Effects of Excessive Amounts of Dietary Iron on Pregnant Rats : Iron, Copper, Zinc, Manganese and Selenium Statuses in Mothers and Fetuses

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Abstract The effects of excessive amounts of dietary iron (Fe) on pregnant rats which were fed adequate and deficient levels of dietary copper (Cu) were investigated to measure trace mineral statuses in the dams and fetuses. Forty female Wistar rats with an average age of 46 days were fed diets containing adequate amounts of Fe and Cu (43 mg Fe and 6.0 mg Cu/kg), adequate amounts of Fe and deficient amounts of Cu (43 mg Fe and 0.6 mg Cu/kg), excessive amounts of Fe and adequate amounts of Cu (1165 mg Fe and 6.0 mg Cu/kg) and excessive amounts of Fe and deficient amounts of Cu (1165 mg Fe and 0.6 mg Cu/kg) and mated. The rats were killed after a gestation period of 20 days and their blood, livers, kidneys, hearts, spleens, femurs and fetuses were sampled. Excessive amounts of dietary Fe decreased liver and heart weight in dams and increased individual fetal weight. The Fe concentrations in maternal and fetal tissues were increased by the Fe excessive diet. The concentrations of selenium (Se) in maternal livers, manganese (Mn) in maternal livers and hearts, zinc (Zn) in maternal serum and femurs, Se in fetal whole bodies and Mn in fetal whole bodies and livers were decreased by excessive amounts of dietary Fe. Excessive amounts of dietary Fe in the diet did not decrease Cu concentrations in maternal and fetal tissues. The Cu concentrations in maternal and fetal tissues were decreased by deficient levels of dietary Cu. The Cu deficient diet for dams fed excessive amounts of dietary Fe decreased Fe concentrations in maternal serum and fetal whole bodies and livers.

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Although Fe has important functions in animals since it is a component of hemoglobin, myoglobin, cytochrome, and the enzymes catalase and peroxidase, there is little convincing evidence that dietary Fe deficiency ever occurs in farm animals except for piglets²⁵⁾. Conversely, excessive amounts of Fe in diets have influenced the performance in both farm and laboratory animals^{6,22,30)}. Copper concentra-

tions of livers were greatly decreased in rats, sheep and cattle fed a excessive amount of Fe^{3,5,28)}. Zinc and Mn metabolisms in rats and cattle were also affected by a large amount of Fe ingestion^{11,12,22)}.

Deficiencies of trace minerals during gestation have profound effects on mineral status and cause disorders in dams and their offsprings. Deficiencies of Cu, Zn and Mn in

ruminants resulted in retarded growth and congenital malformations in newborns^{2,9,19}. Selenium deficiency in cows caused retained placenta in dams and nutritional muscular dystrophy in calves^{1,14}. Since Fe demand is increased during the latter period of a pregnancy by the presence of a fetus, many researches on Fe deficiency during gestation have been done^{18,24,27}. However, there are few studies on the effects of high levels of dietary Fe and the interactive effects of dietary Fe and Cu on the performance and mineral statuses in pregnant animals and their offsprings. Rats were used for this experiment to investigate the effects of excessive amounts of dietary Fe on pregnant dams and their fetuses. The rats were fed adequate or deficient levels of dietary Cu and their trace mineral statuses were examined.

Materials and Methods

Animals and diets: Forty female Wistar rats, weaned at the age of 28 days, were raised until they were 34–37 days old on a commercial diet for growing rats (MF, Oriental Yeast Co., LTD). The animals were accustomed to a purified diet containing 43 mg Fe and 6.0 mg Cu/kg for 8–13 days. The following 4 purified diets were given when the rats were 44–48 days old; a diet with adequate amounts of Fe and Cu (FeACuA, 43 mg Fe and 6.0 mg Cu/kg, $n=8$), a diet with adequate amounts of Fe and deficient amounts of Cu (FeACuD, 43 mg Fe and 0.6 mg Cu/kg, $n=12$), a diet with excessive amounts of Fe and adequate amounts of Cu (FeECuA, 1165 mg Fe and 6.0 mg Cu/kg, $n=8$) and a diet with excessive amounts of Fe and deficient amounts of Cu (FeECuD, 1165 mg Fe and 0.6 mg Cu/kg, $n=12$). The composition of a basal diet is shown in Table 1. Ferric citrate and copper carbonate monohydrate were used to compose each diet. Groups of four animals each were housed in a suspended stainless-steel cage in a room controlled through temperature, light and humidity (22°C,

