and collection of food samples and medications and in the collection of feces, urine, and vomitus. Written instructions were also provided. All equipment needed for weighing, recording and collecting samples was furnished by the laboratory. The importance of complete and accurate recording and collection of samples was stressed. Daily contact with the subjects provided opportunity to discuss any problems encountered during the balance periods.

Food samples were weighed to the nearest gram on Hanson scales and recorded on daily record sheets. Water, tea, coffee, cola, and very small quantities of solids were measured using standard kitchen measuring cups and spoons supplied by the laboratory. A similar sample of all food, medications and supplements were collected by the subjects and saved for analysis.

Twenty-four hour urine collections were preserved with toluene. Fecal samples were collected between Brilliant Blue dye markers for each 7-day balance period. If the fecal samples were not completely cleared of Brilliant

TABLE 2
Calcium and iron content of dietary supplements[a]

Supplement[b]	Ca^{++}	Fe^{++}
	g	*mg*
a	0.23 (as carbonate)	30 (as fumerate)
b		50 (as fumerate)
c		105 (as sulfate)
d	0.25 (as carbonate)	40 (as fumerate)
e		105 (as sulfate)
f	0.25 (as carbonate)	40 (as fumerate)
g	0.25 (as carbonate)	60 (as sulfate)

[a] Medical Economics Incorporated. Physician's Desk Reference to Pharmaceutical Specialties and Biologicals, Oradell, N.J., 1972. Various supplements also contained vitamins A, C, D, the B-complex vitamins and small amounts of several minerals. [b] Supplements correspond to those presented in Table 1.

Blue by the end of the experimental period, Carmine dye was used to mark the end of the collection period. All samples collected were stored in an ice chest which was picked up and taken to the laboratory daily.

Completeness of urine collection was verified by the determination of 24-hr creatinine excretions (12). Analyses for calcium, iron, phosphorus, magnesium, and nitrogen were made on 7-day composites of intake (including food, medications and supplements), urine and feces (including any vomitus) for each subject. The macro-Kjeldahl method was used for nitrogen analysis (12).

Acidified ash solutions of composites and untreated drinking water samples were analyzed for calcium, iron, and magnesium using a Perkin-Elmer Atomic Absorption Spectrophotometer 303 (Perkin-Elmer Corp., Norwalk, Conn.). Phosphorus was determined colorimetrically (13).

Results

The average weight gain during pregnancy was 10.3 kg (22.6 pounds). Hematocrits determined in early pregnancy ranged from 36 to 42% with an average of 39% for the 10 subjects. All subjects remained in good health and delivered normal babies.

Because of the naturalistic conditions of the study, there was both intra-subject and inter-subject variation from one 7-day experimental period to another, as indicated by the large standard deviations. So that these variations would be included in the statistical analyses, the Student's *t* test, analysis of variance and simple linear regression were calculated using the data for each 7-day experimental period.

Forty-eight 7-day experimental periods were completed. However, the balance period conducted during the sixteenth week of gestation for Subject 6 was deleted from all calculations. Diarrhea occurring at the end of the experimental period made the final separation of the fecal sample impossible. Subject 2 received iron supplementation during only the experimental period conducted during the nineteenth week of gestation. Supplementation was discontinued approximately a month before the next experimental period began. Data collected during this week of gestation were not included in the analysis of the iron data. The ingestion of the iron supplement by subject 6 was irregular. Because this irregularity might obscure physiological adaptation to the intake, only the iron data collected before supplementation began were included in the analysis of the iron data.

The data was divided into six groups as to week of gestation as shown in Table 1. One-way analysis of variance determined that the calcium, iron, phosphorus, and magnesium balances did not differ significantly ($P > 0.05$) over the duration of the pregnancy. Possibly, the fluctuation of intakes of the minerals obscured any physiological adaptation occurring during the later part of pregnancy.

