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Relationship between pre-pregnancy body mass index and mineral concentrations in serum and amniotic fluid in pregnant women during labor

Iwona Lewicka[a,1], Rafał Kocyłowski[b,c,1], Mariusz Grzesiak[b], Zuzanna Gaj[b,d], Adam Sajnóg[e], Danuta Barałkiewicz[e], Constantin von Kaisenberg[f], Joanna Suliburska[a,*]

[a] Institute of Human Nutrition and Dietetics, Poznan University of Life Sciences, ul. Wojska Polskiego 31, 60-624 Poznań, Poland
[b] Department of Obstetric, Perinatology and Gynecology, Polish Mother's Memorial Hospital Research Institute, ul. Rzgowska281/289, 93-338 Łódz, Poland
[c] PreMediCare New Med Medical Centre, ul. Drużbickiego 13, 61-693 Poznań, Poland
[d] Scientific Laboratory of the Center of Medical Laboratory Diagnostics and Screening, Polish Mother's Memorial Hospital-Research Institute, ul. Rzgowska281/289, Łódz, 93-338, Poland
[e] Department of Trace Element Analysis by Spectroscopy Method, Faculty of Chemistry, Adam Mickiewicz University in Poznań, ul. Umultowska89b, 61-614 Poznan, Poland
[f] Department of Obstetrics and Gynecology, Hannover Medical School, Carl-Neuberg-Str. 1, D-30625 Hannover, Germany

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ABSTRACT

The aim of the study was to determine the correlations between body mass index (BMI) values before pregnancy and the concentrations of selected elements (Mg, Co, Cu, Zn, Sr, Cd, Ba, Pb, U, Ca, Cr, Al, Mn, V, Fe) in blood serum and amniotic fluid (AF) in pregnant women. Elemental analysis of serum and amniotic fluid in 225 Polish women (Caucasian/white) showed a relationship between the concentration of minerals in the above-mentioned samples and the pre-pregnancy BMI. Analysis of blood serum was performed by using ICP-MS and it demonstrated that iron concentration was significantly lower in overweight and obese women. Being underweight in pregnant women was associated with a significantly lower concentration of magnesium and cobalt in the blood serum. Both underweight and overweight women were associated with significantly lower concentrations of calcium and strontium in the blood serum. The concentration of cobalt was significantly higher in underweight women. The concentration of lead in the blood serum of overweight and obese women was significantly higher than in other groups. Analysis of the AF showed that the concentration of copper was significantly lower in overweight and obese women, and the concentration of manganese and vanadium significantly higher than in other groups of women. A deficiency in essential minerals and an excess of heavy metals in women may be associated with abnormal body weight and this is important in the etiopathogenesis of pregnancy and fetal development disorders.

1. Introduction

Both excessive body weight and being underweight in pregnant women are associated with numerous disturbances in the course of pregnancy and fetal development [1–4]. Obesity in pregnancy may be the cause of gestational diabetes, hypertension and pre-eclampsia. In addition, miscarriage and birth by cesarean section are more frequent in women with a high body mass index (BMI) [1–4]. Both overly low and overly high body weight in pregnant women pose a risk of premature labor [4]. Moreover, fetal growth disorders of the LGA (large for gestational age) and SGA (small for gestational age) type and higher rates of morbidity and mortality among newborns are more likely to be found in women with abnormal body weight [4–6].

Body weight disorders are largely due to improper nutritional habits. In women of childbearing age and pregnant women, a low dietary supply of iron, calcium, zinc, iodine and magnesium is often observed [7–12].

Deficiencies in essential minerals in women are often associated

Abbreviations: BMI, body mass index; AF, amniotic fluid; LGA, large for gestational age; SGA, small for gestational age

* Corresponding author.
E-mail addresses: iwona.lewicka@up.poznan.pl (I. Lewicka), biuro@new.med.pl (R. Kocyłowski), mariusz.grzesiak@iczmp.edu.pl (M. Grzesiak), zuzanna.gaj@iczmp.edu.pl (Z. Gaj), asajnog@amu.edu.pl (A. Sajnóg), danutaba@amu.edu.pl (D. Barałkiewicz), vonKaisenberg.Constantin@mh-hannover.de (C. von Kaisenberg), jsulibur@up.poznan.pl (J. Suliburska).

[1] Both authors contributed equally to this work.

