Journal of Elementology ISSN 1644-2296

Suliburska, J., Cholik, R., Włodarczyk, P., Szmyt, K., Bakinowska, E., Von Kaisenberg, C. and Kocyłowski, R. (2025)
'Impact of oral magnesium supplementation on maternal and fetal parameters in the second trimester of pregnancy',
Journal of Elementology, 30(4), 571-587,
available: https://doi.org/10.5601/jelem.2025.30.1.3539

RECEIVED: 30 March 2025
ACCEPTED: 16 August 2025

ORIGINAL PAPER

Impact of oral magnesium supplementation on maternal and fetal parameters in the second trimester of pregnancy*

Joanna Suliburska[1], Rafsan Cholik[1], Piotr Włodarczyk[2], Konrad Szmyt[2], Ewa Bakinowska[3], Constantin von Kaisenberg[4], Rafał Kocyłowski[2,5]

[1] Department of Human Nutrition and Dietetics
Poznan University of Life Science, Poznan, Poland
[2] PreMediCare Prenatal Research Center, Poznan, Poland
[3] Institute of Mathematics, Poznan University of Technology, Poznan, Poland
[4] Department of Obstetrics and Gynecology
Hannover Medical School, Hannover, Germany
[5] New Med Medical Center, Poznan, Poland

Abstract

Magnesium supplementation during pregnancy is believed to reduce the risk of maternal complications and abnormal fetal development. This observational study aims to evaluate maternal and fetal parameters in pregnant women during the second trimester who received magnesium supplementation. The study included 200 healthy women in the second trimester of pregnancy. Participants were divided into two groups: one received a recommendation for magnesium supplementation (n=100), while the other did not (n=100). Magnesium concentrations in maternal serum (MS) and amniotic fluid (AF) were measured using atomic absorption spectrometry (AAS). Maternal parameters, including blood pressure and prepregnancy body mass index, and fetal parameters, including estimated fetal weight (EFW), Doppler measurements, and cytogenetic karyotype, were measured. Magnesium supplementation increased magnesium concentrations in both MS and AF, with a positive correlation observed between these parameters. EFW was significantly higher in the supplementation group than in the nonsupplemented group. Moreover, serum magnesium concentration correlated positively with EFW. An inverse relationship was noted between AF magnesium concentration AF and gestational age. Magnesium supplementation initiated early in pregnancy improves MS and AF magnesium concentrations in the second trimester. Supplementation contributes to enhanced fetal development, as reflected in increased fetal weight compared to nonsupplemented pregnancies.

Keywords: pregnancy, magnesium, serum, amniotic fluid, fetus

Prof. dr hab. Joanna Suliburska, PhD DSc Prof., Department of Human Nutrition and Dietetics, Poznan University of Life Science, ul. Wojska Polskiego 31, 60-624 Poznan, Poland, e-mail: joanna.suliburska@up.poznan.pl

* The source of funding (Institute of Mathematics, Poznań University of Technology was funded under grant no. 0213/SBAD/0119).

INTRODUCTION

An adequate supply of nutrients during pregnancy is essential for maternal health and proper fetal development. However, nutritional deficiencies are prevalent among pregnant women in many countries, including developed ones (Kocyłowski et al. 2018, Adams et al. 2021). These deficiencies often involve vitamins and minerals, with a significant proportion of pregnant women consuming inadequate amounts of iron, folic acid, vitamin D, calcium, and magnesium (Kocyłowski et al. 2018, Kanasaki, Kumagai 2021).

Among these nutrients, magnesium plays a crucial role in numerous biochemical and physiological processes. It is involved in various biological and cellular functions, serving as a cofactor in over 600 enzymatic reactions and an activator for 200 enzymes (Dalton et al. 2016). Magnesium is essential for energy metabolism, the synthesis of proteins, fatty acids, and nucleic acids, the transmission of nerve impulses, mitochondrial function regulation, and immune cell activation. Moreover, it contributes to bone formation and supports bone health by favoring calcium assimilation into bones and aiding in vitamin D activation in the kidneys (Kanasaki, Kumagai, 2021).

Several studies have reported a decline in magnesium concentrations in maternal serum (MS) and amniotic fluid (AF) during pregnancy (Suliburska et al. 2016, Kanasaki, Kumagai, 2021). Pregnant women are at risk of developing magnesium deficiency, which has been associated with adverse pregnancy outcomes, including preterm birth, preeclampsia, gestational diabetes, small-for-gestational-age infants, and intrauterine growth restriction (Dalton et al. 2016). Both human and experimental studies have linked low magnesium levels in serum, plasma, red blood cells, and the placenta to an increased risk of preeclampsia (Chiarello et al. 2018, Kawasaki et al. 2019, Hao et al. 2024). Additionally, lower serum magnesium levels have been observed in women with gestational diabetes and polycystic ovary syndrome (PCOS) (Ren et al. 2023, Skrypnik et al. 2024).

Research indicates that magnesium supplementation during pregnancy may help reduce the risk of various maternal and fetal complications, including preeclampsia and gestational diabetes (Yuan et al. 2022, Luo et al. 2024). To mitigate the risk of pregnancy-related diseases, obstetricians should consider recommending magnesium supplementation early in pregnancy. Nutritional studies on pregnant women in Poland have observed low magnesium intake, and the mother's magnesium status declines as pregnancy progresses (Kocyłowski et al. 2018). Therefore, many gynecologists and obstetricians recommend magnesium supplementation for pregnant women.

