Journal of Elementology ISSN 1644-2296

Gryszczyńska, B., Grupińska, J., Kasprzak, M., Krasiński, Z. and Iskra, M. (2025) 'Calcium, magnesium and iron blood plasma levels in abdominal aortic aneurysm: The effects of pre- and postoperative treatment', *Journal of Elementology*, 30(4), 699-714, available: https://doi.org/10.5601/jelem.2025.30.1.3530

RECEIVED: 5 March 2025
ACCEPTED: 4 October 2025

ORIGINAL PAPER

Calcium, magnesium and iron blood plasma levels in abdominal aortic aneurysm: The effects of pre- and postoperative treatment*

Bogna Gryszczyńska[1], Joanna Grupińska[1], Magdalena P. Kasprzak[1], Zbigniew Krasiński[2], Maria Iskra[1]

[1] Chair and Department of Medical Chemistry and Laboratory Medicine
[2] Department of Vascular, Endovascular Surgery, Angiology and Phlebology
Poznan University of Medical Science, Poznan, Poland

Abstract

The risk of an abdominal aortic aneurysm (AAA), a life-threatening condition, is increased by a number of factors, such as older age, male sex, hypertension, smoking, and coronary heart disease. The pathophysiology of an AAA is complex, and some studies emphasize the degradation of connective tissues, genetic determinants, inflammation, as well as oxidative stress. However, maintaining the homeostasis of certain macroelements and microelements may decrease chronic inflammation and oxidative stress. The aim of the present study was to evaluate the effects of pre- and postoperative treatment on the levels of calcium (Ca), magnesium (Mg) and iron (Fe) in AAA patients qualified for surgery. The study involved 40 AAA patients, divided into two groups based on interviews and clinical examination: a high-surgical-risk (EVAR) group included 20 patients, and a low-surgical-risk (OR) group also comprised 20 patients. Mg, Ca and Fe levels were measured using colorimetric assay kits. The concentrations of Ca, Mg and Fe did not differ between the OR and EVAR groups prior to surgery. Postoperatively, the tendency to a decrease in Mg levels was observed in the OR group (1 day after surgery: 2.11±0.36 mg dl^{-1}; 2-4 days after surgery: 1.81±0.56 mg dl^{-1}). Moreover, the OR group demonstrated significantly lower Mg levels in comparison to EVAR 2-4 days after surgery, and Fe levels were considerably lower both in the OR and EVAR groups postoperatively, as compared to the values observed before surgery. According to the results, AAA development did not affect blood levels of Ca, Mg and Fe. However, OR procedures contributed to a decrease in Mg levels during the postoperative period and postoperative treatment reduced plasma concentration of Fe, regardless of the type of surgery.

Keywords: calcium, magnesium, iron, abdominal aortic aneurysm, open surgical and endovascular aneurysm repair

Bogna Gryszczyńska, PhD, Assoc. Prof., Department of Medical Chemistry and Laboratory Medicine, Poznan University of Medical Sciences, Rokietnicka 8, 60-806 Poznan, Poland, e-mail: bognagry@ump.edu.pl

* This study was financially supported by Poznan University of Medical Sciences

INTRODUCTION

Abdominal aortic aneurysm (AAA) constitutes a life-threatening condition, and its early diagnosis, treatment and perioperative care significantly affect the patient's prognosis (Kośmicki 2024). Clinical and epidemiological studies have revealed a highly complex pathogenesis of AAA. Currently, both the basic mechanisms underlying the formation of abdominal aortic aneurysms, such as the proteolytic degradation of aortic wall connective tissue, as well as the risk factors, including male sex, tobacco smoking, and genetic conditions, have been identified (Jawien et al. 2014, Kuivaniemi et al. 2015).

In terms of the pathogenesis of AAA, the role of oxidative stress is being increasingly emphasized (Guzik et al. 2013, Gryszczyńska et al. 2017). Generation of reactive oxygen species (ROS) depends on the increased activity of ROS-generating systems, such as NADPH oxidase, as well as on the decreased levels or activities of endogenous and exogenous antioxidants, such as superoxide dismutase, glutathione peroxidase, glutathione and polyphenols (McCormick et al. 2007, Guzik et al. 2013, Wiernicki et al. 2019). Moreover, enhanced ROS production may result in progressive cell and tissue damage, play an essential role in activating matrix metalloproteinases (MMPs), and induce vascular smooth muscle cell apoptosis (Guzik et al. 2013, Wiernicki et al. 2019). In fact, numerous studies have demonstrated associations between oxidative stress parameters, aneurysm size and significant risk factors in AAA patients (Guzik et al. 2013, Budzyń et al. 2017, Gryszczyńska et al. 2017).

Open surgical repair of AAA (OR) is a highly complex and burdensome treatment (Schanzer, Oderich 2021). The up-to-date research clearly indicates that the ischemia-reperfusion phenomenon, which occurs during OR, generates ROS and may therefore increase oxidative stress (Miller et al. 2002, Wiernicki et al. 2019, Schanzer and Oderich 2021). Therefore, in view of the high risk of complications associated with conventional surgery, particularly in patients with comorbidities, less invasive treatments for AAA have been developed. A minimally invasive procedure referred to as endovascular aneurysm repair (EVAR) significantly minimizes the risk of intraoperative and postoperative complications (Siwko et al. 2016) Additionally, since there is no need for abdominal aorta clamping, the risk of ischemia-reperfusion injury is eliminated, thereby limiting the induction of oxidative stress during conventional surgery when blood circulation is restored.