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with abnormal body weight and may be important in the etiopathogenesis of pregnancy and fetal development disorders [13–15]. Minerals, being a part of numerous compounds with regulatory activity such as enzymes and hormones, play an important role in the division and differentiation of fetal cells and in their further development. Mineral deficiencies in pregnant women correlate with congenital fetal defects and growth disorders [16,17]. Overweight and obese pregnant women who also use a high-energy diet low in micronutrients may be at higher risk of mineral deficiencies [18–20].

A low concentration of iron, zinc, manganese and copper in the body of a pregnant woman may contribute to fetal growth disorders, and development of pre-eclampsia and anemia in both the mother and the child [7–10,21]. Low serum iron concentration in pregnant women also correlates with the occurrence of neurodevelopmental disorders in infants [22]. Similarly, studies involving children from obese pregnant women have demonstrated a relationship between maternal obesity and the occurrence of neurological disorders in children [23]. An increased concentration of selenium and copper in the umbilical cord blood serum may be associated with the occurrence of lipid metabolism disorders in infants [24].

Zinc, selenium, manganese, and copper are a key element of the complex enzymatic systems responsible for the antioxidant protection of the organism. A relationship has been found between the occurrence of obesity in pregnant women and increased oxidative stress and decreased antioxidant activity in placental tissue [25]. Antioxidant function of minerals seems to be particularly important during pregnancy, which is physiologically associated with a greater intensity of oxidation reactions [26,27]. Being overweight and obese when pregnant constitutes an additional factor intensifying the mentioned processes. The literature data show a relationship between the decreased concentration of mineral components with antioxidant activity in the body of pregnant women and an increased risk of hypertension, gestational diabetes as well as pre-eclampsia and miscarriage [28–30].

The aim of this study was to determine the relationship between BMI before pregnancy and the concentration of selected mineral components in the blood serum and AF of pregnant women.

2. Materials and methods

The study protocol was approved by the Local Ethics Committee of the Polish Mother's Memorial Hospital Research Institute in Łódź, Poland (approval no. 50/2016). This study was conducted in accordance with the Declaration of Helsinki.

2.1. Examined group

All subjects were informed of the study's aims, procedures, and measurement methods, and the written consent of each patient for study participation was obtained. The study group consisted of a total of 225 examined deliveries of singleton pregnancies by women (Caucasian/white; average, 39 weeks of gestation; range, 38–42 weeks), by vaginal birth (68.5%) or by cesarean section (31.5%). The study included (43.4%) male and (56.6%) female babies. The median maternal age was 29.4 ± 4.7 years (range, 18–43 years). AF and maternal blood were collected concurrently at birth.

The criteria for inclusion in the study were as follows: a live intrauterine pregnancy over 34 weeks, the normal course of pregnancy monitored by a doctor and midwife and informed consent for participation in the study. Exclusion criteria included genetic defects of the pregnant woman and/or fetus, abnormal amounts of amniotic fluid (oligohydramnios, polyhydramnios), multiple pregnancies, use of drugs affecting the mineral balance in the body, and maternal exposure to alcohol, drugs or tobacco smoke.

2.2. Maternal parameters

Maternal weight was measured before delivery to the nearest 0.1 kg using a calibrated digital weighing scale with the subjects in lightweight hospital clothing. Height was measured and pre-pregnancy weights were self-reported. The pre-pregnancy BMI was calculated.

Based on the value of the BMI, the women were divided into three groups: Group 1 – underweight (BMI $< 18.5\ kg/m^2$), Group 2 – with normal body mass (BMI 18.5–24.99 kg/m^2) and Group 3 – overweight and obese (BMI $\geq 25\ kg/m^2$).

Blood samples were collected from a maternal vein at the time of delivery. Monovette test tubes (Neutral or Serum Z/7.5 mL; Sarstedt, Sarstedt AG & Co, Nümbrecht, Germany) were used to obtain blood serum and these were spun within 30 min (3000 rpm/min at 4 °C). Serum samples were frozen and stored at −80 °C. The AF samples were obtained (5 mL) using either a transabdominal puncture in the surgical wound with intact membranes using sterile needles and syringes during cesarean delivery, or with sterile needles and syringes to puncture the amniotic sac while using a vaginal speculum to visualize intact membranes when cervical dilatation was 4 cm or more during vaginal birth. The samples were centrifuged (3000 rpm/min for 10 min at 4 °C), frozen, and stored at −80 °C.