Accordingly, this study aims to evaluate maternal and fetal parameters in pregnant women during the second trimester who received a magnesium supplement recommendation.

MATERIALS AND METHODS

The study was approved by the Bioethics Commission in Poznan University of Medical Sciences, Poland (approval no. 30/15 and 492/21). It was conducted by the Declaration of Helsinki and registered with ClinicalTrials.gov (ID: NCT03598361).

Subjects

Women were informed about the study's purpose, and written consent was obtained from all participants.

The research was conducted between 2016 and 2022. Participants were selected based on inclusion and exclusion criteria. The inclusion criteria were intrauterine pregnancy, singleton pregnancy, second trimester, and a mixed diet. The exclusion criteria included age below 18 or above 45 years, infections, chronic maternal diseases (e.g., diabetes, hypertension, epilepsy), the use of drugs that could affect mineral status, maternal exposure to alcohol, drugs, or tobacco smoke, and signs or symptoms indicating a risk of miscarriage (e.g., vaginal bleeding, pelvic pain, placental hematoma). This was an observational study, with the study group consisting of women recommended to use magnesium supplements, and the control group consisting of women not recommended to use them.

A total of 200 healthy pregnant Caucasian women between 15 and 23 weeks of gestation were included to collect the samples. Participants were divided into two groups: one group at 11-14 weeks of pregnancy (1st-trimester prenatal testing) had recommendations from an obstetrician to supplement magnesium at a dose of 300-1000 mg per day (n=100) and the group without such a recommendation (n=100). Women were advised to take the supplement daily, after meals, with 200 ml of water. Regular use of magnesium supplements was confirmed at subsequent prenatal visits. All participants followed a mixed diet during pregnancy and consulted a dietitian during routine prenatal visits.

Maternal parameters

Body mass index (BMI) was calculated as weight divided by height squared ($kg \cdot m^{-2}$). Height was measured to the nearest 0.5 cm. Prepregnancy weight was self-reported by participants during routine medical interviews.

Maternal blood samples were collected from a maternal forearm/cubital vein. Specimens were obtained using Monovette test tubes. After collecting approximately 5 ml of blood, the samples were left at room temperature for 30 min before being centrifuged at 2000 g for 15 min at 4°C. Serum samples were then frozen and stored at -80°C.

Amniotic fluid samples were collected during routine invasive prenatal tests performed due to a high risk of chromosomal abnormalities. AF was

obtained via transabdominal aspiration using sterile spinal and diagnostic puncture needles and plastic syringes. The samples were centrifuged at 1300 g for 5 min at 4°C, and the supernatant was then frozen and stored at -80°C.

Resting blood pressure was measured by a qualified nurse while participants were seated. Regular cuffs were used, and measurements were taken on both arms following the guidelines of the European Society of Hypertension (McEvoy et al. 2024).

Fetal parameters

Estimated fetal weight (EFW) and Doppler parameters were measured using the ProSound Alpha 7 (Aloka Co.) and GE Voluson E8 Expert ultrasound systems, equipped with a convex 5-7 MHz probe. Fetal measurements followed standard protocols for fetal biometry (Suliburska et al. 2022). Fetal gender was determined during this measurement. More details on the protocol and methods were described previously (Suliburska et al. 2022).

Cytogenetic karyotype analysis

Cytogenetic karyotyping was performed on AF samples in a certified diagnostic laboratory. Metaphase chromosomes were prepared using the standard GTG banding procedure. In this study, only information on whether the karyotype was normal or abnormal was considered; specific chromosomal aberrations were not detailed. More details on the protocol and methods were described previously (Suliburska et al. 2022).

Magnesium analysis

MS and AF samples were mineralized in 65% spectrally pure HNO_3 (Merck, Kenilworth, NJ, USA) in a microwave digestion system (Speed Xpert, Berghof, Eningen, Germany). Samples were then diluted with 0.5% lanthanum (III) chloride (Merck KGaA, Darmstadt, Germany) and deionized water. Magnesium concentration was determined with atomic absorption spectrometry (Atomic Absorption Spectrometer ZA3000, Hitachi). The validity of the analytical method was assessed using certified reference material (Hum Asy Control 2, Sero, Billingstad, Norway). The accuracy for magnesium measurement was 95% recovery.

Statistical analysis

Statistical analyses were conducted using Statistica 13.3 and RStudio software (R version 3.4.0; R Core Team, Vienna, Austria, 2017). The normality of data distribution was assessed according to the Shapiro-Wilk test. Differences between groups were analyzed with the Mann-Whitney test. A logistic model was applied to compare categorized data (e.g., gender, gravidity, chromosomal abnormalities) using the clm function from the ordinal package in R.

Correlation coefficients were calculated by Spearman's rank analysis. Confidence intervals for correlation coefficients and linear regression estimates were generated in *R* software (*R* version 4.1.2). Statistical significance was set at $p<0.05$ for all analyses.