Maintaining the homeostasis of macro- and microelements may restrict chronic inflammation and oxidative stress. Although various studies have shown the beneficial effects of magnesium homeostasis and magnesium supplementation on the cardiovascular system, it is of note that patients especially elderly ones with concomitant diseases, frequently develop hypomagnesemia. Researchers have demonstrated that reduced magnesium levels result in the activation of inflammation via leukocyte and macrophage activation, the release of inflammatory cytokines, including Il-1 and Il-6 and acute-phase proteins, such as C-reactive protein and fibrinogen, as well as in an increased generation of ROS (Jolly et al. 2015, Liu and Dudley 2020). Furthermore, an association between circulating Ca concentrations and myocardial infarction or cardiovascular disease (CVD) has also been reported (Reid et al. 2017). The Calcium-Sensing Receptor (CaSR) is a pivotal regulator for serum Ca balance that controls Ca excretion by the kidneys, regulates PTH release from the parathyroid glands, and plays an essential function in inflammatory response in several tissues and in cancer development. Ca ions may act as second messengers and stimulate cytokine secretion, promoting inflammation and immune cell activation (Olszak et al. 2000, Reid et al. 2017). In the case of Mg ions deficiency, cellular Ca ions level increase extracellular inflow via Ca channels, which constitutes the primary mechanism of inflammation stress triggered by Mg deficiency (Nielsen 2018). Fe homeostasis is strongly associated with iron absorption, transportation, utilization, and storage (Sawicki et al. 2023, Wang et al. 2024), whereas the proper functioning of the cardiovascular system is related to the mitochondrial function, which depends on appropriate iron levels (Budzyń et al. 2017, Gryszczyńska et al. 2017, Sawicki et al. 2023). The potential mechanisms that promote the development of CVD include oxidative stress, inflammation, endothelial dysfunction and disturbed lipid metabolism, which are based on iron accumulation causing the activation of numerous signaling pathways, such as increased ROS generation, lipid peroxidation, induction of endothelial dysfunction, and increase in proinflammatory macrophages (Sawicki et al. 2023). Cytokines and metalloproteinases (MMP-2 and MMP-9) secreted by macrophages in the aortic wall cause aortic structural disruption which, in turn, leads to aneurysm formation and rupture (Sawada et al. 2015, Kawakatsu et al. 2024)

The present study aimed to evaluate the effects of postoperative treatment on Ca, Mg, and Fe levels in AAA patients qualified for surgery. The authors determined the impact of the patients' condition before surgery, surgical techniques implemented, and the resulting postoperative treatment on the level of the abovementioned elements.

MATERIALS AND METHODS

Patients

The study protocol followed the ethical standards outlined in the World Medical Association's Declaration of Helsinki. Every participant met the inclusion criteria and completed the study. Prior to starting the project, the study was approved by the Bioethical Committee of Poznan University of Medical Sciences (approval number 854/14). All participants completed a thorough interview, underwent clinical examination, and their medical history was carefully reviewed based on hospital and outpatient records. The exclusion criteria involved diabetes mellitus, an active acute infection at present or within the past month, immunosuppressive therapy, a history of tumors within the last 5 years, or a history of smoking and/or alcohol abuse in the past 5 years. The most significant characteristics of the studied groups, including pre-operative clinical data, diagnosed comorbidities, medications received by certain patients, as well as the biochemical parameters of all the participants are presented in Figure 1. The study group consisted of 40 AAA patients admitted to the Department of Vascular, Endovascular Surgery, Angiology and Phlebology of Poznan University of Medical Sciences, Poland. On the basis of the interviews and clinical examinations, the participants were divided into two groups, i.e., a low-surgical-risk and eligible for open repair group (OR group – 20 men), and a high-surgical-risk group (EVAR group – 20 men).

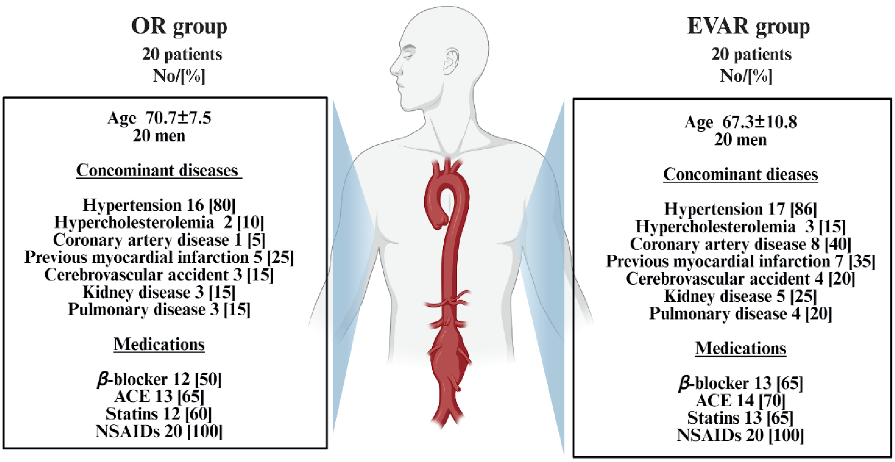

Fig. 1. Characteristics of the study groups. Created with BioRender.com

Sample collection

Venous blood samples were obtained pre-operatively, before the induction of anesthesia (referred to as "before surgery"), and postoperatively: 1 day after the surgery ("1 day after surgery") and 2-4 days after the operation ("2-4 days after surgery"). The venipuncture site was located on the patients' arms, and samples were collected in the recumbent position into heparin anticoagulant tubes. Subsequently, the tubes were centrifuged at 3.000 rpm for 15 min, and plasma samples were stored at −80°C until all assays were performed.

Ca, Mg and Fe concentration

Plasma calcium (Ca), magnesium (Mg) and iron (Fe) concentrations were measured using the commercially available Biomaxima kit (Biomaxima, Poland). Arsenazo III sodium salt was used to measure Ca ions concentrations. As a result of the reaction, blue complex is formed, which may be analyzed spectrophotometrically at 630-670 nm. According to the procedure, Mg ions form a purple product with Xylydil Blue I, which may undergo spectrophotometric analysis at 490-520 nm. The iron colorimetric assay kit is designed to measure the reaction between ferrous ions (obtained via prior reduction of ferric ions by sodium ascorbate) and ferrozine, forming a colored product with an absorbance maximum at 560 nm. In terms of the magnesium concentration measuring kit, the manufacturer provides the following data: limit of detection: 0.01 mg dl^{-1} or 0.004 mmol l^{-1}; precision within run: % CV < 1.00%. In terms of the calcium concentration measuring kit, the manufacturer provides the following data: limit of detection: 0.1 mg dl^{-1} or 0.03 mmol/l; precision within run: % CV < 1.50%. In terms of the iron concentration measuring kit, the manufacturer provides the following data: limit of detection: < 10 μg dl^{-1} or < 1.8 μmol l^{-1}; precision within run: % CV < 2.00%. More parameters are listed in the manual procedures and details of the correlation study are available on request.

