MAGNESIUM INTAKE AS A POTENTIAL THEURAPEUTIC APPROACH FOR OBESITY AND METABOLIC SYNDROME: A LITERATURE REVIEW

Puspita Nuraissa[1], Dian Handayani[2] and Widya Rahmawati[2]

[1]Master of Nutrition Science Program, [2]Department of Nutrition, Faculty of Health Sciences, Universitas Brawijaya, Malang, Indonesia

Abstract. Magnesium plays a crucial role in metabolic processes, influencing various aspects of health, including glucose regulation, insulin sensitivity, and lipid metabolism. This literature review aims to summarize current evidence on the potential role of dietary magnesium intake as a therapeutic strategy for managing obesity and metabolic syndrome. A selection of relevant articles published from 2019 to 2024 was reviewed based on defined inclusion and exclusion criteria. The articles were sourced from PubMed, ScienceDirect, and Google Scholar databases. This review was conducted following the PRISMA guidelines to ensure a systematic and transparent approach. Out of 8,662 articles initially retrieved, 14 met the eligibility criteria and were proceeded to the review. Of the selected articles, 4 employed RCTs including different dosage of magnesium supplement 250-300 mg/day, with duration 12-24 weeks were entered to this study. Furthermore, 1 RCT recommends an RDA of magnesium intake for children and adolescents of 360-410 mg/day. Five articles utilized cross-sectional designs while there were 3 cohort studies and 1 case-control study. An inverse association has been consistently reported between magnesium intake, whether from diet or supplementation, and the risk of metabolic disorders. This review highlights various studies that examine the effects of magnesium supplementation on health outcomes, alongside those focusing on the benefits of consuming magnesium-rich foods. By exploring both dietary and supplemental magnesium intake, this review provides a balanced perspective on how magnesium affects health, considering different sources and forms of intake.

Keywords: magnesium intake, obesity, metabolic syndrome

Correspondence: Puspita Nuraissa, Department of Nutrition, Faculty of Health Science, Universitas Brawijaya, Jl. Pelabuhan 2, Kampung Cibodas Village of Kertaraharja, Cikembar Subdistrict Sukabumi Regency, West Java 43157, Indonesia
Tel: +62 81212660406 E-mail: puspitanuraissa13@gmail.com

INTRODUCTION

Obesity is a complex and multifaceted global health challenge that significantly impacts quality of life and increases the risk of several chronic diseases. The prevalence of obesity has increased worldwide in the last 50 years, reaching pandemic levels (Blüher, 2019; Hoffman *et al*, 2021). The World Health Organization (WHO) report, more than 2 billion adults worldwide are overweight or obese (WHO, 2024) while according to the latest estimates of the International Diabetes Federation (IDF), the number of individuals with diabetes has increase significantly from 151 million in 2000 to 537 million in 2021 which was predicted to be 643 million and 783 million by 2030 and 2045, respectively (IDF, 2022). Obesity and its related conditions, such us metabolic syndrome and type 2 diabetes, are a significant global health problem (Piuri *et al*, 2021). The accumulation of excess of adipose tissue, a defining feature of obesity, has been associated with endocrine-metabolic alterations that contribute to dyslipidemia, which is characterized by increase plasma levels of triacylglycerols, total cholesterol, and low density lipoprotein-cholesterol (LDL-c) along with decreased high density lipoprotein-cholesterol (HDL-c) (Dos Santos *et al*, 2021).

Obesity is the result of unhealthy diets such as excessive consumption of fast food that is high in calories but poor in essential nutrients influenced by social, economic, and demographic variables, including gender, living location, adolescents' educational background, parents' jobs and earnings, and patterns of online food purchasing

(Briawan *et al*, 2023; Ruze *et al*, 2023). As a result, individuals with obesity are often deficiency in micronutrient such as magnesium (Morais *et al*, 2017). The developments of obesity, metabolic syndrome, and type 2 diabetes mellitus are interconnected through common pathophysiological pathways characterized by persistent low-grade systemic inflammation (Saltiel and Olefsky, 2017). It has been demonstrated that individuals with obesity often presented lower plasma magnesium concentration than healthy individuals, which can compromise the physiological functions of this nutrient (Cruz *et al*, 2019; Dos Santos *et al*, 2021). Higher levels of serum magnesium, along with increased dietary intake and supplementation, are associated with lower blood pressure, implying that magnesium deficiency may be involved in the onset of hypertension (Pitzer Mutchler *et al*, 2023). Magnesium is an essential mineral in the human organism that plays a role in regulating various physiological functions (Liu *et al*, 2024). This micronutrient serves as a cofactor or activator in more than 300 enzymatic reactions, play a role in RNA and DNA synthesis, metabolism of protein, lipids and carbohydrate, maintenance of cell membranes stability, bone and calcium metabolism, or nervous and immune system function (Gröber *et al*, 2015; Schwalfenberg and Genuis, 2017).