RESULTS AND DISCUSSION

The study included 200 White Caucasian pregnant women, aged 22 to 45 years. Table 1 presents maternal and fetal parameters categorized based on magnesium supplementation recommendations. When comparing both groups, average values for age, prepregnancy body mass, and weeks of pregnancy were similar. However, the median prepregnancy body mass and mean weeks of pregnancy were slightly higher in the supplementation group than in the nonsupplemented group. Gravidity ranged from 0 to 4 and was comparable between groups. The proportion of fetal sexes was similar in both

Table 1

Characteristic of the subjects (mean±SD/median/*Q*25–*Q*75)

Parameter	Group without supplementation (*n*=100)	Group with supplementation (*n*=100)	*P* value
Maternal parameters			
Age (years)	33.02±5.17 34 30-37	33.16±5.49 34 29-37	0.853
Prepregnancy body mass (kg)	66.83±11.85 65 57.75-72.25	69.76±12.49 68.35 60.85-76.30	0.090
Weeks of gestation	16.82±2.45 16 15-19	17.32±2.42 16 16-20	0.148
Gravidity (*n*) 0 1 2 3 >3	 40 45 14 1 0	 56 35 6 2 1	0.277
Fetal parameters			
Gender (*n*) M F	 50 50	 53 47	0.777
Chromosomal abnormalities (n)	10	13	0.658

SD – standard deviation, Q1 – the first quartile, Q3 – the upper quartile, M – male, F – female, *p* – level of significance, statistical significance at $P<0.05$.

groups. The incidence of chromosomal aberrations was also comparable, though slightly higher in the supplementation group.

Magnesium concentration analysis revealed that the supplementation group had significantly higher magnesium levels in MS and AF (Figure 1).

Systolic and diastolic blood pressure did not differ between groups (Figure 2). Similarly, Doppler parameters measuring blood flow in the placenta and umbilical cord showed no significant differences between groups (Figure 3). BMI values were comparable between the two analyzed groups. However, EFW was significantly higher in the supplementation group (Figure 4).

These findings suggest that magnesium supplementation started in the first trimester improves maternal magnesium status and has a direct effect on fetal magnesium levels in the second trimester. It is important to note that serum magnesium concentrations in both groups remained within the normal range and were comparable to values reported in other studies involving pregnant women in the second trimester (Bocos Terraz et al. 2011, Hansu, Cikim, 2022). Similarly, AF magnesium concentrations in the second trimester were consistent with findings from previous studies (Suliburska et al. 2016, 2022).

A literature review indicates that magnesium supplementation in pregnant women serves multiple purposes, including reducing the risk of preeclampsia, gestational diabetes, and neurological disorders. It also significantly increases the concentration of magnesium in the serum of pregnant women and improves pregnancy outcomes (Asemi et al. 2015, Guerrero--Romero et al. 2015, García Alonso et al. 2018). A prospective cohort study conducted on neonates born before 32 weeks of gestation demonstrated a linear relationship between the dose of magnesium (administered as $MgSO_4$) received by mothers and neonatal serum magnesium levels (García Alonso et al. 2018).

The placenta plays a crucial role in transporting magnesium and other minerals from maternal circulation to the fetus (Ryan, Kovacs, 2020). Minerals are actively transported across the placenta against concentration and electrochemical gradients, *resulting* in higher fetal mineral serum concentrations compared to maternal serum levels (Sethi et al. 2020). This mechanism ensures the maintenance of appropriate mineral levels in the fetus, supporting its proper development. The mineral content in AF depends on maternal nutritional status and includes minerals excreted by fetal kidneys (Suliburska et al. 2016).

Table 2 presents correlations between magnesium concentration in MS and AF and maternal and fetal parameters. Across the entire study population, a significant positive correlation was observed between magnesium levels in MS and AF. Additionally, maternal serum magnesium concentration correlated positively with EFW. Furthermore, an inverse correlation was noted between magnesium concentration in amniotic fluid and gestational age.

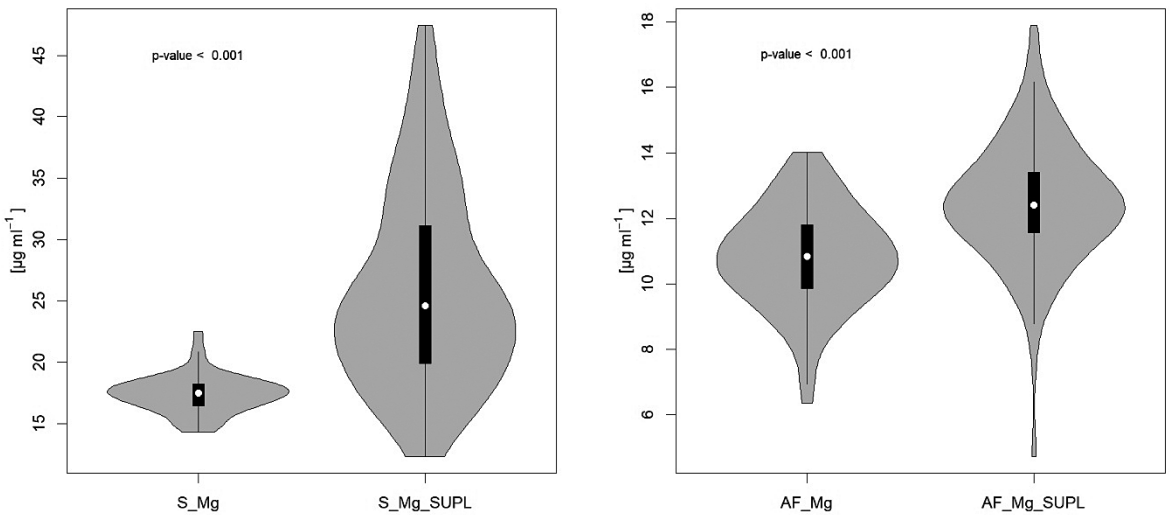


Fig. 1. Magnesium concentration (µg m^{-1}) in maternal serum and amniotic fluid. Supl denotes the group receiving magnesium supplementation. The lower part of the violin plot represents the minimum magnesium concentration, while the upper part represents the maximum magnesium concentration. The lower boundary of the black box indicates the lower quartile (Q1), and the upper boundary represents the upper quartile (Q3). The white dot inside the black box denotes the median value. *P* represents the significance level, with statistically significant differences set at P=0.05.