Statistical analysis

Statistical analysis was conducted using GraphPad Prism software 9.0 (GraphPad Software, San Diego, CA). The Kolmogorov-Smirnov, Shapiro-Wilk, and D'Agostino & Pearson tests were used for normal distribution testing. Normally distributed, continuous variables were analyzed using the Student's *t*-test, whereas data which did not follow Gaussian distribution were analyzed using the Mann-Whitney test. A one-way analysis of variance (ANOVA) was used in order to determine whether any statistically significant differences between the mean values of the investigated parameters were observed before surgery, 1 day, as well as 2-4 days after surgery in both studied groups. The Pearson or the Spearman's correlation coefficients were used to test the strength of any associations between different variables. In all cases, a value ≤ 0.05 was considered significant.

RESULTS

The mean levels of Ca, Mg and Fe concentrations (Figures 2, 3 and 4, respectively) were within the reference range, and did not differ between the studied patient groups before the surgery (OR: Ca=8.32±0.98 mg dl^{-1}, Mg=2.18±0.26 mg dl^{-1}, Fe=61.94±19.98 μg dl^{-1}, EVAR: Ca=8.50±0.88 mg dl^{-1}; Mg=2.11±0.33 mg dl^{-1}; Fe=53.29 ±21.60 μg dl^{-1}). The data presented in Figure 2 show insignificant changes in Ca concentrations obtained on the first day following the procedure (OR: 7.75±1.08 mg dl^{-1}; EVAR: 8.07±1.27 mg dl^{-1}), as well as those observed 2-4 days after the surgery (OR: 7.95±2.69 mg dl^{-1};

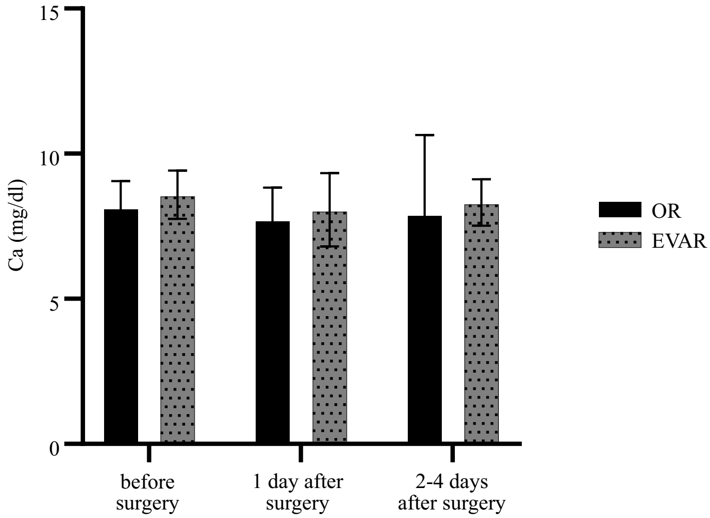

Fig. 2. Blood plasma Ca ions levels of patients qualified for OR or EVAR before surgery and during postoperative treatment. The results are presented as a mean and standard deviation

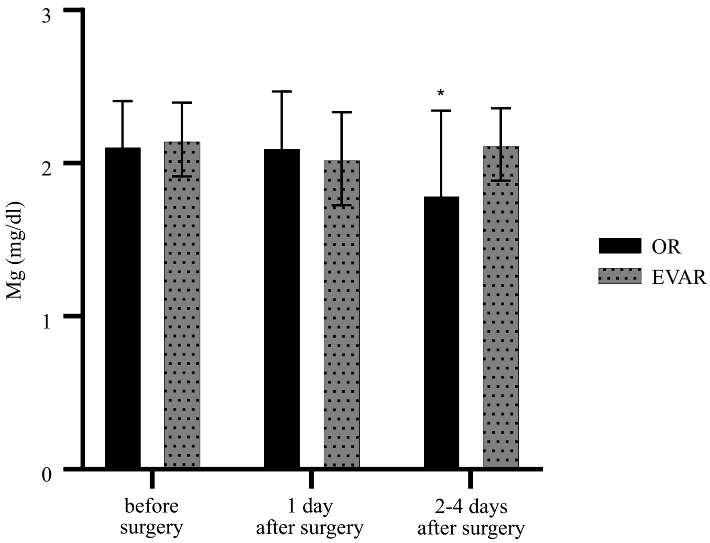

Fig. 3. Blood plasma Mg ion levels of patients qualified for OR or EVAR before surgery and during postoperative treatment. The results are presented as a mean and standard deviation. * Significant difference vs. EVAR 2-4 days after surgery (analyzed using the Mann-Whitney test), $P \leq 0.05$ was considered statistically significant

EVAR: 8.32±0.80 mg dl^{-1}), as compared to the pre-operative values, respectively. No significant differences were found between Ca levels on the first day and 2-4 days after OR and EVAR procedures.

Furthermore, there were no significant differences in Mg levels between the postoperative (1 day after: 2.03±0.30 mg dl^{-1}, 2-4 days after:

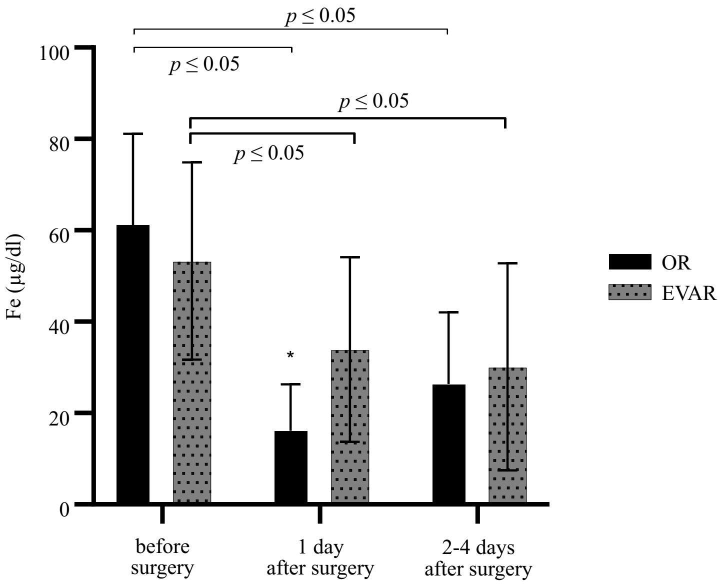

Fig. 4. Blood plasma Fe ion levels of patients qualified for OR or EVAR before surgery and during postoperative treatment. The results are presented as a mean and standard deviation. The data were analyzed using the Friedman test, followed by the Dunn's multiple comparison test. * Significant difference vs. EVAR 1 day after surgery (analyzed with the Mann-Whitney test). $P \leq 0.05$ was considered statistically significant