2.3. Newborns' parameters

The newborns' weights were measured after birth using a digital weighing scale. The week of gestation was determined on the basis of the first trimester prenatal ultrasonography. Newborn's health was assessed by Apgar score and neonatal examination in the first 10 min after birth. Newborns were looked after in a rooming-in system at the maternity ward or in the neonatal unit in the case of complications (neurological, respiration, metabolic and thermoregulation disorders, symptoms of infection, congenital malformations). The need to administer antibiotics and the length of stay in the hospital were analyzed.

2.4. Mineral element determination

Mineral analysis and sample preparation were described in our previous paper [31].

Samples were mineralized in a high-pressure, closed, microwave digestion system (Ethos One, Milestone). The solutions thus obtained were quantitatively transferred to a volumetric flask and diluted to 10 mL with demineralized water (TKA Smart2Pure, Niederelbert, Germany). The procedural blank solutions were prepared in the same manner as the tested samples.

An Elan DRC II ICP-MS (PerkinElmer SCIEX, Ontario, Canada) was used to determine Mg, Co, Cu, Zn, Sr, Cd, Ba, Pb, U, Ca, Cr, Al, Mn, V, Fe concentrations. The validity of the analytical method was assessed by analyzing the certified reference material (CRM) Seronorm™ Trace Elements Serum L-2. The values of recovery are within an acceptable range for all elements. The recovery rates were shown in our previous paper [31].

2.5. Statistical analysis

All statistical analyses were performed with Statistica 10 for Windows. Data were tested for normal distribution using the Shapiro–Wilk test. ANOVA Kruskal-Wallis and Duncan's tests and Chi2 tests were used to compare differences between groups for all the studied parameters. The level of statistical significance was set to $p < 0.05$.

3. Results

Table 1 presents maternal parameters related to the pre-pregnancy BMI. Analysis of the pre-pregnancy body weight of women and their

Table 1
Maternal parameters related to pre-pregnancy BMI index value.

Examined parameter		In total n = 225	Group 1 underweight n = 26	Group 2 normal n = 148	Group 3 overweight and obese n = 51
Age (years) (mean ± SD)		29.5 ± 4.8	28.4 ± 5.2	30.4 ± 4.3	27.3 ± 5.4
Body weight before pregnancy (kg) (mean ± SD)		62.8 ± 11.5	48.9 ± 3.2[a]	59.9 ± 5.9[b]	76.8 ± 10.3[c]
Body weight before birth (kg) (mean ± SD)		77.3 ± 12.8	63.7 ± 7.7[a]	75.2 ± 9.2[b]	91.5 ± 11.8[c]
Pre-pregnancy BMI (kg/m^2) (mean ± SD)		22.6 ± 3.9	16.9 ± 3.5[a]	21.5 ± 1.6[b]	28.0 ± 3.0[c]
Body weight gain during pregnancy (kg) (mean ± SD)		15.0 ± 6.0	13.9 ± 4.8	15.3 ± 5.6	15.0 ± 6.0
Hypertension during pregnancy (%)		9.8	0	6.8	13.7
Diabetes during pregnancy (%)		9.8	11.5	8.8	11.8
Inflammations (%)		20.2	23.1	12.2	21.6
Taking drugs (%)		46.9	38.5	37.8	58.8
Birth (%)	Natural	68.5	73.1	62.1	57.0
	Cesarean section	31.5	26.9	37.9	43.0

a,b,c – differences between Groups 1–3 are statistically significant; $p < 0.05$.

body weight before the birth showed a relationship between these parameters. The body weight of women both before the pregnancy and before the birth was the highest in group 3 and the lowest in group 1.

The average weight gain during pregnancy in the group of women with normal body weight (group 2) and women who were overweight or obese (group 3) presented similar values (Table 1). The group of overweight and obese women was characterized by the highest incidence of metabolic diseases (hypertension, diabetes), and women in this group were more likely to use drugs. The delivery of women from group 3 was more often by cesarean section. The parameters presented in Table 1 did not differ significantly between the groups.

Table 2 characterizes the newborns born in the examined population of pregnant women. Over half of them were female babies. The vast majority were children born at term The percentage of children born prematurely did not exceed 20%. Newborns of women with excessive body weight more often suffered from metabolic diseases, congenital malformations and developmental disorders (Table 2). However, no significant differences were found between groups 1–3.