Calcium data were then grouped as twenty-three 7-day experimental periods in which a calcium supplement was not part of the calcium intake and twenty-four 7-day experimental periods in which supplemental calcium carbonate provided approximately 18% of the calcium intake. The retention of calcium by the supplemented group was comparable to that of the group ingesting only food sources of the mineral (Table 3). The calcium intakes of both groups exceeded the allowance of 1.2 g daily for pregnant women (5). However, four of the six subjects receiving a calcium supplement had a mean daily intake of 1.47 g of calcium. Since 0.25 g of calcium was provided by a prenatal supplement, 1.22 g were provided by the subject's diets. That is, of the 10 subjects, all but two essentially met the recommended daily allowance of calcium through their diet alone.

Supplemental iron as ferrous fumerate or ferrous sulfate was received from the vitamin and mineral supplement, the iron supplement, or both (Table 1). The experimental periods were grouped as twenty-four 7-day periods in which iron supplementation had been ingested and 19 periods in which no iron supplement had been included.

The iron content of the drinking water was less than 2 ppm; therefore, total iron intake does not include drinking water. The urinary losses were also less than 2 ppm. Man and Wadsworth (14) determined urinary losses of iron in men and nonpregnant women to be less than 100 μg/24 hr. Coons (15) found urinary losses in pregnant women were usually less than 2% of that in the diet and did not affect the final balance appreciably. Therefore, iron balance was calculated as intake minus fecal loss.

Both the intake and balance of the supplemented group were significantly higher than that of the unsupplemented group (Table 3). The retention of iron whether provided en-

TABLE 3
Mean[a] daily calcium and iron retention with and without supplementation

Mineral	Mean supplementation	No. of 7-day experimental periods	Total intake	Urinary loss	Fecal loss	Balance (intake − excretion)
					±SD	
Calcium (g)		47	1.37 ± 0.29	0.26 ± 0.11	1.19 ± 0.52	−0.08 ± 0.52
Supplemented	0.245	24	1.35 ± 0.32	0.26 ± 0.12	1.24 ± 0.48	−0.15 ± 0.58
Unsupplemented		23	1.39 ± 0.25	0.26 ± 0.08	1.14 ± 0.57	−0.01 ± 0.46
Iron (mg)		43	45 ± 29		41 ± 28	4 ± 12
Supplemented	45	24	66 ± 19[b]		60 ± 22	6 ± 14[c]
Unsupplemented		19	18 ± 6[b]		16 ± 9	2 ± 8[c]

[a] Data for each 7-day experimental period/no. of 7-day experimental periods. [b] Supplemented iron intake significantly different ($P < 0.001$) from unsupplemented intake. [c] Supplemented iron balance significantly different ($P < 0.01$) from unsupplemented balance.

TABLE 4
Mean[a] daily phosphorus, magnesium, and nitrogen retention

Mineral	No. of 7-day experimental periods	Total intakes	Urinary loss	Fecal loss	Balance (intake − excretion)
			±SD		
Phosphorus (g)	47	1.34 ± 0.28	0.69 ± 0.14	0.62 ± 0.21	0.03 ± 0.26
Magnesium (mg)	47	269 ± 55	94 ± 28	215 ± 69	−40 ± 50
Nitrogen (g)	47	9.2 ± 2.2	7.6 ± 1.6	1.0 ± 1.6	0.6 ± 2.0

[a] Data for each 7-day experimental period/no. of 7-day experimental periods.

tirely from food or partially from these iron salts was more dependent on the magnitude of the iron intake than on the sources of the iron.

The retention of phosphorus, magnesium, and nitrogen is presented in Table 4. Although no supplement received by any subject contained phosphate, the phosphorus intakes met the recommended allowance of 1.2 g daily (5). However, the phosphorus intake was significantly related ($P < 0.001$) to the dietary calcium intake. Consequently, the adequate intakes of phosphorus reflected diets which provided adequate allowances for calcium.

The mean magnesium intake was only 60% of the recently recommended allowance of 450 mg daily (5). Only two of the prenatal supplements contained magnesium, and the amount provided in these supplements was negligible, 0.15 mg. Of forty-seven 7-day balance periods, only three magnesium balances were positive.