2.12±0.24 mg dl^{-1}) and pre-operative values in the EVAR group (2.15±0.24 mg dl^{-1}) – Figure 3. In the case of OR surgery, a decrease in Mg levels was observed postoperatively (1 day after: 2.11±0.36 mg dl^{-1}; 2-4 days after: 1.81±0.56 mg dl^{-1}) – Figure 3. Additionally, a significantly lower Mg concentration in the OR group was found 2-4 days after surgery in comparison to the EVAR group.

A statistically significant decrease in Fe level was demonstrated both in the OR and EVAR groups in the postoperative period (OR 1 day after surgery: 16.80±10.17 µg dl^{-1}, 2-4 days after: 27.02±15.72 µg dl^{-1}; EVAR 1 day after: 33.95±20.21 µg dl^{-1}, 2-4 days after: 30.12±22.70 µg dl^{-1}) as compared to the values prior to surgery (OR: 61.94±19.98 µg dl^{-1}; EVAR: 53.29 ±21.60 µg dl^{-1}) – Figure 4. Notably, the patients who qualified for OR presented significantly lower Fe concentrations than the EVAR group on the first day following the procedure (OR median and range: 12.82 (6.56-44.00) µg dl^{-1}; EVAR median and range: 28.70 (10.90- 94.36) µg dl^{-1}, P=0.0009).

The plasma Ca/Mg ratio in both studied groups is shown in Figure 5. No differences were observed in the Ca/Mg ratio between the OR and EVAR patients before (OR: 4.05±0.51; EVAR: 4.04±0.78) on the first (OR: 3.80±0.55, EVAR: 4.05±0.83) and 2-4 days after surgery (OR: 4.38±0.86, EVAR: 3.97±0.63). However, an increase in the Ca/Mg ratio was found during the postoperative treatment (2-4 days after surgery) in comparison to the values

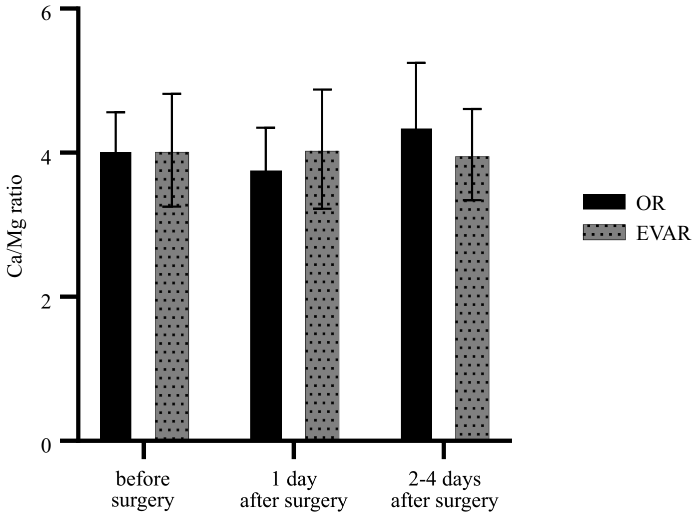

Fig. 5. Blood plasma Ca/Mg ion ratio of patients qualified for OR or EVAR before surgery and during postoperative treatment. The results are presented as a mean and standard deviation

demonstrated before surgery in the OR group. It is vital to note that in each studied time interval in both groups, the mean Ca/Mg ratio, as well as each ratio analyzed separately for individual patients were markedly above the optimal 2:1 balance.

In the present study, the authors verified the correlations between the diameter of the aneurysm and the studied parameters, including ion levels and inflammation parameters. Figure 6 presents the correlation between aneurysm diameter and Mg concentration in patients qualified for the EVAR procedure (Spearman r= -0.6913; P=0.0002).

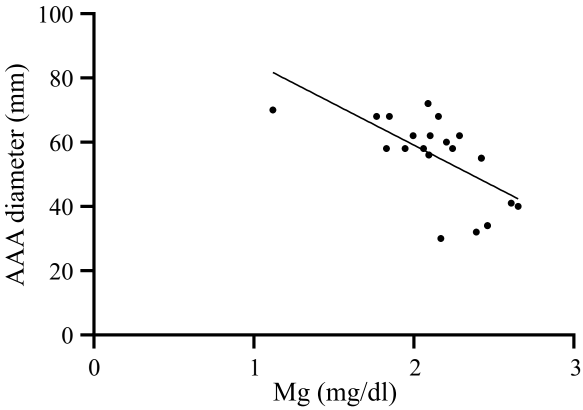

Fig. 6. The correlation between Mg levels and the diameter of the aneurysm in abdominal aortic aneurysm (AAA) patients qualified for the EVAR procedure. The Spearman's correlation coefficient r=-0.6913, P=0.0002

DISCUSSION

Magnesium is crucial for the appropriate functioning of the body's energy system. It is a co-factor of various biological reactions catalyzed by enzymes; it is also involved in glucose regulation and the synthesis of proteins, etc. (Kalita et al. 2017). Numerous studies indicate an association between magnesium deficiency and a number of diseases, such as hypertension, atherosclerosis, cardiac arrhythmias, dyslipidemia, metabolic syndrome, osteoporosis, and neuropsychiatric disorders (Cieslewicz et al. 2013, Liu et al. 2020). It is of note that the majority of the Polish population is characterized by an insufficient supply of Mg (61%-90% of men and 52%-70% women), and the issue continues to exacerbate (Jędrzejek et al. 2021) Moreover, it has been suggested that hypomagnesemia may promote oxidative stress (Malinowska et al. 2020), and that hypo- or hypermagnesemia may be associated with an increased risk of in-hospital mortality (Singh et al. 2016, Parotto, Djaiani 2019).