Analysis of the blood serum and AF showed a relationship between the element concentrations in the above-mentioned samples and pre-pregnancy BMI (Table 3 and 4). Serum iron concentration in pregnant women who were overweight or obese was significantly lower (around 15%) than in the group of women with normal body weight. The magnesium content in the serum of women who were underweight was 10% lower than in groups 2 and also lower than group 3 (around 14%). In the case of calcium and strontium, it was observed that abnormal body weight before pregnancy (both underweight as well as overweight and obese) was associated with its significantly lower serum content

Table 2
Newborn parameters related to mother pre-pregnancy BMI index value.

Examined parameter		In total n = 225	Group 1 underweight n = 26	Group 2 normal n = 148	Group 3 overweight and obese n = 51
Child's sex (%)	female	56.6	42.3	51.4	62.7
	male	43.4	57.7	48.6	37.3
Week of birth (mean ± SD)		38.3 ± 2.2	38.4 ± 2.4	38.2 ± 2.2	38.8 ± 1.6
Birth < 37 week of pregnancy (%)		14.2	11.5	16.9	7.8
Body weight (g) (mean ± SD)		3224.5 ± 589.6	3145.0 ± 591.6	3219.5 ± 560.7	3379.4 ± 632.0
Macrosomia/LGA (%)		9.3	3.8	10.1	15.7
Hypotrophy/SGA (%)		11.1	15.4	9.5	13.7
Congenital defects (%)		5.4	3.8	4.7	5.9
Neurological disorders (%)		1.2	0	0.7	3.9
Respiratory disorders (%)		5.4	7.7	6.8	2.0
Circulatory disorders (%)		3.5	0	3.4	5.9
Antibiotic therapy (%)		6.7	3.8	6.8	7.8

There are no significant group differences ($p < 0.05$).

Table 3
Concentration of chemical elements in blood serum of examined pregnant women related to their pre-pregnancy BMI value (mean ± SD, median/min-max).

Parameter	In total n = 225	Group 1 underweight n = 26	Group 2 normal n = 148	Group 3 overweight and obese n = 51
Fe	1.3 ± 0.5	1.3 ± 0.4^{ab}	1.3 ± 0.5^{b}	1.1 ± 0.4^{a}
[mg L^{-1}]	1.2	1.2	1.3	1.0
	0.6-2.8	0.7-2.4	0.6-2.8	0.6-2.4
Mg	15.3 ± 2.7	13.8 ± 2.5^{a}	15.3 ± 2.8^{b}	16.0 ± 2.2^{b}
[mg L^{-1}]	15.5	14.0	15.7	15.8
	9.0-2.3	9.0-18.6	9.8-21.0	10.9-23.3
Ca	95.9 ± 19.6	82.6 ± 17.7^{a}	99.2 ± 18.9^{b}	84.2 ± 18.6^{a}
[mg L^{-1}]	95.0	84.6	98.5	85.4
	47.7-163.4	60.1-121.7	69.0-163.4	47.7-125.8
Cu	2.1 ± 0.4	2.1 ± 0.4	2.2 ± 0.4	2.1 ± 0.4
[mg L^{-1}]	2.1	2.1	2.1	2.0
	0.8-3.0	1.4-2.8	1.1-3.0	0.8-3.0
Zn	1.0 ± 0.3	1.0 ± 0.3	0.9 ± 0.3	1.0 ± 0.3
[mg L^{-1}]	0.9	1.0	0.9	1.0
	0.4-2.2	0.5-1.7	0.4-2.2	0.4-1.9
Mn	12.1 ± 7.5	13.3 ± 9.2	11.9 ± 7.1	12.4 ± 7.9
[μg L^{-1}]	10.7	10.6	10.6	10.8
	0.7-38.0	3.2-33.7	1.0-38.0	0.7-36.8
Cr	4.8 ± 4.0	4.7 ± 5.1	4.1 ± 3.3	6.3 ± 4.9
[μg L^{-1}]	3.6	2.5	3.2	4.6
	0.7-18.9	1.3-18.8	0.7-16.0	1.0-18.9
V	0.3 ± 0.1	0.3 ± 0.1	0.3 ± 0.1	0.3 ± 0.2
[μg L^{-1}]	0.3	0.2	0.3	0.3
	0.1-0.9	0.1-0.6	0.1-0.7	0.1-0.9
Cd	0.1 ± 0.1	0.1 ± 0.4	0.2 ± 0.1	0.2 ± 0.1
[μg L^{-1}]	0.1	0.1	0.1	0.1
	0.02-0.6	0.04-0.2	0.03-0.6	0.02-0.4
Pb	6.1 ± 11.3	1.3 ± 1.2^{a}	6.3 ± 10.5^{ab}	10.8 ± 14.8^{b}
[μg L^{-1}]	1.4	0.9	1.4	1.6
	0.2-37.2	0.2-6.2	0.3-37.2	0.6-35.9
Sr	118.1 ± 120.7	52.5 ± 17.6^{a}	146.1 ± 136.1^{b}	62.5 ± 38.0^{a}
[μg L^{-1}]	59.1	48.1	60.8	53.2
	23.0-464.0	29.8-96.2	25.6-463.9	23.0-200.7
Ba	17.7 ± 11.1	24.2 ± 11.1^{b}	16.6 ± 11.3^{a}	17.6 ± 9.8^{a}
[μg L^{-1}]	18.7	23.2	17.1	19.0
	0.3-51.4	2.0-51.4	0.3-48.9	1.5-46.8
Co	0.6 ± 0.2	0.5 ± 0.2^{a}	0.6 ± 1.4^{b}	0.6 ± 0.2^{b}
[μg L^{-1}]	0.6	0.5	0.6	0.6
	0.2-1.0	0.2-0.9	0.2-1.0	0.4-1.0
U	0.3 ± 0,09	0.3 ± 0.1	0.3 ± 0.1	0.3 ± 0.1
[μg L^{-1}]	0.3	0.3	0.3	0.3
	0.2-0.7	0.2-0.5	0.2-0.7	0.2-0.7
Al	326.7 ± 183.0	256.9 ± 135.2	332.7 ± 191.3	347.7 ± 175.4
[μg L^{-1}]	270.7	245.6	290.7	274.5
	71.2-693.4	123.3-646.6	71.2-933.0	133.3-693.4