Table 1. Composition of a basal diet

Component	%
Corn starch	41.5
Milk casein	25.0
α -Starch	10.0
Cellulose powder	8.0
Vegetable oil	6.0
Granulated sugar	5.0
Mineral mixture ¹⁾	3.5
Vitamin mixture ²⁾	1.0

¹⁾Oriental Yeast Co., LTD. Tokyo. Modified AIN-76 mineral mixture without iron and copper (g/kg of diet): CaHPO₄, 17.5; NaCl, 2.59; K₃C₆H₅O₇ · H₂O, 7.7; K₂SO₄, 1.82; MgO, 0.84; MnCO₃, 0.12; ZnCO₃, 0.056; Na₂SeO₃ · 5 H₂O, 0.00035; KIO₃, 0.00035; and CrK (SO₄)₂ · 12 H₂O, 0.019.

²⁾Oriental Yeast Co., LTD. Tokyo. AIN-76 vitamin mixture (mg/kg of diet): choline bitartrate, 2000; vitamin K₃, 0.05; vitamin B₁ hydrochloride, 6; vitamin B₂, 6; vitamin B₆ hydrochloride, 7; vitamin B₁₂, 0.01; D-biotin, 0.2; folic acid, 2; calcium pantothenate, 16; nicotinic acid, 30; vitamin A acetate 4000 IU/kg diet and vitamin D₃ 1000 IU/kg diet.

a cycle of 13 hours of light and 11 hours of darkness and 60% humidity). The diet and ion-exchanged water were fed ad libitum. Body weights were recorded weekly. The vaginal smears of rats were tested every day after the rats were allocated the experimental diets. When each rat had reached its pre-estrus day after turning 51–58 days old, every female rat was removed overnight and mated with a male Wistar rat. Day 0 of gestation was assumed when sperms were observed in the smear.

Sample procedures: On the 20th day of gestation, the rats were starved for 24 hours and given an intraperitoneal injection of pentobarbital. Blood samples from the abdominal aorta were taken. The blood was then transferred into centrifuge tubes. A small portion of the blood sample was used for measuring the hematocrits and the rest of the blood sample was centrifuged for 15 minutes at 3000 g. Maternal livers, kidneys, hearts and

spleens were removed, trimmed free of fat, washed with saline and weighed after wiping. The right femurs from mothers were removed, trimmed free of connective tissue, dried for 48 hours at 120°C and weighed. The uteri were opened and the fetuses were removed. The fetuses were then washed with saline, examined for apparent fetal malformations and weighed after wiping. The fetuses in the right uterine horns were decapitated, the hematocrits were measured and the livers were removed. The fetuses in the left uterus were freeze-dried and ground by a coffee mill. The samples of serum and tissues from dams were transferred into polypropylene tubes and stored in a freezer at -20°C for later mineral analyses.

Analyses: Soft tissues and serum were digested by a 4:1 mixture of 60% nitric and perchloric acids. Femur samples were digested in a muffle for 6 hours at 600°C and dissolved in 1N hydrochloric acid. The Fe, Cu, Zn and Mn concentrations in tissue and serum samples were analysed by flame atomic absorption spectrophotometry. The concentrations of Se were analysed by fluorometrical spectrophotometry through the WATKINSON²⁹⁾ method.

Statistics: The values were statistically analysed by the following mathematical

model:

$$Y = \mu + F_i + C_j + (FC)_{ij} + E_{ijk}$$

where:

Y : each value

μ : the overall mean

F_i : the effect associated with Fe level in the diet

C_j : the effect associated with Cu level in the diet

$(FC)_{ij}$: the interaction effect between Fe and Cu levels in the diet

E_{ijk} : residual

All statistical analyses were conducted through the least square analysis of variance procedure by HARVEY¹³⁾.