The present study found that Mg concentrations for individual patients and the mean Mg levels in both groups before the surgery were within the reference range despite the advanced age of patients and concomitant diseases. The analysis of postoperative treatment revealed the tendency to decrease Mg concentrations 2-4 days after OR surgery compared to the values found before and one day after the intervention. Such a tendency was not observed in patients qualified for EVAR intervention. Even though Mg levels remain in the reference range postoperatively, the decrease compared to the value found before surgery may suggest that the changes in electrolyte composition strongly depend on surgery severity – which is reflected in a significant reduction in the Mg level in the OR group versus the EVAR group 2-4 days after surgery.

The issue of surgical trauma and its impact on both fluid volume and electrolyte composition, postoperative discomfort and the average time of postoperative hospitalization was frequently discussed in various papers. Lambe et al. (2018) studied serum Mg levels in patients undergoing emergency surgeries (Group I) and planned surgical procedures (Group II). They found a significant decrease in Mg concentrations in both groups on postoperative days 3 and 6 compared to the pre-operative period, respectively. In fact, Mg levels were significantly higher in Group II than in Group I both pre-operatively and postoperatively. Jolly K et al. (2015) demonstrated hypomagnesemia in 73% of individuals who qualified for the elective open repair (OR) and in 32% of the EVAR patients (the difference was statistically significant) [29]. Nevertheless, they did not observe a correlation between serum Mg levels and the length of hospitalization in both studied groups, although they also reported several inpatient deaths in the OR group (Jolly et al. 2015). Similarly to the findings mentioned above, in our study, a comparison of two different surgical techniques demonstrated that the more severe procedure resulted in a decrease in Mg levels, noted 2-4 days after the procedure. It is worth bearing in mind that stress, accompanying each surgical intervention, affects the endocrine system involved in the release of corticosteroid hormones, thereby elevating renal Mg excretion, which in turn, may lead to hypomagnesemia (Sigel et al. 2013).

In contrast, plasma total Mg levels, measured in the course of the current study, is a parameter commonly used in clinical practice, which, however, does not provide comprehensive information regarding the body's Mg status (Malinowska *et at*. 2020) Some authors suggest that the ionized Mg level, which represents 55–70% of total magnesium and is a biologically active fraction, is a more suitable marker of disorders associated with Mg metabolism and the Mg blood concentration (Munoz et al. 2000, Iskra et al. 2005) It seems that measuring Mg levels in erythrocytes and estimating the plasma ionized/total Mg ratio would be a better tool aiming to reflect Mg changes during postoperative treatment. Interestingly, certain studies suggest that analyzing the 24-hour urine excretion of Mg provides reliable data with regard to Mg metabolism. This stems from the fact that reduced urinary Mg excretion indicates increased Mg embedding to the bones, whereas Mg load excretion above 60% should exclude Mg deficiency (Jahnen-Dechent and Ketteler 2012).

Due to interactions between different organ systems and the interdependence of Mg with K and Ca in maintaining body homeostasis, the biology of Mg is complex (Malinowska et al. 2020). Additionally, as a natural Ca channel antagonist, Mg prevents the maturation of calciprotein particles and hydroxyapatite formation (Afonso et al. 2022, Ter Braake et al. 2022). In recent years, it has been emphasized that these two cations should be analyzed together rather than separately, since a blood plasma Ca/Mg ratio above 2:1 has been associated with an elevated risk of inflammatory and cardiovascular disorders, as well as with renal and metabolic dysfunctions (Li et al. 2019) Some studies have suggested that there is a relation between higher calcium–magnesium ratios in hair and a more significant coronary artery calcification (Park et al. 2017). Iskra et al. (1997) demonstrated that AAA patients presented higher Ca/Mg, Ca/Zn, Mg/Zn and Mg/Cu ratios in the plasma than in atherosclerosis obliterans (AO) individuals. They also found positive correlations between Ca and Mg in the arterial wall of AAA and AO subjects. Furthermore, according to their study, higher levels of Ca, Mg, Zn and Cu were observed in the plaque than in the surrounding tissue. In our study, the Ca/Mg ratios of individual patients in both the OR and EVAR groups were considerably higher than 2:1.

We found a negative correlation between the diameter of the abdominal aortic aneurysm and Mg levels in the EVAR group, which was observed neither in the OR group, nor in all the patients studied together. The mean AAA diameter was significantly lower in the EVAR group (55.60±13.06 mm) than in the OR group (65.22±8.44 mm, P=0.0115). In our previous study, classifying AAA patients based on the surgical procedure type was a secondary consideration, since it was more essential to divide them into three groups based on the diameter of the aneurism (group I – below 55, group II – between 55 and 70 mm, and group III – over 70 mm). We demonstrated a consistent relation between increased inflammation and decreased antioxidant mechanisms, and the size of the aneurysm (Kasprzak et al. 2023). Although such a classification was not applied in the present study, the EVAR group included all small-size and almost half of all the medium-size AAA cases. Therefore, the abovementioned negative correlation may suggest a lower risk of aneurysm rupture due to decreased blood pressure, oxidative stress and reduced inflammation response, as well as an improvement in vascular endothelial function as a result of Mg supplementation (Mauskop et al. 2018).