Numerous studies have demonstrated the health benefits of magnesium, a recent systematic review and meta-analysis of double-blind randomized clinical trials suggested that magnesium supplementation may play a beneficial role and enhance glucose parameters in individuals with type 2 diabetes. In obese subjects and/or subjects with glucose intolerance, at high risk of diabetes, magnesium supplementation was found to significantly improved plasma glucose levels and markers of insulin sensitivity (Veronese *et al*, 2021). The optimal dosage of magnesium, whether from dietary sources or supplementation, remains incompletely understood in relation to changes in metabolic function and inflammatory profiles.

The objective of this study was to evaluate the optimal dosage of magnesium intake, whether through diet or supplementation, by reviewing current evidence on its effects in individuals with obesity and metabolic syndrome.

MATERIALS AND METHODS

This literature review has been carried out following the Preferred Reporting Items for Systematic Reviews and Meta-Analysis guidelines (PRISMA). The search was performed using electronic database is PubMed, ScienceDirect and Google Scholar with a comprehensive set of search terms, including "Magnesium", "Mg", "Dietary Magnesium", "Supplementation", "Micronutrients", "Obesity", "Body weight", "Metabolic syndrome". These terms were systematically combined in pairs to enhance the search strategy and to ensure a thorough exploration of relevant literatures.

Eligibility and exclusion criteria

Publications needed to meet the following inclusion criteria: a) being the studies in human population; b) being either randomized control trial, parallel or cross-over design; c) report about benefit of magnesium intake on metabolic syndrome; d) being the studies with interventions that included compared with other interventions; e) report at least one of the following outcomes: anthropometry, dietary magnesium, blood glucose, blood pressure; and f) being published during 2019-2024. Exclusion criteria of this study were: a) not being the original research (such as reviews, letters, conference proceedings or commentaries); b) cannot be accessed in full text. The text included in the manuscript provides a clear list of search terms used in the systematic search.

The systematic search was conducted using a combination of keywords related to "magnesium," "obesity," "metabolic syndrome," and "inflammation," applied across three databases (*ie* PubMed, Scopus, and ScienceDirect). Boolean operators (AND, OR) were used to structure the search strategy. For example, terms such as "magnesium" AND "mg" OR "metabolic syndrome" were combined to retrieve relevant studies.

Only articles published in English between 2019 and 2024 were included. Articles written in other languages were excluded during the screening process.

Study selection, data extraction and quality assessment

The titles and abstracts of the retrieved articles were screened independently by two reviewers to identify potentially relevant studies. Articles that met the inclusion criteria were then assessed in full text. The quality of the included studies was evaluated using the JBI Critical Appraisal Checklist for Systematic Reviews and Research Syntheses (The Joanna Briggs Institute, 2017). These questions aim to identify whether certain safeguards have been implemented to minimize the risk of bias and address other aspects related to the validity or quality of the study. Each question can be scored as met (yes), unmet (no), unclear, or not applicable. According to JBI scoring systems, a score of less than four is considered low quality, a score between four and six is considered medium quality, and a score of seven or even higher is considered high quality. In the current literature review, only articles with scores of four or higher were included.

RESULTS

Based on the results of a literature review related to the benefits

of magnesium for metabolic syndrome, searches across three databases (PubMed, ScienceDirect, and Google Scholar) obtained a total of 8,662 articles. Subsequently, 8,527 articles that were considered irrelevant based on their titles were excluded and removed. Additional exclusions were made based on unsuitable study designs (58 articles), not open access or paid articles (41 articles), and duplicate articles (22 articles). This process resulted in 14 articles remaining for further review. The screening results confirmed that these 14 articles met the inclusion criteria. The process of selecting articles for this literature review is illustrated in the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) shown in Fig 1.