a,b - differences between Groups 1–3 are statistically significant; $p < 0.05$.

(over 15% for calcium and around 60% for strontium). A reverse relationship was observed when analyzing the calcium concentration in AF. The concentration of lead in the blood serum of women from group 3 was nearly 88% higher than in the underweight group. Barium content in women's blood serum was around 40% higher in the case of underweight women compared to the other groups. A significantly lower cobalt concentration (nearly 17%) was found in the underweight group compared to groups 2 and 3 (Table 3).

Elemental analysis of AF showed that the concentration of copper in the group of overweight and obese women was significantly lower by 16% than in control group. In turn, the concentration of Mn and V was the highest in group 3 and both elements were higher by around 17% in overweight and obese group than in control group.

4. Discussion

Few studies have investigated the subject of an extended analysis of element concentrations in the body of pregnant women in relation to their body weight. The most numerous are studies on iron concentration [32–34]. In our study, it was observed that being overweight or obese in pre-pregnancy women was associated with significantly lower serum iron levels. Some studies indicate disturbed iron homeostasis in obesity [35]. The research results described so far are consistent with the presented values [33,34,36]. Jones et al. [33] observed significantly lower values for iron concentrations in both maternal serum and umbilical cord blood serum from obese women. Bastian et al. [7] observed a relationship between iron deficiency during fetal life and infancy, and the occurrence of nervous system disorders. The authors demonstrated that iron deficit may result in abnormalities in brain development and the occurrence of cognitive disorders at a later time [7]. These observations have also been confirmed in other studies [37–39]. Similarly, the incidence of congenital malformations, neurological disorders and circulatory disorders was the highest among children of overweight and obese mothers. The described developmental disorders in children may be associated with an insufficient supply of iron during fetal life, which is often observed in obese women [37–39]

Serum calcium concentrations in pregnant women who were overweight or obese were significantly lower than in women with normal body weight. No similar relationship was observed with regard to the concentration of calcium in the amniotic fluid. To date, there are few

Table 4
Concentration of chemical elements in amniotic fluid of examined pregnant women related to their pre-pregnancy BMI value (mean ± SD, median/min-max).