Iron imbalance contributes to various ailments, such as anemia, but also to the overproduction of ROS via the Fenton reaction due to Fe overload (Naito, Ishihara 2022). The conducted clinical studies have revealed that Fe status is associated with the pathogenesis of aortic disease, including abdominal aortic aneurysm, myocardial infarction, coronary artery disease and atherosclerosis (Sawada et al. 2015, Naito, Ishihara 2022, Sawicki et al. 2023, Wang et al. 2024). Hence, the issue of iron homeostasis is complex and requires further research with regard to systemic Fe levels, local Fe levels and Fe metabolism in the aortic region (Naito, Ishihara 2022). The results obtained in our study demonstrated that postoperative treatment affected plasma Fe levels in both studied groups, and the decrease was significantly lower in the OR group compared to the EVAR group one day after the surgery. As mentioned in the section devoted to the results, prior to surgery, all patients investigated individually showed blood Fe levels within the reference range. The change in postoperative Fe levels, however, depended on the severity of the surgical procedures. Major elective surgery subjects patients to adverse effects of pre-operative anemia, blood loss and red cell transfusion, which may further affect postoperative complications, the length of hospital recovery and mortality risk (Muñoz et al. 2015, 2017). A retrospective analysis of pooled clinical and analytical data of patients undergoing elective procedures, including cardiac surgery (n = 691); colorectal cancer resection (n=735); radical prostatectomy (n=362); gynecological surgery (n=203) and resection of liver metastases (n=122) demonstrated that one-third of subjects suffered from anemia based on their hemoglobin levels (Muñoz et al. 2017). Additionally, over two-thirds of subjects with anemia exhibited iron deficiency, or iron sequestration, whereas more than 50% of non-anemic patients presented iron deficiency or low iron stores. It is of note that a prospective observational study of 55 patients following open aortic surgery (1, 2, 4, 30, and 45 days), whose iron status was determined based on parameters such as iron levels, transferrin, transferrin saturation index, transferrin-soluble receptor, ferritin, red cell count, hemoglobin and serum CRP, revealed that iron depletion and iron status parameters reached the maximum at 48 hours postoperatively and did not return to expected levels after 45 days (Solis et al. 2006). Similar findings were reported in terms of other studied parameters. The amount of iron in the body represents only a part of the body's iron status; thus, other more specific parameters reflecting iron metabolism should be evaluated in further studies. However, the results of our study seem to suggest that a significant decrease in Fe levels during the postoperative period in the OR group stems from moderate or high blood loss and insufficient stored iron. A decrease in the Fe level during the postoperative period following the EVAR procedure was potentially the effect of insufficient stored iron, possibly due to the co-existing diseases.

Study limitations

In the present study, the group consisted of 40 abdominal aortic aneurysm patients. However, division into two groups according to a low-surgical-risk and a high-surgical-risk group resulted in a small number of patients in both studied group. The findings of our study should be interpreted with caution given its limited sample size. In our study, no dietary history or meal frequency questionnaire was conducted because most patients were elderly, suffering from various comorbidities or underwent urgent surgery. Nevertheless, the mean levels of Ca, Mg and Fe concentrations found prior to surgery were within the reference range for both studied groups, and may indirectly reflect proper nutrition. Moreover, the main objective of the study was to evaluate the effects of postoperative treatment on Ca, Mg and Fe levels in AAA patients qualified for different interventions.

CONCLUSIONS

The development of AAA did not affect the concentration of Ca, Mg and Fe in the blood. Moreover, plasma Mg concentrations remained within the reference values after both surgical procedures; only OR contributed to its reduction in the postoperative period. Dilatation of the artery wall was accompanied by a decrease in Mg concentration in the EVAR group, as indicated by a negative correlation between Mg concentration and the diameter of the aneurysm. The postoperative treatment reduced the Fe plasma concentration, regardless of the type of surgery. OR surgery and the accompanying blood loss may subject the patient to a prolonged period of postoperative treatment.

Author contributions

B.G., J.G., M.P.K., Z.K., M.I. – conceptualization, B.G. methodology and formal analysis, B.G. and J.G. – performed the experiments, B.G. and Z.K. – collected the data, B.G., J.G., M.P.K. – analyzed the data, B.G. – wrote original draft, B.G. – visualization, Z.K. – funding acquisition, M.I. – reviewed and edited the manuscript. All authors have read and agreed to the published version of the manuscript.

Conflicts of interest

The authors ensure that they have neither professional nor financial connections related to the manuscript sent to the Editorial Board. 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.

Ethical compliance statement

This study was performed according to the principles of the Declaration of Helsinki and approved by the Bioethics Committee at Poznan University of Medical Sciences (approval number 854/14). All patients qualified for this study underwent a careful interview and a clinical examination, including the evaluation of patients' history based on the hospital and outpatient.

REFERENCES

Afonso, R., Marques, R.C., Borges, H., Cabrita, A., Silva, A. P. (2022) 'The usefulness of calcium/magnesium ratio in the risk stratification of early onset of renal replacement therapy', *Diagnostics*, 12(10), 2470, available: https://doi.org/10.3390/diagnostics12102470

Budzyń, M., Gryszczyńska, B., Majewski, W., Krasiński, Z., Kasprzak, M.P., Formanowicz, D., Strzyżewski, K.W., Iskra, M. (2017) 'The association of serum thrombomodulin with endothelial injuring factors in abdominal aortic aneurysm', *BioMed Research International*, 2017(1), 2791082, available: https://doi.org/10.1155/2017/2791082

Cieslewicz, A., Jankowski, J., Korzeniowska, K., Balcer-Dymel, N., Jablecka, A. (2013) 'The role of magnesium in cardiac arrhythmias', *Journal of Elementology*, 18(2), available: DOI: 10.5601/jelem.2013.18.2.11

Gryszczyńska, B., Budzyń, M., Formanowicz, D., Formanowicz, P., Krasiński, Z., Majewska, N., Iskra, M., Kasprzak, M.P. (2019) 'Advanced oxidation protein products and carbonylated proteins levels in endovascular and open of an abdominal aortic aneurysm: The effect of pre-, intra-, and postoperative treatment', *BioMed Research International*, 2019(1), 7976043, available: https://doi.org/10.1155/2019/7976043

Gryszczyńska, B., Formanowicz, D., Budzyń, M., Wanic-Kossowska, M., Pawliczak, E., Formanowicz, P., Majewski, W., Strzyżewski, K.W., Kasprzak, M.P., Iskra, M. (2017). Advanced oxidation protein products and carbonylated proteins as biomarkers of oxidative stress in selected atherosclerosis-mediated diseases. *BioMed Research International*, 2017, https://doi.org/10.1155/2017/4975264