All selected articles analyzed the effects of magnesium supplementation on obesity, type 2 diabetes mellitus (T2DM) patients, and healthy individuals, mainly assessed based on the impact of magnesium intake on metabolic syndrome. The studies analyzed in this literature review involved populations with diverse demographic characteristics. Most studies included human participants with age range from 11.3 to 79 years, comprising both males and females. Participants' body mass index (BMI) also varied, spanning from the normal category (18.5-24.9 kg/m^2) to obesity (>30 kg/m^2). Of 14 articles proceeded to the review, 5 employed randomized, double-blind, placebo-controlled trials, 5 utilized cross-sectional study designs, 3 used cohort study designs, and 1 employed a case-control study design.

Based on the literature review of fourteen eligible articles, three methods were found to assess magnesium intake in research subjects. The three methods are the 24-hour recalls, the food frequency questionnaire (FFQ) and the dietary records. Furthermore, there are 5 articles using 24-hour recalls, 4 articles using FFQ, 3 articles using dietary records and 2 articles do not include the intake assessment method.

The results of study findings highlighted various parameters related

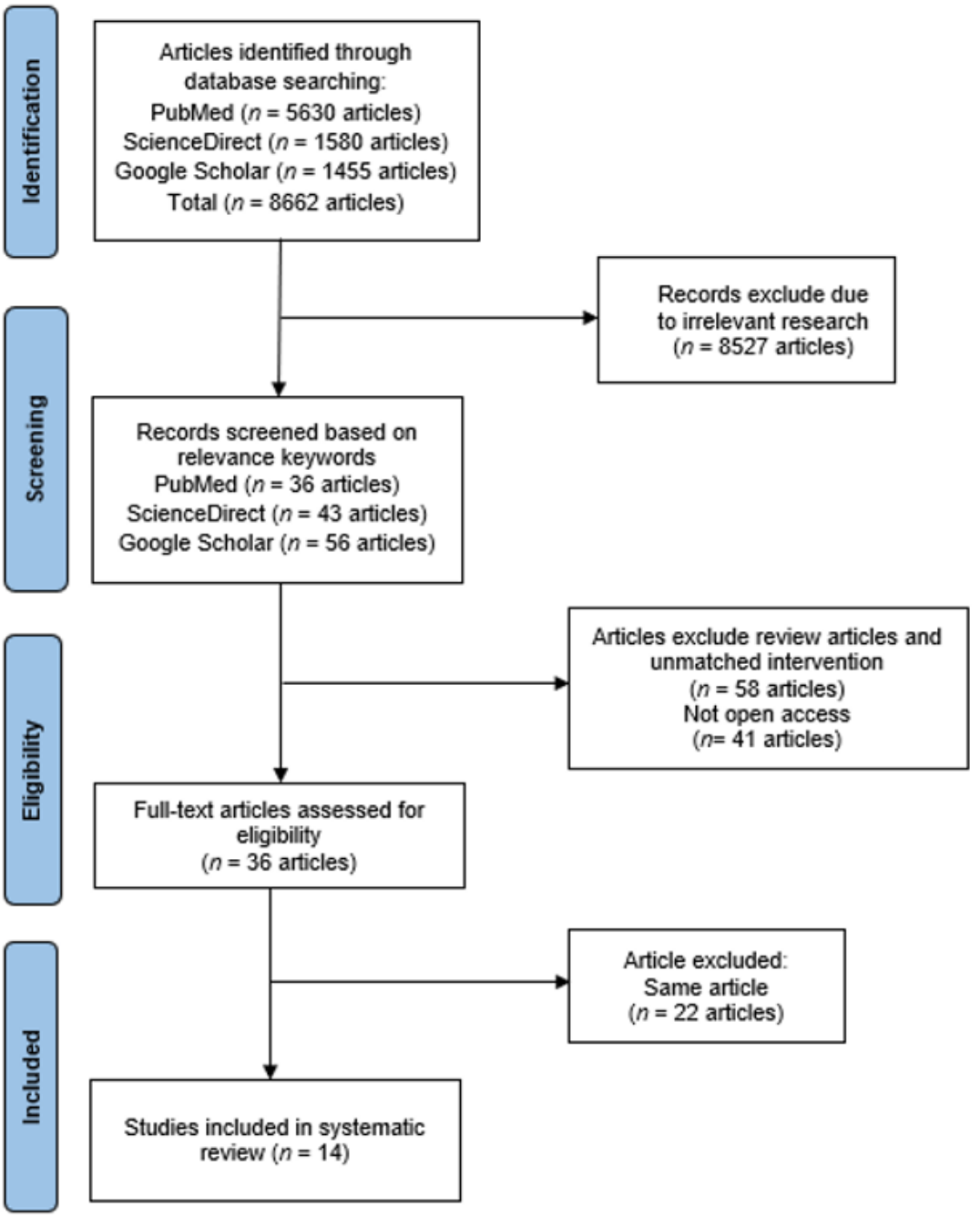

Fig 1 - PRISMA flowchart showing the article selection process for this literature review
PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-Analyses