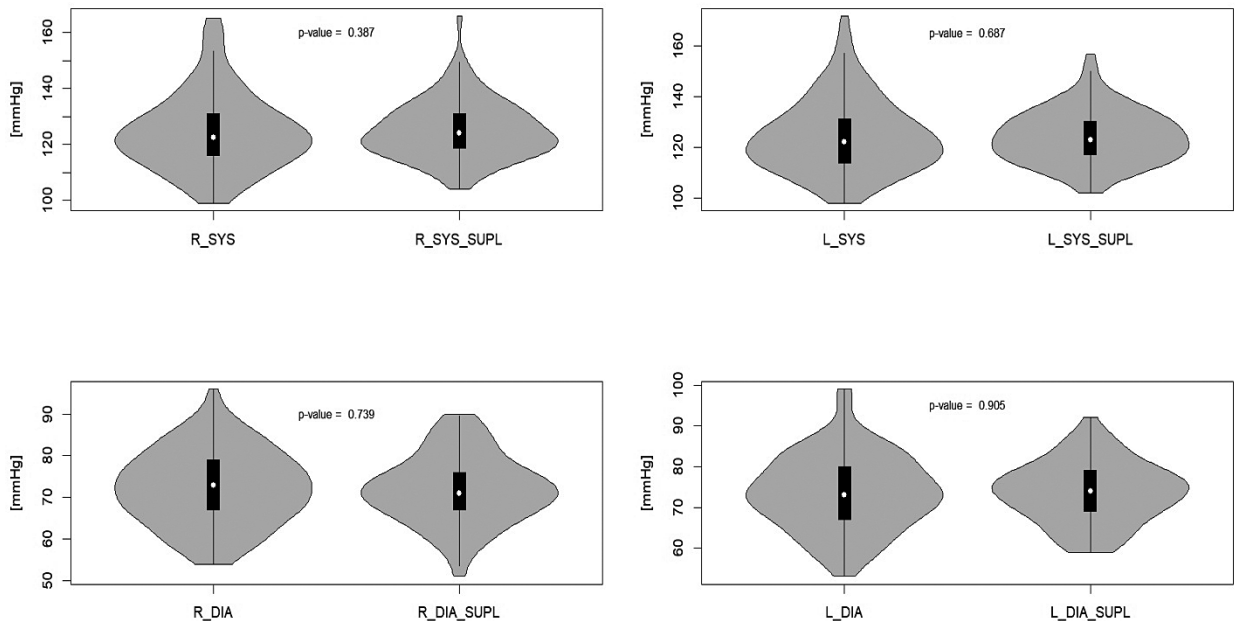


Fig. 2. Systolic and diastolic blood pressure (mm Hg) was measured in the left (L) and right (R) arms. SUPL denotes the group receiving magnesium supplementation. The lower part of the violin plot represents the minimum blood pressure value, while the upper part represents the maximum blood pressure value. The lower boundary of the black box indicates the lower quartile (Q1), and the upper boundary represents the upper quartile (Q3). The white dot inside the black box denotes the median value. *P* represents the significance level, with statistically significant differences set at P=0.05.