Guzik, B., Sagan, A., Ludew, D., Mrowiecki, W., Chwała, M., Bujak-Gizycka, B., Filip, G., Grudzień, G., Kapelak, B., Zmudka, K., Mrowiecki, T., Sadowski, J., Korbut, R., Guzik, T.J. (2013) 'Mechanisms of oxidative stress in human aortic aneurysms – association with clinical risk factors for atherosclerosis and disease severity', *International Journal of Cardiology*, 168(3), 2389-2396, available: https://doi.org/10.1016/j.ijcard.2013.01.278

Iskra, M., Barałkiewicz, D., Majewski, W., Pioruńska-Stolzmann, M. (2005) 'Serum magnesium, copper and zinc concentration changes in lower limb ischemia and postoperative treatment', *Magnesium Research*, 18(4), 261-267

Iskra, M., Patelski, J., Majewski, W. (1997) 'Relationship of calcium, magnesium, zinc and copper concentrations in the arterial wall and serum in atherosclerosis obliterans and aneurysm', *Journal of Trace Elements in Medicine and Biology*, 11(4), 248-252, https://doi.org/10.1016/S0946-672X(97)80020-X

Jahnen-Dechent, W., Ketteler, M. (2012). Magnesium basics. *Clinical Kidney Journal*, 5 (Suppl 1), i3-i14, https://doi.org/10.1093/ndtplus/sfr163

Jawien, A., Formankiewicz, B., Derezinski, T., Migdalski, A., Brazis, P., Woda, L. (2014). Abdominal aortic aneurysm screening program in Poland. *Gefasschirurgie*, 19(6), 545, available: https://doi.org/10.1007/s00772-014-1348-4

Jędrzejek, M., Mastalerz-Migas, A., Bieńkowski, P., Cichy, W., Matusiewicz, H., Szymański, F. M., Woroń, J. (2021) 'Stosowanie preparatów magnezu w praktyce lekarza rodzinnego', *Lekarz POZ*, 7(2).

Jolly, K., Faulconer, R., McEwan, R., Becker, H., Garnham, A. (2015) 'The incidence of hypomagnesaemia following abdominal aortic aneurysm surgery', *The Annals of The Royal College of Surgeons of England*, 97(5), 379-381, available: https://doi.org/10.1308/003588415X14181254790004

Kalita, R., Pande, P.K., Agrawal, H., Ravikanth, M. (2017) 'Effect of surgical trauma on serum magnesium levels in the early postoperative period', *International Journal of Research in Medical Sciences*, 5, 3907-11, available: DOI: https://doi.org/10.18203/2320-6012.ijrms20173610

Kasprzak, M.P., Gryszczyńska, B., Olasińska-Wiśniewska, A., Urbanowicz, T., Jawień, A., Krasiński, Z., Formanowicz, D. (2023) 'Blb-NRF2-PON1 cross-talk in abdominal aortic aneurysm progression', *Antioxidants*, 12(8), 1568, available: https://doi.org/10.3390/antiox12081568

Kawakatsu, T., Kamio, Y., Makino, H., Hokamura, K., Imai, R., Sugimura, S., Kimura, T., Hiramatsu, H., Umemura, K., Hashimoto, T., Kurozumi, K. (2024) 'Dietary iron restriction protects against aneurysm rupture in a mouse model of intracranial aneurysm', *Cerebrovascular Diseases*, 53(2), 191-197, available: https://doi.org/10.1159/000531431

Kośmicki, M. (2004) 'Czynniki zakaźne w patogenezie choroby wieńcowej', *Przewodnik Lekarza/Guide for GPs,* 7(11), 35-43.

Kuivaniemi, H., Ryer, E.J., Elmore, J.R., Tromp, G. (2015) 'Understanding the pathogenesis of abdominal aortic aneurysms', *Expert Review of Cardiovascular Therapy*, 13(9), 975-987, available: https://doi.org/10.1586/14779072.2015.1074861

Lambe, S.D., Karmarkar, S.S., Naik, P.S., Patil, A.B. (2016) 'Study of serum magnesium in surgical stress', *Journal of Krishna Institute of Medical Sciences (JKIMSU),* 5(4).

Li, Q., Chen, Q., Zhang, H., Xu, Z., Wang, X., Pang, J., Ma, J., Ling, W., Li, D. (2020) 'Associations of serum magnesium levels and calcium–magnesium ratios with mortality in patients with coronary artery disease', *Diabetes & Metabolism*, 46, 384-391, available: https://doi.org/10.1016/j.diabet.2019.12.003

Liu, M., Dudley, S.C., Jr. (2020) 'Magnesium, oxidative stress, inflammation, and cardiovascular disease', *Antioxidants*, 9(10), 907, available: https://doi.org/10.3390/antiox9100907

Malinowska, J., Małecka, M., Ciepiela, O. (2020) 'Variations in magnesium concentration are associated with increased mortality: study in an unselected population of hospitalized patients', *Nutrients*, 12(6), 1836, available: https://doi.org/10.3390/nu12061836

McCormick, M.L., Gavrila, D., Weintraub, N.L. (2007) 'Role of oxidative stress in the pathogenesis of abdominal aortic aneurysms', *Arteriosclerosis, Thrombosis, and Vascular Biology*, 27(3), 461-469, available: https://doi.org/10.1161/01.ATV.0000257552.94483.14

Miller F.J. Jr., Sharp, W.J., Fang, X., Oberley, L.W., Oberley, T.D., Weintraub, N.L. (2002) 'Oxidative stress in human abdominal aortic aneurysms: a potential mediator of aneurysmal remodeling', *Arteriosclerosis, Thrombosis, and Vascular Biology*, 22(4), 560-565, available: https://doi.org/10.1161/01.ATV.0000013778.72404.3

Mofrad, M.D., Djafarian, K., Mozaffari, H., Shab-Bidar, S. (2018) 'Effect of magnesium supplementation on endothelial function: A systematic review and meta-analysis of randomized controlled trials', *Atherosclerosis*, 273, 98-105, available: https://doi.org/10.1016/j.atherosclerosis.2018.04.020

Muñoz, M., Gómez-Ramírez, S., Campos, A., Ruiz, J., Liumbruno, G.M. (2015) 'Pre-operative anaemia: prevalence, consequences and approaches to management', *Blood Transfusion*, 13(3), 370, available: doi: 10.2450/2015.0014-15