Parameter	In total n = 225	Group 1 underweight n = 26	Group 2 normal n = 148	Group 3 overweight and obese n = 51
Fe	466.6 ± 185.4	474.9 ± 177.1	450.1 ± 168.9	510.0 ± 227.8
[μg L^{-1}]	401.6	439.0	398.3	429.7
	282.6-1266.7	282.7-878.3	282.6-1266.7	301.2-1263.1
Mg	9.1 ± 2.4	9.8 ± 1.8	9.1 ± 2.3	8.9 ± 2.9
[mg L^{-1}]	9.4	10.2	9.1	9.7
	0.1-18.2	4.5-13.4	0.1-18.2	1.8-14.8
Ca	71.2 ± 20.6	79.4 ± 14.1^{b}	68.5 ± 21.5^{a}	74.9 ± 19.2^{ab}
[mg L^{-1}]	69.3	77.4	64.4	75.60
	25.9-124.9	55.3-112.5	25.9-124.9	38.0-116.7
Cu	69.8 ± 22.6	69.5 ± 22.1^{ab}	73.0 ± 21.7^{b}	61.1 ± 23.1^{a}
[μg L^{-1}]	65.1	66.4	67.8	58.9
	6.4-132.2	35.7-112.6	29.9-132.2	6.4-108.0
Zn	522.1 ± 273.5	569.9 ± 255.2	524.2 ± 284.7	489.7 ± 247.4
[μg L^{-1}]	454.0	573.8	452.8	442.7
	78.2-1787,0	209.7-1057.3	78.2-1787.0	91.0-1066.8
Mn	5.9 ± 2.8	6.31 ± 3.0^{ab}	5.53 ± 2.6^{a}	6.72 ± 3.0^{b}
[μg L^{-1}]	5.05	5.5	5.2	6.0
	1.6-16.0	2.9-16.0	1.6-12.4	2.0-14.1
Cr	2.5 ± 2.4	2.2 ± 1.7	2.3 ± 2.4	3.1 ± 2.9
[μg L^{-1}]	1.5	1.3	1.5	1.8
	0.03-14.0	0.9-6.5	0.03-13.9	0.1-10.3
V	0.3 ± 0.2	0.24 ± 0.1^{a}	0.3 ± 0.2^{ab}	0.35 ± 0.2^{b}
[μg L^{-1}]	0.2	0.2	0.2	0.3
	0.03-1.0	0.1-0.5	0.1-1.0	0.02-1.0
Cd	0.1 ± 0.1	0.1 ± 0.1	0.1 ± 0.1	0.1 ± 0.1
[μg L^{-1}]	0.1	0.1	0.1	0.1
	0.01-0.8	0.04-0.4	0.02-0.8	0.01-0.6
Pb	45.3 ± 99.6	36.4 ± 59.8	52.9 ± 116.7	27.7 ± 46.3
[μg L^{-1}]	14.3	4.5	17.5	5.0
	0.2-42.3	3.4-158.4	0.2-1070.8	0.6-158.9
Sr	71.4 ± 56.2	73.4 ± 60.2	76.2 ± 61.2	53.7 ± 25.0
[μg L^{-1}]	48.7	47.9	51.1	46.0
	10.1-341.8	21.5-210.3	10.2-341.8	20.0-148.9
Ba	11.0 ± 6.7	12.3 ± 7.0	11.1 ± 6.9	9.9 ± 6.0
[μg L^{-1}]	10.0	10.2	10.0	9.6
	1.1-42.3	3.0-30.9	1.7-42.3	1.1-35.0
Co	0.3 ± 0.1	0.2 ± 0.1	0.3 ± 0.1	0.3 ± 0.1
[μg L^{-1}]	0.2	0.2	0.3	0.2
	0.06-0.7	0.1-0.5	0.1-0.7	0.1-0.6
U	0.05 ± 0.06	0.04 ± 0.06	0.05 ± 0.06	0.05 ± 0.07
[μg L^{-1}]	0.03	0.03	0.03	0.02
	0.002-0.6	0.008-0.3	0.002-0.6	0.006-0.5
Al	1314 ± 63.2	125.0 ± 62.0	134.9 ± 66.1	123.0 ± 53.3
[μg L^{-1}]	117.0	98.6	122.0	121.6
	35.8-331.0	51.3-248.1	35.8-331.0	39.9-259.6

a,b - differences between Groups 1–3 are statistically significant; $p < 0.05$.

studies analyzing calcium levels in the AF. Jafrin et al. [40] observed a significantly lower concentration of calcium in the blood serum of pregnant women with pre-eclampsia. The development of pre-eclampsia and disorders of blood pressure during pregnancy significantly correlates with excessive body weight in women and mineral deficiencies [4,41,42]. Similarly, the highest percentage of cases of hypertension was observed in our study in women who were overweight or obese. The decreased serum calcium concentration in women with excessive body weight was associated with the mentioned disorders. Moreover, it was observed that low calcium status promotes adiposity [43].