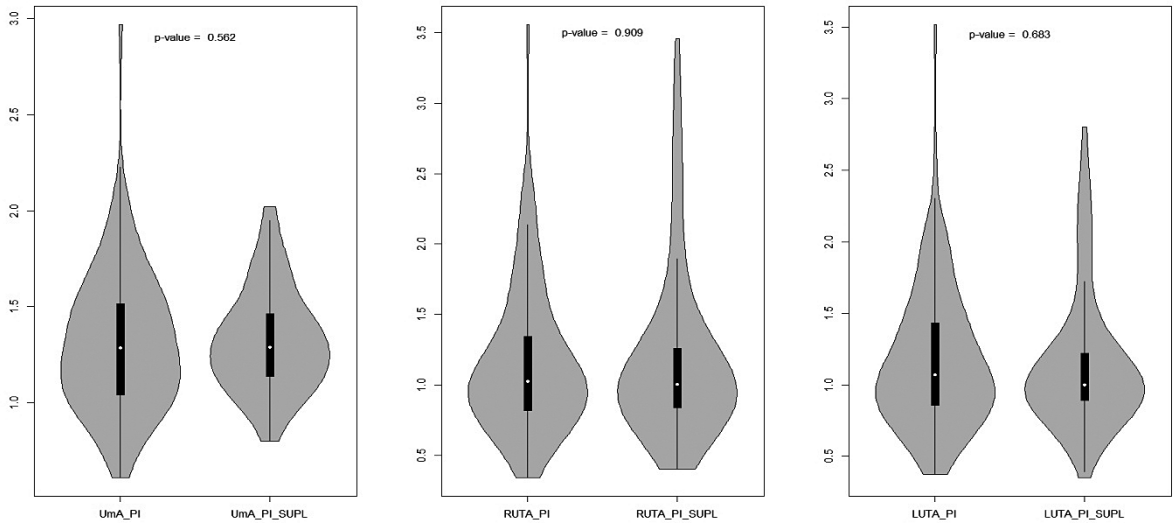


Fig. 3. Pulsatility index for the umbilical artery (UmA_PI), right uterine artery (RUTA_PI), and left uterine artery (LUTA_PI). *SUPL* denotes the group receiving magnesium supplementation. The lower part of the violin plot represents the minimum value, while the upper part represents the maximum value. The lower boundary of the black box indicates the lower quartile (Q1), and the upper range of the black box is the upper quartile (Q3). The white dot inside the black box denotes the median value. *P* represents the significance level, with statistically significant differences set at P=0.05.

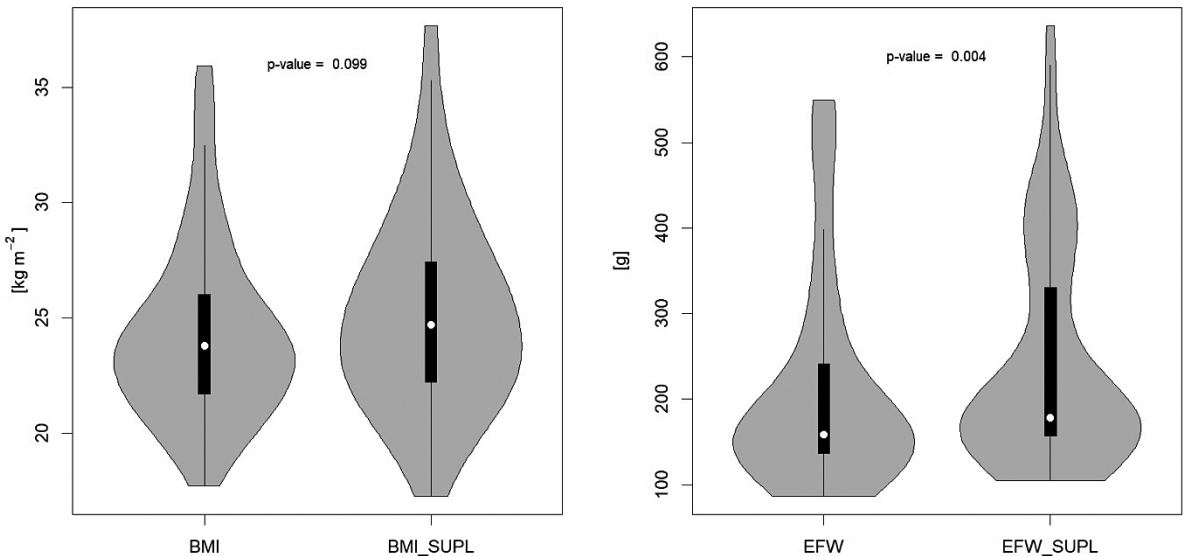


Fig. 4. Prepregnancy body mass index (kg m^{-2}) and estimated fetal weight (g). SUPL denotes the group receiving magnesium supplementation, BMI – body mass index, EFW – estimated fetal weight. The lower part of the violin plot represents the minimum value, while the upper part represents the maximum value. The lower boundary of the black box indicates the lower quartile (Q1), and the upper boundary represents the upper quartile (Q3). The white dot inside the black box denotes the median value. *P* represents the significance level, with statistically significant differences set at P=0.05.

Table 2

Correlations between magnesium concentration in maternal serum and amniotic fluid and maternal and fetal parameters

	Parameters	Correlation coefficient (R)	*P* value	CI 95% confidence interval for R
S_Mg	AGE	−0.09	0.1877	−0.230, 0.046
	BODY_MASS	0.04	0.5779	−0.100, 0.178
	BMI	0.01	0.9382	−0.133, 0.144
	L_SYS	0.04	0.6173	−0.104, 0.173
	L_DIA	0.09	0.226	−0.053, 0.222
	R_SYS	0.02	0.7571	−0.117, 0.160
	R_DIA	0.05	0.4948	−0.091, 0.186
	GRAVIDA	−0.11	0.1112	−0.248, 0.026
	WEEK	0.07	0.2925	−0.065, 0.211
	EFW	**0.16**	**0.0277**	**0.017, 0.288**
	AF_Mg	**0.36**	**<0.001**	**0.228, 0.471**
	UmA_PI	−0.001	0.9837	−0.140, 0.137
	RUTA_PI	−0.01	0.8733	−0.150, 0.128
	LUTA_PI	−0.04	0.5825	−0.177, 0.100
AF_Mg	AGE	0.12	0.0969	−0.021, 0.252
	BODY_MASS	0.02	0.7928	−0.120, 0.157
	BMI	0.01	0.8659	−0.127, 0.151
	L_SYS	0.02	0.773	−0.119, 0.159
	L_DIA	0.04	0.5918	−0.101, 0.176
	R_SYS	0.04	0.5689	−0.099, 0.178
	R_DIA	−0.01	0.836	−0.153, 0.124
	GRAVIDA	−0.01	0.8404	−0.153, 0.125
	WEEK	**−0.16**	**0.0256**	**−0.290, −0.0196**
	EFW	−0.04	0.5531	−0.180, 0.097
	UmA_PI	−0.06	0.3701	−0.201, 0.076
	RUTA_PI	0.03	0.6483	−0.107, 0.170
	LUTA_PI	−0.1	0.1488	−0.238, 0.0368