Muñoz, M., Laso-Morales, M.J., Gómez-Ramírez, S., Cadellas, M., Núñez-Matas, M.J., García--Erce, J.A. (2017) 'Pre-operative haemoglobin levels and iron status in a large multicentre cohort of patients undergoing major elective surgery', *Anaesthesia*, 72(7), 826-834, available: https://doi.org/10.1111/anae.13840

Munoz, R., Laussen, P.C., Palacio, G., Zienko, L., Piercey, G., Wessel, D.L. (2000) 'Whole blood ionized magnesium : Age-related differences in normal values and clinical implications of ionized hypomagnesemia in patients under-going surgery for congenital cardiac disease', *The Journal of Thoracic and Cardiovascular Surgery*, 119, 891-898, available: https://doi.org/10.1016/S0022-5223(00)70083-3

Naito, Y., Ishihara, M. (2022) 'Focus on Cellular Iron Metabolism in Aortic Disease', Reviews in *Cardiovascular Medicine*, 23(5), 169, available: https://doi.org/10.31083/j.rcm2305169

Nielsen, F.H. (2018) 'Magnesium deficiency and increased inflammation: current perspectives', *Journal of Inflammation Research*, 18;11: 25-34, available: https://doi.org/10.2147/JIR.S136742

Olszak, I.T., Poznansky, M.C., Evans, R. H., Olson, D., Kos, C., Pollak, M.R., Brown, E.M., Scadden, D.T. (2000) 'Extracellular calcium elicits a chemokinetic response from monocytes in vitro and in vivo', *Journal of Clinical Investigation,* 105, 1299-1305, available: https://doi.org/10.1172/JCI9799

Park, B., Kim, M.-H., Cha, C.K., Lee, Y.-J., Kim, K.-C. (2017) 'High calcium–magnesium ratio in hair is associated with coronary artery calcification in middle-aged and elderly individuals', *Biological Trace Element Research*, 179, 52-58, available: https://doi.org/10.1007/s12011-017-0956-8

Parotto, M., Djaiani, G. (2019) 'Perioperative Hypomagnesemia and Increased Postoperative Morbidity and Mortality: Myth or Reality?', *Journal of Cardiothoracic and Vascular Anesthesia*, 33(2), 480-481, available: http://dx.doi.org/10.1053/j.jvca.2018.05.042

Reid, I. R., Birstow, S.M., Bolland, M.J. (2017) 'Calcium and cardiovascular disease', *Endocrinology and Metabolism*, 32(3), 339-349, available: https://doi.org/10.3803/EnM.2017.32.3.339

Sawada, H., Hao, H., Naito, Y., Oboshi, M., Hirotani, S., Mitsuno, M., Miyamoto, Y., Hirota, S., Masuyama, T. (2015) 'Aortic iron overload with oxidative stress and inflammation in human and murine abdominal aortic aneurysm', *Arteriosclerosis, Thrombosis, and Vascular Biology*, 35(6), 1507-1514, available: https://doi.org/10.1161/ATVBAHA.115.305586

Sawicki, K.T., De Jesus, A., Ardehali, H. (2023) 'Iron metabolism in cardiovascular disease: physiology, mechanisms, and therapeutic targets', *Circulation Research*, 132(3), 379-396, available: https://doi.org/10.1161/CIRCRESAHA.122.321667

Schanzer, A., Oderich, G.S. (2021). Management of abdominal aortic aneurysms. *New England Journal of Medicine*, 385(18), 1690-1698, https://doi.org/10.1056/nejmcp2108504

Sigel, A., Sigel, H., Sigel, R.K. (2013) 'Interrelations between essential metal ions and human diseases', In: Metal Ions in Life Sciences, vol. 13, Springer, Dordrecht, ISBN: 978-94-007-7499-5, https://doi.org/10.1016/j.jinorgbio.2014.05.004

Singh, R.R., Shekhar, S., Akhtar, M.J., Shankar, V. (2016) 'Serum electrolyte changes in major surgical trauma', *International Journal of Research in Medical Sciences*, 4(7):2893-6, available: DOI: https://doi.org/10.18203/2320-6012.ijrms20161972

Siwko, A., Hendiger, W., Eberhardt, A., Kwietniak, Z., Madycki, G., Walerian Staszkiewicz, W. (2016) 'Parametryzacja wymiarów tętniaków aorty brzusznej w materiale Kliniki Chirurgii

Naczyniowej i Angiologii Centrum Medycznego Kształcenia Podyplomowego Szpitala Bielańskiego w Warszawie', *Postępy Nauk Medycznych*, 29(11B), 21-24, available: DOI: 10.5604/08606196.1226589

Solis, J.V., Portero, J.L., Diaz, J., Garcia, R., Ligero, J.M., Vazquez, E., Lodeiro, C., Ballesteros, L. (2006) 'Iron deficiency in the acute-phase reaction after open aortic surgery', *Vascular and Endovascular Surgery*, 40(5), 392-398, available: https://doi.org/10.1177/1538574406293749

Ter Braake, A.D., Vervloet, M.G., de Baaij, J.H.F., Hoenderop, J.G.J. (2022) 'Magnesium to prevent kidney disease-associated vascular calcification: crystal clear?', *Nephrology, Dialysis, Transplantation*, 37, 421-429, available: https://doi.org/10.1093/ndt/gfaa222

Wang, H., Huang, Z., Du, C., Dong, M. (2024) 'Iron dysregulation in cardiovascular diseases', *Reviews in Cardiovascular Medicine*, 25(1), 16, available: https://doi.org/10.31083/j.rcm2501016

Wiernicki, I., Parafiniuk, M., Kolasa-Wołosiuk, A., Gutowska, I., Kazimierczak, A., Clark, J., Baranowska-Bosiacka, I., Szumilowicz, P., Gutowski, P. (2019) 'Relationship between aortic wall oxidative stress/proteolytic enzyme expression and intraluminal thrombus thickness indicates a novel pathomechanism in the progression of human abdominal aortic aneurysm', *The FASEB Journal*, 33(1), 885-895, available: https://doi.org/10.1096/fj.201800633R