In our study, women with excessive body weight had a significantly lower content of copper in the AF. The reason for this lower concentration in the group of pregnant women who were overweight or obese may be the high demand by the body for nutrients with an antioxidant activity. An excessive accumulation of adipose tissue in the body of pregnant women significantly increases the intensity of oxidation reactions. It can be concluded, on the basis of the results of this study and previous published studies, that lower concentrations of copper in AF of overweight and obese women may be associated with a higher incidence of hypertension and fetal growth disorders, especially hypotrophy, in this group [42]. Copper plays an important role in fetal development, a positive correlation has been found between its concentration in AF and biometric parameters of the fetus [44,45]. In our study, the percentage of children with hypotrophy and the incidence of hypertension was higher in women who were overweight or obese, which may be related to decreased levels of elements with antioxidant activity in the body, including copper.

Few studies so far have addressed the topic of manganese concentrations in AF. The average value of this element's concentration in the present study is consistent with our previous study [45]. The concentration of manganese in AF in overweight and obese women was significantly higher than in other groups of women. This may be related to the above-mentioned increased need of the mother and fetus organisms for components with antioxidant activity in the situation of the co-existence of being overweight or obese. Yerlikaya et al. [46], studying the concentration of manganese in the blood serum of women, observed that it is significantly lower in obese women with diabetes. Manganese plays an important role in the process of the synthesis and secretion of insulin, a hormone exhibiting an anabolic activity [46].

Studies with pregnant women give inconclusive results; however, they suggest that both a deficiency and excess of this element during pregnancy is associated with fetal growth abnormalities and neurological disorders in the child [11,23]. In our study, growth disorders and neurological disorders were predominant in children of overweight and obese women, which may be related to manganese levels during pregnancy.

In the examined group of pregnant women that the concentration of metals, including lead, strontium or vanadium in the blood serum and AF, changed significantly depending on the body mass index of women. There are no studies describing the concentration of heavy metals in the bodies of pregnant women depending on their body weight. The values of metal concentrations described so far in the literature differ, which results to a large extent from the degree of environmental pollution and food consumption in the studied population of pregnant women [12,47–49]. In our study, the higher concentration of heavy metals in the group of overweight and obese women results, to a large degree, from the quality and quantity of food consumed by them. A high concentration of heavy metals in the woman's organism affects the normal development of the fetus. Studies conducted so far suggest the effect of heavy metals, mainly lead, on the birth weight of children and the development of their nervous system [12,48,49]. In our study, the average birth weight of children was consistent with the current recommendations of the World Health Organization: the percentage of newborns with macrosomia and hypotrophy did not exceed 10% [50,51]. However, the highest percentage of hypotrophy, macrosomia and neurological disorders in children occurred in the group of overweight and obese women, in whom the concentration of heavy metals was the highest. The research results collected so far indicate the relationship of elevated concentrations of heavy metals in people who are overweight or obesity [52,53]. Increased concentrations of heavy metals in the body result from the environmental exposure of the organism, including food consumption, and the degree of environmental pollution in the place of residence [52].

5. Conclusions

Being overweight and obesity in women before and during pregnancy is associated with low concentrations of minerals important for fetal development and pregnancy course, including iron, calcium and copper. In addition, an excessive body weight favors high levels of lead in the body, which may threaten the health of the mother and the fetus. Therefore, obese women of reproductive age as well as obese pregnant women should be included in the nutritional and health education program. Verification of current recommendations for mineral supplementation depending on the pre-pregnancy body mass index in women also seems to be justified.

Ethics

Study has been approved by the Local Ethics Committee of the Polish Mother's Memorial Hospital Research Institute in Łódź, Poland (approval no. 50/2016) and have therefore been performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and its later amendments. All subjects gave their written informed consent prior to their inclusion in the study.

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Declarations of interest

None

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