R – Spearman's rho, *p* – level of significance, statistical significance at $P<0.05$, CI – 95% confidence interval for R, BMI – body mass index, S_Mg – magnesium concentration in serum, AF_Mg – magnesium concentration in amniotic fluid, L_SYS – systolic blood pressure in the left hand, L_DIA – diastolic blood pressure in the left hand, R_SYS – systolic blood pressure in the right hand, R_DIA – diastolic blood pressure in the right hand, GRAVIDA – gravidity (number of all pregnancies), EFW – estimated fetal weight, AF_Mg – magnesium concentration in amniotic fluid, S_MG – magnesium concentration in serum, UmA_PI – umbilical artery pulsatility index, RUTA_PI – right uterine artery pulsatility index, LUTA_PI – left uterine artery pulsatility index

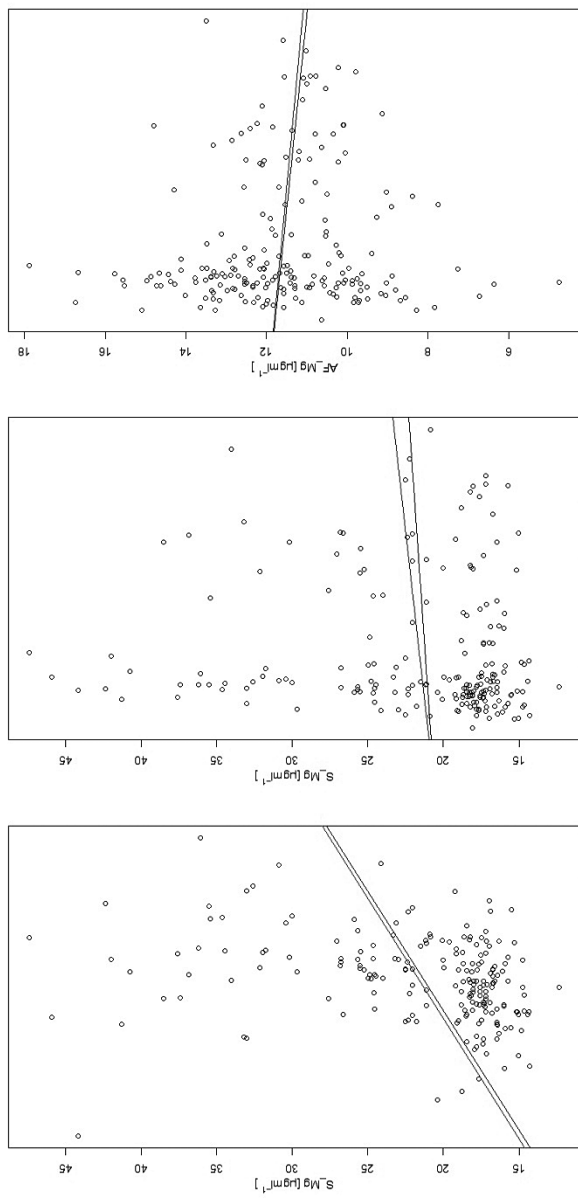


Fig. 5. Linear regression between parameters. The regression line (red) and the regression line (blue) adjusted for age, gravidity, gestational week, and prepregnancy body mass index are shown; S_Mg – magnesium concentration in serum, AF_Mg – magnesium concentration in amniotic fluid, EFW – estimated fetal weight

Standard linear regression was used to describe the relationships between parameters. Each regression model was adjusted for maternal age, weeks of gestation, gravidity, and BMI. A mixed model incorporating a fixed effect for magnesium concentration and random effects for confounding factors was developed. The regression line (red) and the regression line adjusted for confounders (blue) were plotted on the scatterplot (Figure 5). Linear regression analysis indicated that confounders had a negligible impact on the observed relationships.

Finding positive correlation between maternal serum and AF magnesium concentrations suggests that AF magnesium levels may reflect maternal magnesium status and indirectly indicate fetal magnesium content. Additionally, an inverse correlation was observed between AF magnesium concentration and gestational age, aligning with previous findings that magnesium levels decrease as pregnancy progresses (Suliburska et al. 2016). This decline may be linked to fetal growth and the utilization of magnesium for tissue development. Jalali and Koski (2018) also reported that AF mineral content, including magnesium, is associated with fetal growth in both early and late pregnancy. However, their study found that prenatal supplement use did not affect birth weight (Jalali, Koski 2018).

In contrast, this study observed higher EFW in pregnant women who received magnesium supplementation. The positive correlation between MS magnesium concentration and fetal weight underscores the importance of adequate maternal magnesium levels for fetal health and subsequent neonatal outcomes. This relationship suggests that maintaining optimal magnesium status during the first and second trimesters significantly influences fetal growth during this critical period. Magnesium ions are essential for placental development and fetal growth, while magnesium deficiency during pregnancy has been associated with placental abnormalities and fetal growth restriction (Schlegel et al. 2015). Animal studies have demonstrated that magnesium ions play a vital role in early embryonic development (An et al. 2019). Additionally, human studies indicate that low mineral levels, including magnesium, in the first trimester increase the risk of spontaneous miscarriage (Sairoz et al. 2023).