Results

One rat fed an FeACuD diet, 2 rats fed an FeECuA diet and 5 rats fed an FeECuD diet did not conceive in the first mating. Two rats from the FeECuA and FeECuD diets, respectively, conceived in the second mating. One rat fed the FeACuD diet and 3 rats fed the FeEDuD diet, which missed conception in the first mating, did not conceive in the second mating as well. These rats were removed from the experiment.

There were no significant differences in

Table 2. Daily gain during pregnancy and tissue weight of dams

Item	Diet				Significance of differences ¹⁾		
	FeACuA (n=8)	FeACuD (n=11)	FeECuA (n=8)	FeECuD (n=9)	Fe	Cu	Fe×Cu
Daily gain during pregnancy (g)							
	7.7 ±0.3 ²⁾	7.1 ±0.2	7.2 ±0.3	7.4 ±0.4	NS	NS	NS
Tissue weight ³⁾ (g)							
Liver	13.6 ±0.8	13.4 ±0.6	12.2 ±0.5	12.2 ±0.6	*	NS	NS
Kidney	1.77±0.10	1.79±0.07	1.72±0.06	1.59±0.06	NS	NS	NS
Heart	0.98±0.05	0.99±0.04	0.89±0.04	0.90±0.04	*	NS	NS
Spleen	0.50±0.03	0.49±0.02	0.46±0.02	0.50±0.04	NS	NS	NS
Femur	0.39±0.02	0.41±0.01	0.38±0.01	0.40±0.01	NS	NS	NS

¹⁾ *, $P < 0.05$; NS, not significant.

²⁾ Least square means ± standard error of means.

³⁾ Values of liver, kidney, heart and spleen are wet weight and those of femurs are dry weight.

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Table 3. Hematocrit and mineral concentrations in serum and tissues of dams

Item	Diet				Significance of differences ¹⁾		
	FeACuA (n=8)	FeACuD (n=11)	FeECuA (n=8)	FeECuD (n=9)	Fe	Cu	Fe×Cu
Hematocrit	28.1 ± 1.3 ²⁾	30.5 ± 1.1	34.9 ± 1.0	35.6 ± 0.9	**	NS	NS
Serum (μg/ml)							
Iron	0.28± 0.03	0.39± 0.05	1.75± 0.30	0.66± 0.13	**	**	**
Copper	1.51± 0.13	0.23± 0.03	1.51± 0.08	0.24± 0.03	NS	**	NS
Zinc	1.08± 0.02	1.46± 0.05	1.05± 0.06	1.17± 0.05	**	**	**
Liver (μg/g on a wet basis)							
Iron	29.2 ± 1.0	50.3 ± 5.0	171.2 ± 25.0	266.8 ± 26.8	**	**	*
Copper	4.2 ± 0.1	1.8 ± 0.1	4.7 ± 0.1	2.1 ± 0.1	**	**	NS
Zinc	17.4 ± 0.2	17.2 ± 0.3	18.2 ± 0.3	17.5 ± 0.5	NS	NS	NS
Manganese	3.7 ± 0.1	3.7 ± 0.1	3.0 ± 0.2	3.1 ± 0.1	**	NS	NS
Selenium	0.37± 0.02	0.38± 0.03	0.31± 0.02	0.30± 0.02	**	NS	NS
Kidney (μg/g on a wet basis)							
Iron	36.5 ± 1.5	35.7 ± 1.4	55.3 ± 1.6	51.6 ± 2.9	**	NS	NS
Copper	6.0 ± 0.5	3.2 ± 0.1	7.6 ± 1.1	3.4 ± 0.1	NS	**	NS
Zinc	24.2 ± 0.2	23.1 ± 0.4	23.8 ± 0.8	23.2 ± 0.5	NS	NS	NS
Manganese	1.02± 0.02	1.00± 0.04	1.00± 0.05	1.01± 0.04	NS	NS	NS
Heart (μg/g on a wet basis)							
Iron	55.1 ± 3.1	55.2 ± 1.7	66.9 ± 1.4	65.8 ± 2.6	**	NS	NS
Copper	5.2 ± 0.1	4.1 ± 0.1	5.3 ± 0.1	4.3 ± 0.1	NS	**	NS
Zinc	17.4 ± 0.4	16.7 ± 0.3	16.9 ± 0.5	16.1 ± 0.3	NS	NS	NS
Manganese	0.38± 0.02	0.45± 0.02	0.36± 0.02	0.40± 0.01	*	**	NS
Spleen (μg/g on a wet basis)							
Iron	116.4 ± 7.9	104.5 ± 5.5	259.0 ± 44.3	282.0 ± 79.4	**	NS	NS
Copper	1.31± 0.06	0.53± 0.06	1.21± 0.08	0.73± 0.11	NS	**	NS
Zinc	20.4 ± 0.2	20.0 ± 0.2	20.4 ± 0.3	18.8 ± 1.3	NS	NS	NS
Manganese	1.21± 0.10	1.22± 0.14	1.26± 0.09	0.99± 0.08	NS	NS	NS
Femur (μg/g on a dry basis)							
Iron	39.4 ± 2.0	39.7 ± 2.1	79.3 ± 2.8	101.5 ± 30.3	**	NS	NS
Copper	6.7 ± 0.6	5.9 ± 0.4	6.5 ± 0.1	5.8 ± 0.2	NS	NS	NS
Zinc	229.1 ± 14.8	221.9 ± 6.6	200.7 ± 2.7	207.3 ± 5.2	*	NS	NS
Manganese	3.5 ± 0.2	3.7 ± 0.1	3.3 ± 0.1	3.4 ± 0.1	NS	NS	NS