to metabolic syndrome, such as blood glucose profiles, lipid profiles, blood pressure, and inflammatory responses, which differed across the selected articles. Data extracted from these articles were organized into several themes, including: Effects of magnesium supplementation on alleviating weight parameters, blood glucose control, blood pressure, inflammatory response and dietary magnesium on obesity and metabolic syndrome are summarized in Table 1.

DISCUSSION

Effects of magnesium on alleviating weight parameters

There are 4 articles indicating that increased magnesium intake may have a positive effect on reducing body mass index (BMI) or body fat and could serve as an intervention for obesity prevention (Chu *et al*, 2023; Jiang *et al*, 2020; Lu *et al*, 2020; Naseeb *et al*, 2021).

The first article (Naseeb *et al*, 2021) noticed that changes in magnesium intake among middle school students were negatively associated with changes in BMI percentage, with a recommended dietary allowance (RDA) of 360-410 mg/day (Institute of Medicine, 1997). Another study reported that children aged 2-14 years with overweight and obesity had lower serum magnesium levels (2.08 ± 0.211 mg/dl) compared with normal weight children (2.55 ± 0.155 mg/dl, p-value <0.001) (Hassan *et al*, 2017). The research findings suggest that a multicomponent intervention may contribute to a lower risk of developing T2DM in children and adolescents. This effect could potentially be influenced, at least in part, by the role of magnesium. The study highlights a cost-effective strategy for mitigating T2DM risk in this age group.

Obesity is not only limited to children and adolescent, but can also occur in adults and elderly. An analysis of NHANES 2007-2014

Table 1
Magnesium intake as a therapeutic approach for managing components of metabolic syndrome

References	Type of study	Population	Doses	Sources of magnesium	Results
Naseeb *et al* (2021)	Randomized, cluster-design study	Ethnically diverse students aged 11.3-13.7 years	Magnesium intake of 360-410 mg/day	Daily food intake	Magnesium intake was significantly related to changes in BMI percentile from 6^{th} – 8^{th} grade in intervention and in control schools.
Jiang *et al* (2020)	Cross-sectional study	Adult individuals (≥20 years)	Mg intake of 382 mg/day	Daily food intake and supplement	Mg intakes were negatively correlated with BMI (p-value <0.05 at the quantiles of 0.1-0.9) and WC (p-value <0.05 at 0.1-0.9 quantiles) after adjusting for age and gender.
Chu *et al* (2023)	Prospective cross-sectional study	155 Chinese with IGT 53-62 years	Magnesium 313 mg/day and potassium 2,295 mg/day	Daily food intake	Magnesium could lower body fat percentage in people with IGT. However, associations between magnesium and glucose-dependent parameters were not observed.
Lu *et al* (2020)	Multicenter longitudinal cohort study (30-year follow-up)	American young adults aged 18-30 years	Magnesium intake >208.1 mg/1000kcal –	Daily food intake	Higher magnesium intake was linked to lower levels of BMI, skinfold thickness at various sites (triceps, suprailiac, subscapular), along with decreased fasting insulin and C-reactive protein.

Table 1 (cont)