It is important to note that although both study groups had an equal median gestational age, the supplemented group had a slightly higher mean and range of gestational weeks, which may have influenced the results. As pregnancy progresses, fetal weight increases, but magnesium levels in serum and amniotic fluid decrease. Magnesium supplementation likely replenishes magnesium losses during pregnancy, which is why we observed a positive correlation between serum magnesium concentration and EFW. The significant correlation observed between MS magnesium and EFW strongly supports the role of maternal magnesium status in fetal growth.

Unexpectedly, this study did not identify any association between magnesium supplementation and blood pressure or blood flow in the umbilical

and uterine arteries. Although magnesium supplementation has been suggested to reduce the risk of preeclampsia, some studies have not found a clear effect on blood pressure during pregnancy (Bullarbo et al. 2018).

However, several studies have reported improved blood flow in the umbilical, uterine, and fetal cerebral arteries in pregnant women receiving magnesium supplementation (Maged et al. 2016, Xing et al. 2024). Notably, significant effects of magnesium on blood pressure and blood flow in maternal and fetal arteries are primarily observed in studies involving women with severe preeclampsia. This study included healthy women without hypomagnesemia, and the incidence of chromosomal aberrations was low and comparable between groups. In healthy pregnant women, magnesium supplementation is likely to have a less pronounced effect on maternal and fetal parameters.

The results obtained in this study may indicate the need for magnesium supplementation in pregnant women, but interventional studies are necessary to formulate recommendations.

Strengths and limitations

This study has several strengths and limitations. One key strength was the collection of data from pregnant women in the second trimester, with equal group sizes. Additionally, magnesium levels were analyzed in both maternal serum and amniotic fluid, providing a comprehensive assessment.

However, this study did not account for magnesium intake from dietary sources, which is a limitation. Furthermore, data on the specific dose, type of magnesium salt, or form of supplementation used by participants were not collected.

CONCLUSION

Magnesium supplementation started in the first trimester of pregnancy is effective in increasing magnesium concentrations in maternal serum and amniotic fluid in the second trimester. This supplementation may contribute to improved fetal development by increasing fetal weight. Moreover, magnesium concentration in amniotic fluid may serve as a supplementary marker for monitoring maternal and fetal magnesium status during pregnancy.

Further intervention studies, including magnesium intake and the dose and type of magnesium salt in the supplement used, are necessary to formulate recommendations for magnesium supplementation in pregnant women.

Author contributions

J.S. – conceptualization, methodology, formal analysis, resources, data curation, writing-original draft, supervision, funding acquisition, visualiza-

tion, writing-review & editing, R.C. – methodology, formal analysis, data curation, P.W. – investigation, data curation, K.S. – investigation, data curation, E.B. – software, formal analysis, funding acquisition, CvK – supervision, R.K. – conceptualization, investigation, methodology, data curation, resources, supervision, project administration, funding acquisition. All authors have read and agreed to the published version of the manuscript.

ACKNOWLEDGMENTS

The scientific activity of the Institute of Mathematics, Poznań University of Technology was funded under grant no. 0213/SBAD/0119.

We are grateful to Translmed Publishing Group (https://translmed.com/) for language correction.

Conflicts of interest

The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

REFERENCES

Adams, J.B. et al. (2021) 'Evidence-based recommendations for an optimal prenatal supplement for women in the U.S., part two: Minerals', *Nutrients*, 13(6), 1-28, available: https://doi.org/10.3390/nu13061849

An, L. et al. (2019) 'Magnesium is a critical element for competent development of bovine embryos', *Theriogenology*, 140, 109-116, available: https://doi.org/10.1016/j.theriogenology.2019.08.015

Asemi, Z. et al. (2015) 'Magnesium supplementation affects metabolic status and pregnancy outcomes in gestational diabetes: A randomized, double-blind, placebo-controlled trial', *American Journal of Clinical Nutrition*, 102(1), 222-229, available: https://doi.org/10.3945/ajcn.114.098616

Bocos Terraz, J.P. et al. (2011) 'Magnesium concentration in amniotic fluid in the early weeks of the second trimester of pregnancy', *BMC Research Notes*, 4(1), 185, available: https://doi.org/10.1186/1756-0500-4-185.

Bullarbo, M. et al. (2018) 'Magnesium supplementation and blood pressure in pregnancy: A double-blind randomized multicenter study', *Journal of Pregnancy*, 2018, available: https://doi.org/10.1155/2018/4843159

Chiarello, D.I. et al. (2018) 'Mechanisms of the effect of magnesium salts in preeclampsia', *Placenta*, 69, 134-139, available: https://doi.org/10.1016/j.placenta.2018.04.011

Dalton, L.M. et al. (2016) 'Magnesium in pregnancy', *Nutrition Reviews*, 74(9), 549-557, available: https://doi.org/10.1093/nutrit/nuw018

García Alonso, L. et al. (2018) 'Prenatal Therapy with Magnesium Sulfate and Its Correlation with Neonatal Serum Magnesium Concentration', *American Journal of Perinatology*, 35(2), 170-176, available: https://doi.org/10.1055/s-0037-1606358

Guerrero-Romero, F. et al. (2015) 'Oral magnesium supplementation improves glycaemic status in subjects with prediabetes and hypomagnesaemia: A double-blind placebo-controlled randomized trial', *Diabetes and Metabolism*, 41(3), 202-207, available: https://doi.org/10.1016/j.diabet.2015.03.010