¹⁾ *, P<0.05; **, P<0.01; NS, not significant.

²⁾ Least square means±standard error of means.

weight gain of maternal rats between the treatment groups during pregnancy. The weights of livers and hearts from rats fed Fe excessive diets were significantly lower than those of rats fed an Fe adequate diets (p<0.05) (Table 2). No significant differences of tissue weights was observed between the rats fed Cu deficient diets and those fed Cu adequate diets.

Excessive amounts of Fe intake significantly increased hematocrits and Fe concentrations in serum, livers, kidneys, hearts, spleens and femurs from mothers (p<0.01) (Table 3). Notably, Fe concentrations in livers from mothers fed excessive amounts of Fe were 5 times higher than those fed adequate amounts of Fe. The high levels of dietary Fe signifi-

Table 4. Fetal number, total fetal weight and individual fetal weight

Item	Diet				Significance of differences ¹⁾		
	FeACuA (n=8)	FeACuD (n=11)	FeECuA (n=8)	FeECuD (n=9)	Fe	Cu	Fe×Cu
Fetal Number	13.6 ± 0.8 ²⁾	11.6 ± 0.8	12.5 ± 0.6	12.7 ± 0.7	NS	NS	NS
Fetal weight (g)							
Total weight	52.7 ± 2.9	42.9 ± 2.7	53.6 ± 3.4	52.2 ± 3.7	NS	NS	NS
Individual weight	3.92 ± 0.08	3.73 ± 0.15	4.27 ± 0.08	4.09 ± 0.10	**	NS	NS

¹⁾ **, P<0.01; NS, not significant.²⁾ Least square means ± standard error of means.