References	Type of study	Population	Doses	Sources of magnesium	Results
Talari *et al* (2019)	Randomized, double-blind, placebo-controlled trial	Diabetic hemodialysis patients	Magnesium supplementation of 250 mg/day for 24 weeks by diabetic HD	Supplementations	The study findings indicate that 24 weeks of magnesium supplementation in diabetic hemodialysis patients led to significant improvements in the mean and maximum levels of left CIMT, mean levels of right CIMT, insulin metabolism, HbA1c, total and LDL cholesterol, hs-CRP, TAC, and MDA levels.
Solati *et al* (2019)	Randomized double blind clinical trial	Overweight non-diabetic individuals	Herbal supplement capsule containing 300 mg $MgSO_4$ for 6 months on a daily basis	Supplementations	Oral herbal supplement containing $MgSO_4$ (300 mg/day) could improve plasma insulin level, lipid profile, and insulin resistance in non-diabetic overweight volunteers.
Yang *et al* (2020)	Cross-sectional study	8,120 Chinese participants	Dietary Mg intake of 7.66 ± 2.06 mg/kg body weight	Daily food intake	Higher magnesium intake was associated with lower HOMA-IR, reduced HbA1c, and the decreased prevalence of metabolic syndrome.
Kocyigit *et al* (2023)	Case-control study	80 women (40 patients diagnosed with T2DM and 40 healthy controls) aged 35-60 years	≥50% of the dietary reference intake	Daily food intake	Lower serum magnesium levels were associated with higher HbA1c levels in subjects with T2DM. Increased dietary magnesium intake in T2DM may enhance HOMA-IR.

Table 1 (cont)

References	Type of study	Population	Doses	Sources of magnesium	Results
Hamedifard *et al* (2020)	Randomized, double-blind, placebo-controlled trial	60 subjects suffering from CHD and T2DM	250 mg magnesium oxide + 150 mg zinc sulfate for 12 weeks	Supplementations	Supplementation of magnesium and zinc for 12 weeks led to improvements in fasting plasma glucose, HDL-cholesterol, CRP, insulin levels, total nitrite, TAC, as well as depression and anxiety scores (BDI and BAI). These findings indicate that combined magnesium and zinc supplementation may offer therapeutic benefits for patients with both T2DM and CHD.
Dominguez *et al*, (2020)	Prospective, longitudinal, multipurpose, and permanently open cohort study	Mediterranean population	Dietary magnesium intake up to 500 mg/day	Daily food intake	The risk of developing hypertension was reduced, especially in individuals who were overweight or obese.
Yang *et al* (2024)	cross-sectional study	2980 participants aged 40-79 years	Daily intake 0-1500 mg consumption of magnesium-rich foods	Daily food intake	A daily intake of 0-1,500 mg of magnesium-rich foods has been associated with improved metabolic function and vascular health, including lowered blood pressure and reduced plaque accumulation in the arteries.

Table 1 (cont)

References	Type of study	Population	Doses	Sources of magnesium	Results
Wang *et al* (2022)	Retrospective cohort study	Adult individuals aged 19-65 years	Daily magnesium intake of <250 mg/day	Daily food intake	Magnesium intake of <250 mg/day was associated with decreased all-cause, CVD, and cancer mortality and well-controlled diabetes (HbA1c ≤7.0%).
Dong *et al* (2022)	Cross-sectional study	766 adolescents aged 14- 18 years	<410 mg/day of magnesium for males and 360 mg/day for females	Daily food intake	Lower magnesium intake was associated with higher CRP and lower muscle mass. Low magnesium intake may also augment the inverse relationship between CRP and FFM.
Drenthen *et al* (2024)	randomized, double-blind, placebo-controlled, 2-period, crossover study	12 adults with type 2 diabetes (insulin-treated)	Magnesium intake of 270 mg/ day	Supplementations	Magnesium intake of 270 mg/day improved serum magnesium, reduced IFN-γ (CD8+, Th1), suppressed Th2 cytokines (IL-4, IL-5, IL-13), and lowered CRP in insulin-treated T2DM patients.

BAI: Beck Anxiety Inventory; BDI: Beck Depression Inventory; BMI: body mass index; CHD: Coronary Heart Disease; CIMT: Carotid Intima-Media Thickness; CRP: C-reactive protein; CVD: cardiovascular disease; FFM: fat free mass; HbA1c: Hemoglobin A1c; HDL: high-density lipoprotein; HD: hemodialysis; HOMA-IR: Homeostatic Model Assessment of Insulin Resistance; hs-CRP: high-sensitivity C-reactive protein; IFN-γ: interferon-gamma; IGT: impaired glucose tolerance; IL: interleukin; kcal: kilocalories; LDL: low-density lipoprotein; MDA: malondialdehyde; MetS: metabolic syndrome; mg: milligram; $MgSO_4$: magnesium sulfate; QUICKI: Quantitative Insulin Sensitivity Check Index; TAC: total antioxidant capacity; Th1: T-helper 1; T2DM: type 2 diabetes mellitus; WC: waist circumference

data revealed that mineral intake, including magnesium, had an inverse relationship with BMI and waist circumference (Jiang *et al*, 2020). This finding supports the hypothesis that a magnesium-rich diet may contribute to weight control, emphasizing the importance of mineral intake in obesity prevention. Studies has consistently shown that consuming foods rich in magnesium is strongly associated with a reduced risk of obesity. This finding underscores magnesium's potential role in promoting healthy weight regulation and maintaining overall metabolic health (Lu *et al*, 2020). Higher magnesium and potassium intake were associated with a lower body fat among individuals with impaired glucose tolerance, suggesting a potential role of these minerals in supporting better body composition and metabolic health (Chu *et al*, 2023).