The mean nitrogen intake of the 10 subjects was 9.2 g daily (58.3 g protein). Three subjects had mean nitrogen intakes less than 9.0 g (56.2 g protein). The mean intake of the other seven subjects was 10.1 g nitrogen (62.8 g protein), representing intakes of at least 75% of the recommended allowance of 76 g of protein.[6]

Discussion

Performing "at home" balance studies with self-selected diets presented problems that would have been avoided with a more controlled laboratory investigation. The variability of the diets not only between subjects, but within a subject from period to period, resulted in large statistical deviations. This variability may have been responsible for obscuring physiological adaptation occurring during the later part of pregnancy. However, if the nutritional status of the obstetrical patient is to be evaluated, it must be determined as nearly as possible under real conditions representative of those existing for self-determining women.

For this group of women, the need for the calcium provided in prenatal supplements was not substantiated. The indiscriminate

[6] Photostat or microfilm copies of tables of calcium, iron, phosphorus, magnesium and nitrogen retention by individual subjects, daily creatinine values and statistical values are available at moderate cost from the National Auxiliary Publications Service of the American Society for Informational Science.

prescribing of this mineral without ascertaining its need by means of an adequate dietary history is of doubtful value.

The Council on Foods and Nutrition of the American Medical Association (16) has stated that many women enter pregnancy with inadequate storage of iron. For this reason, prophylactic administration of iron was justified. Estimating that the mean daily iron replacement required during pregnancy is 3.5 mg/day, the Council suggested that up to 30 mg of supplemental iron is required daily during the last half of pregnancy. The National Research Council recommended 30 to 60 mg of iron supplementation daily (5). The subjects reported ingested approximately 45 mg of supplemental iron daily. Concomitantly, their mean iron retention approached 6 mg, while the mean retention of the group receiving no iron supplementation was 2 mg daily. For both groups, iron retention represented approximately 10% of the iron intake. The supplemental iron appeared to be as well utilized as dietary iron in meeting the increased requirements of pregnancy.

Since calcium-rich foods are generally good sources of phosphorus, the phosphorus intakes of the subjects reflected diets which adequately met allowances for calcium. The results suggest that had the calcium intake been more dependent on a phosphorus-free calcium supplement, the phosphorus intake might have been lower, and subsequently, the phosphorus balance more negative.

The negative magnesium balances indicated that the magnesium intakes were not sufficient to produce equilibrium. Hunt and Schofield (17) reported that young nonpregnant women remained in equilibrium with magnesium intakes less than 200 mg if the protein intake was also limited. Leichsenring et al. (18) reported that the urinary excretion of magnesium in young nonpregnant women increased as the intakes of calcium and phosphorus were increased. The intakes of protein, calcium, and phosphorus of the pregnant women reported could have been influential in the severity of the negative magnesium balances. However, the intake of these nutrients was not excessive, and the low magnesium intakes of these women with diets providing adequate amounts of the other minerals investigated indicates that emphasis should be placed on the importance of including good sources of magnesium in the prenatal diet: whole-grain cereals and flour, soybeans, dried beans and peas, nuts, peanut butter, chocolate, hard cheeses, lean beef, most green vegetables, corn, most seafood, bananas.

Although the calcium and iron salts provided by prenatal supplements appeared to be well utilized, the need for the supplemental calcium was not substantiated for this group. The adult pregnant women of this investigation were private obstetric patients concerned about the well-being and development of the fetus and receiving regular prenatal care. These results do not lessen the importance that prenatal supplements have in meeting nutritional needs of pregnant women with poor dietary intakes or special circumstances: the low-income group, the pregnant teenager, the lactose-intolerant group, and so on. Of concern is the possibility that reliance on the effectiveness of mineral supplements may lead to a lessened emphasis by the physician on the importance of a good prenatal diet. Even for the women reported in this study, protein intakes were approximately three-fourths of the recommended allowances, the intake of phosphorus was dependent on the inclusion of calcium-rich foods, and there was a lack of adequate magnesium in the prenatal diet. These results illustrate the need for dietary counseling of the expectant mother.

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