Table 5. Hematocrit and mineral concentrations and contents in fetuses

Item	Diet				Significance of differences ¹⁾		
	FeACuA (n=8)	FeACuD (n=11)	FeECuA (n=8)	FeECuD (n=9)	Fe	Cu	Fe×Cu
Hematocrit	24.1 ± 0.7 ²⁾	25.0 ± 1.4	36.7 ± 1.0	34.4 ± 1.5	**	NS	NS
Whole body (μg/g on a wet basis)							
Iron	19.2 ± 0.9	21.1 ± 1.1	42.7 ± 2.4	36.9 ± 2.3	**	NS	**
Copper	1.86 ± 0.04	0.41 ± 0.03	2.06 ± 0.09	0.34 ± 0.04	NS	**	**
Zinc	16.3 ± 0.3	14.9 ± 0.2	15.4 ± 0.5	15.9 ± 0.9	NS	NS	NS
Manganese	0.36 ± 0.02	0.54 ± 0.02	0.30 ± 0.01	0.33 ± 0.03	**	**	**
Selenium	0.116 ± 0.002	0.112 ± 0.002	0.093 ± 0.004	0.104 ± 0.005	**	NS	NS
Whole body (μg per head)							
Iron	76.4 ± 4.3	78.8 ± 5.5	184.1 ± 12.7	154.0 ± 11.6	**	NS	NS
Copper	7.4 ± 0.2	1.5 ± 0.2	8.8 ± 0.5	1.4 ± 0.2	NS	**	**
Zinc	64.9 ± 1.6	56.0 ± 2.9	66.3 ± 2.9	66.5 ± 5.5	NS	NS	NS
Manganese	1.41 ± 0.06	2.00 ± 0.10	1.31 ± 0.04	1.37 ± 0.11	**	**	**
Selenium	0.46 ± 0.01	0.43 ± 0.02	0.40 ± 0.02	0.42 ± 0.02	*	NS	NS
Liver (μg/g on a wet basis)							
Iron	58.0 ± 2.0	56.8 ± 4.6	181.9 ± 10.0	134.1 ± 7.2	**	**	**
Copper	13.0 ± 0.6	1.0 ± 0.2	14.1 ± 0.6	0.8 ± 0.1	NS	**	NS
Zinc	59.8 ± 3.0	45.7 ± 2.0	58.1 ± 3.5	48.8 ± 2.1	NS	**	NS
Manganese	0.86 ± 0.04	1.18 ± 0.05	0.44 ± 0.03	0.63 ± 0.04	**	**	NS

¹⁾ *, P<0.05; **, P<0.01; NS, not significant.²⁾ Least square means ± standard error of means.

cantly decreased the concentrations of Zn in serum ($p<0.01$), Mn and Se in livers ($p<0.01$), Mn in hearts ($p<0.05$) and Zn in femurs ($p<0.05$) and significantly increased the concentrations of Cu in livers ($p<0.01$). The deficient levels of dietary Cu significantly decreased Cu concentrations in the serum, livers, kidneys, hearts and spleens from dams

($p<0.01$). The concentrations of Zn in the serum and Mn in the hearts were significantly increased by the deficient levels of Cu in the diet ($p<0.01$). An interactive effect of dietary Fe and Cu was observed in the concentrations of Fe in the serum ($p<0.01$) and livers ($p<0.05$) of dams. Low Cu intake markedly decreased the serum Fe concentrations and

increased the liver Fe concentrations in dams fed excessive amounts of dietary Fe.

No apparent malformation was observed in the fetuses. There were no significant effects of dietary Fe and Cu on the fetal numbers (Table 4). Individual fetal weights of excess Fe groups were significantly heavier than those of adequate Fe groups ($p < 0.01$).

Significant effects of dietary Fe on fetal hematocrits and Fe concentrations in fetal whole bodies and livers were observed ($p < 0.01$) (Table 5). Excessive amount of Fe in the diet significantly decreased the concentrations and contents of Mn in fetal whole bodies and the Mn concentrations in fetal livers ($p < 0.01$). Both the concentrations and contents of Se in fetal whole bodies were significantly decreased by the Fe excessive diets ($p < 0.01$ and $p < 0.05$). The Cu deficient diet remarkably decreased the Cu concentrations in fetuses. The Cu concentrations within fetal whole bodies and livers of the Cu deficient groups compared to those of the Cu adequate groups were 20% and 7%, respectively. Low Cu intake significantly increased Mn concentrations in fetal whole bodies and livers ($p < 0.01$) and decreased Zn concentrations in fetal livers ($p < 0.01$). Interactive effects of dietary Fe and Cu were observed in the Fe concentrations of fetal whole bodies and livers ($p < 0.01$). The Fe concentrations of fetal whole bodies and livers from dams fed excessive amounts of Fe were decreased by low Cu concentrations in the diet.