Hansu, K. and Cikim, I.G. (2022) 'Vitamin and mineral levels during pregnancy', *Revista da Associacao Medica Brasileira*, 68(12), 1705-1708, available: https://doi.org/10.1590/1806-9282.20220769

Hao, Y. et al. (2024) 'Reduction in Placental Metal and Metalloid in Preeclampsia: A Case-Control Study', *Nutrients*, 16(6), available: https://doi.org/10.3390/nu16060769

Jalali, L.M. and Koski, K.G. (2018) 'Amniotic fluid minerals, trace elements, and prenatal supplement use in humans emerge as determinants of fetal growth', *Journal of Trace Elements in Medicine and Biology*, 50(June), 139-145, available: https://doi.org/10.1016/j.jtemb.2018.06.012

Kanasaki, K. and Kumagai, A. (2021) 'The impact of micronutrient deficiency on pregnancy complications and development origin of health and disease', *Journal of Obstetrics and Gynaecology Research*, 47(6), 1965-1972, available: https://doi.org/10.1111/jog.14770

Kawasaki, K. et al. (2019) 'Metabolomic profiles of placenta in preeclampsia: Antioxidant effect of magnesium sulfate on trophoblasts in early-onset preeclampsia', *Hypertension*, 73(3), 671-679, available: https://doi.org/10.1161/HYPERTENSIONAHA.118.12389

Kocyłowski, R. et al. (2018) 'Assessment of dietary intake and mineral status in pregnant women', *Archives of Gynecology and Obstetrics*, 297(6), 1433-1440, available: https://doi.org/10.1007/s00404-018-4744-2

Luo, L. et al. (2024) 'The efficacy of magnesium supplementation for gestational diabetes: A meta-analysis of randomized controlled trials', *European Journal of Obstetrics and Gynecology and Reproductive Biology*, 293(August 2023), 84-90, available: https://doi.org/10.1016/j.ejogrb.2023.12.014

Maged, A.M. et al. (2016) 'The effect of loading dose of magnesium sulfate on uterine, umbilical, and fetal middle cerebral arteries Doppler in women with severe preeclampsia: A case control study', *Hypertension in Pregnancy*, 35(1), 91-99, available: https://doi.org/10.3109/10641955.2015.1116552

McEvoy, J.W. et al. (2024) '2024 ESC Guidelines for the management of elevated blood pressure and hypertension', *European Heart Journal*, 3912-4018, available: https://doi.org/10.1093/eurheartj/ehae178

Ren, Q. et al. (2023) 'The Association Between Serum Magnesium Levels and Gestational Diabetes Mellitus: a Systematic Review and Meta-Analysis', *Biological Trace Element Research*. Springer, 5115-5125, available: https://doi.org/10.1007/s12011-023-03591-6

Ryan, B.A. and Kovacs, C.S. (2020) 'Calciotropic and phosphotropic hormones in fetal and neonatal bone development', *Seminars in Fetal and Neonatal Medicine*. W.B. Saunders Ltd, available: https://doi.org/10.1016/j.siny.2019.101062

Sairoz et al. (2023) 'Maternal Serum Zinc, Copper, Magnesium, and Iron in Spontaneous Abortions', *Indian Journal of Clinical Biochemistry*, 38(1), 128-131, available: https://doi.org/10.1007/s12291-022-01043-x

Schlegel, R.N. et al. (2015) 'Maternal hypomagnesemia causes placental abnormalities and fetal and postnatal mortality', *Placenta*, 36(7), 750-758, available: https://doi.org/10.1016/j.placenta.2015.03.011

Sethi, A., Priyadarshi, M. and Agarwal, R. (2020) 'Mineral and bone physiology in the foetus, preterm and full-term neonates', *Seminars in Fetal and Neonatal Medicine*, 25(1), 101076, available: https://doi.org/10.1016/j.siny.2019.101076

Skrypnik, K. et al. (2024) 'Association between serum levels of calcium, magnesium, iron and copper and insulin resistance in women with full blown and not-full blown phenotypes of polycystic ovary syndrome', *Ginekologia Polska*, 95(10), 770-778, available: https://doi.org/10.5603/gpl.98015

Suliburska, J. et al. (2016) 'Concentrations of Mineral in Amniotic Fluid and Their Relations to Selected Maternal and Fetal Parameters', *Biological Trace Element Research*, 172(1), 37-45, available: https://doi.org/10.1007/s12011-015-0557-3

Suliburska, J. et al. (2022) 'Association between the Concentrations of Essential and Toxic Elements in Mid-Trimester Amniotic Fluid and Fetal Chromosomal Abnormalities in Pregnant Polish Women', *Diagnostics*, 12(4), available: https://doi.org/10.3390/diagnostics 12040979

Xing, B. et al. (2024) 'Magnesium sulfate improves blood flow of uterine, umbilical, and fetal middle cerebral arteries in women with severe preeclampsia at 30-34 gestational weeks', *Hypertension in Pregnancy*, 43(1), p. 2404459, available: https://doi.org/10.1080/10641955. 2024.2404459

Yuan, J. et al. (2022) 'Oral Magnesium Supplementation for the Prevention of Preeclampsia: a Meta-analysis or Randomized Controlled Trials', *Biological Trace Element Research*, 200(8), 3572-3581, available: https://doi.org/10.1007/s12011-021-02976-9