Discussion

Although the high levels of dietary Fe did not affect weight gain, it reduced liver and heart weights in dams. A previous study indicated that rats fed the diet supplemented with 2.5% Fe in the form of carbonyl iron for 11-12 weeks reduced food intake and weight gain³⁰. The Fe levels of the Fe excessive diets in this experiment were much lower than that in the previous study. It is likely that 1000 mg/kg Fe in the diet was not toxic enough to

affect the maternal weight gain but had an effect on the liver and heart weights.

The significantly higher individual fetal weights from dams fed excessive amounts of Fe compared to those from dams fed adequate amounts of Fe were observed. The increased fetal weights might have been caused by an increased nutrient flow from the dams to the fetuses since the dry matter weights of fetuses in Fe excess groups were also higher than those in Fe adequate groups (The data were not shown.). However, the mechanism whereby excessive amounts of dietary Fe has this effect is unknown.

The serum Fe concentrations of rats fed FeACuA diets were much lower than those of non-pregnant female rats in a previous experiment even though the dietary mineral composition of the present experiment was similar to that of the previous one¹⁷. Serum Fe concentrations in dams decrease in late pregnancy^{20, 27}. The lower serum Fe concentrations of rats fed FeACuA diets compared to those of previous studies might be due to the gestation.

The Fe excessive diet influenced not only the concentrations of Fe in maternal tissues but also those in fetal tissues. The concentrations of Fe in the whole bodies and livers of fetuses from mothers fed the Fe excessive diet were significantly higher than those from mothers fed the Fe adequate diet. The supplementary Fe was most likely transferred to fetuses across placentas and deposited in fetal tissues. The higher hematocrits in fetuses might be due to the increased Fe flow into fetuses.

The large amounts of Fe did not reduce Cu concentrations in any maternal tissues. Conversely, it significantly increased maternal liver Cu concentrations. The result of this study conflicts with those of previous studies. GORDON and ELLERSIECK¹¹ reported that liver Cu concentrations in male weanling rats fed a 270 mg Fe/kg diet for 21 days were significantly lower than those fed a 90 mg Fe/kg diet.

STOREY and GREGER²³⁾ demonstrated that liver Cu concentrations in male weanling rats fed a 1500 mg Fe/kg diet were significantly lower than those fed a 35 mg Fe/kg diet during 1, 18 and 25 day experiments. However, liver Cu concentrations in male and female weanling rats fed a 300 mg Fe/kg diet for 42 days were not different from those fed a 50 mg Fe/kg diet¹⁷⁾. BREMNER and PRICE³⁾ reported that liver Cu concentrations in male weanling rats fed a 500 mg Fe/kg diet were decreased within 2 weeks and recovered within 6 weeks. They suggested that the rats adapted to the continual intake of a large amount of Fe. The experimental period of this study was averaged 31 days which is longer than those of studies conducted by GORDON and ELLERSIECK¹¹⁾ and STOREY and GREGER²³⁾. There is a possibility that the difference of experimental period caused the inconsistent results among the experiments. Besides, there is another possibility that the inconsistency might be due to the physiological difference of rats. A previous study indicated that the uptake of ⁶⁴Cu was more efficient in pregnant rats than non-pregnant rats⁷⁾. The depletion of Cu caused by Fe loading might be less severe in pregnant rats than weanling rats.

It has not been observed that the concentrations of Se in the livers of rats fed large amounts of Fe were lower than those fed adequate amounts of Fe. As a component of glutathione peroxidase, Se plays an important role in the defense system against peroxidative damage to lipid membranes²¹⁾. Previous evidence *in vivo* indicated that Fe overload caused an accumulation of large quantities of Fe in cells and tissues. Lipid peroxide formation also increased during the Fe loading⁸⁾. In the present study, Fe concentrations in the livers of Fe excess groups were 5 times higher than those of Fe adequate groups. Though the extent of lipid peroxidation in livers was not measured, the Fe accumulation in livers might have increased Se demand to protect mem-

branes against peroxidative damage.

The excessive amounts of Fe in diets decreased the concentrations of Mn in maternal livers and hearts. High concentrations of Fe in diets decreased Mn absorption in the duodenum of rats¹²⁾. The lowered Mn concentrations in the tissues of dams were caused by the excessive amounts of Fe.

The contents of Se and Mn in fetal whole bodies in the excessive Fe groups were lower than those of fetuses in the adequate Fe groups in spite of the increased individual fetal weights. It is likely to indicate that the transfers of Se and Mn from dams to fetuses were peculiarly depressed by the excessive amounts of dietary Fe for dams though a nutrient flow from dams to fetuses were increased. Previous reports suggested that the Se and Mn transfers from dams to fetuses were influenced by maternal Se and Mn statuses^{15,16)}. The low Se and Mn contents in fetuses in the excessive Fe groups might have been due to the low Se and Mn statuses in their dams.

The large amounts of Fe significantly reduced Zn concentrations in the serum and femurs of dams. A previous study indicated that excessive amounts of dietary Fe decreased apparent intestinal Zn absorption in rats²⁶⁾. Plasma Zn concentrations rapidly declined in Zn depletion and femur Zn concentrations then significantly fell⁴⁾. The lowered Zn concentrations in femurs in the excessive Fe groups might be due to the decreased serum Zn concentrations caused by the reduced intestinal absorption of Zn.

The Cu deficient diet remarkably decreased the serum Fe concentrations and increased the liver Fe concentrations in dams fed excessive amounts of dietary Fe. EVANS and ABRAHAM¹⁰⁾ reported that Fe mobilization from liver to serum in rats was disturbed by a low serum ceruloplasmin activity which resulted from a Cu deficient diet. The decrease in serum Fe concentrations and the increase in liver Fe concentrations caused by deficient

dietary Cu in rats might have reflected the decline of Fe released from liver to serum. The Fe concentrations in whole bodies and livers of fetuses from dams fed excessive amounts of dietary Fe were also decreased by the Cu deficient diet for dams. The lowered serum Fe concentrations in dams caused by a low Cu status might have resulted in the decreased transfer of Fe from dams to fetuses.

In conclusion, the excessive amount of dietary Fe did not aggravate the Cu status in pregnant rats and their fetuses. However, the present study suggests that attention should be paid to Se, Mn and Zn statuses in dams and to Se and Mn statuses in their fetuses when the dams are fed a large amount of dietary Fe.

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飼料中の過剰量の鉄が妊娠ラットに及ぼす影響：
母親と胎児の鉄，銅，亜鉛，マンガンおよび
セレンの栄養状態について

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銅を適量および欠乏量与えられた妊娠ラットに対して過剰量の鉄を投与し，母親と胎児の微量元素の栄養状態を調べた．平均 46 日齢のウィスター系雌ラット 40 頭を，鉄適量・銅適量（鉄 43 mg/kg・銅 6.0 mg/kg），鉄適量・銅欠乏量（鉄 43 mg/kg・銅 0.6 mg/kg），鉄過剰量・銅適量（鉄 1165 mg/kg・銅 6.0 mg/kg）および鉄過剰量・銅欠乏量（鉄 1165 mg/kg・銅 0.6 mg/kg）の飼料を与えられる 4 区に分け，交配した．妊娠 20 日目に屠殺し，血液，肝臓，腎臓，心臓，脾臓，大腿骨および胎児を採取した．飼料中の過剰量の鉄は母親の肝臓と心臓の重量を低下させ，胎児 1 頭当りの重量を増加させた．母親と胎児の組織中の鉄濃度は過剰量の鉄の投与によって増加した．また，過剰量の鉄は母親の肝臓中セレン濃度，肝臓・心臓中マンガン濃度および血清・大腿骨中亜鉛濃度，胎児の体中セレン濃度および体中・肝臓中マンガン濃度を低下させたが，母親および胎児の組織中の銅濃度を低下させなかった．一方，飼料中の欠乏量の銅は母親および胎児の組織中の銅濃度を低下させた．過剰量の鉄を与えられた母ラットの血清中铁濃度と胎児の体中・肝臓中铁濃度は欠乏量の銅の投与によって低下した．

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