Inflammatory and endocrine profile

Numerous biochemical markers, such as high-sensitivity C-reactive protein (hs-CRP), white blood cell count (WBC), fibrinogen, IL-6, and TNF-α, are well-established indicators of low-grade inflammation. Previous studies has demonstrated that their levels can be influenced by magnesium status (Shamnani *et al*, 2018).

In individuals with T2DM, magnesium has been shown to reduce the activity of T-cell inflammation (specifically CD4+ and CD8+ cells). While it does not directly affect the number of other immune cells or circulating inflammatory proteins, a decrease in hs-CRP levels approaches statistical significance, indicating its potential benefit in mitigating low-grade inflammation (Drenthen *et al*, 2024; Talari *et al*, 2019). Previous reports support the relevance of extracellular magnesium levels for CD4+ and CD8+ T-cell function (Lötscher *et al*, 2022).

A systematic review and meta-analysis conducted by Dibaba *et al* (2014) revealed a significant inverse association between dietary magnesium intake and serum CRP levels. Furthermore, a wealth of

evidence supports the finding that magnesium consumption is inversely related to various markers of inflammation (Ashique *et al*, 2023; Pethő *et al*, 2024).

Magnesium plays a crucial role in enhancing insulin sensitivity and reducing insulin resistance through various mechanisms. Insufficient magnesium intake is linked to insulin resistance and decreased cellular glucose uptake, while a diet rich in magnesium is associated with a lower risk of developing T2DM and metabolic syndrome (Dominguez *et al*, 2020; Fang *et al*, 2016). Five studies focus on blood glucose control, particularly in diabetic patients (Hamedifard *et al*, 2020; Kocyigit *et al*, 2023; Solati *et al*, 2019; Talari *et al*, 2019; Yang *et al*, 2020). One study found that supplementing with 250 mg/day of magnesium for 24 weeks in diabetic hemodialysis (HD) patients led to improvements in insulin levels, HOMA-IR, QUICKI, and HbA1c (Talari *et al*, 2019). Additionally, magnesium deficiency has been shown to disrupt insulin metabolism by interfering with kinase-dependent pathways and initiating early-phase responses, which ultimately reduces insulin sensitivity and impairs glycemic control (Wang *et al*, 2022). These findings highlight the potential of magnesium supplementation in managing glucose levels and improving insulin function in individuals with diabetes (Talari *et al*, 2019). Individuals with a higher quartile of dietary magnesium intake or ≥50% of the dietary reference intake (DRI), had lower HbA1c levels and had lower HOMA-IR (Kocyigit *et al*, 2023; Yang *et al*, 2020). In the study involving patients with congestive heart failure (CHF) and diabetes, supplementation with 250 mg of magnesium oxide combined with 150 mg of zinc sulfate for 12 weeks resulted in several beneficial outcomes. These included a significant decrease in fasting plasma glucose and insulin levels, an improvement in HDL-cholesterol, a reduction in C-reactive protein (CRP), an increase in total nitrite and total antioxidant capacity (TAC), as well as a decrease in Beck Depression Inventory (BDI) and Beck Anxiety Inventory (BAI) scores (Hamedifard *et al*, 2020).

Solati *et al* (2019) investigated the consumption of $MgSO_4$ (300 mg/day) for six months as a health intervention. This study offers an intriguing perspective on magnesium's role in managing obesity in non-diabetic individuals, highlighting its beneficial effects on increasing plasma insulin levels, lipid profiles, and insulin sensitivity.

Effects of magnesium on dyslipidemia

A randomized, double-blind, placebo-controlled trial in diabetic hemodialysis patients demonstrated that supplementation with 250 mg of magnesium per day for 24 weeks led to a more significant reduction in total cholesterol and LDL-cholesterol levels compared to the control group (Talari *et al*, 2019). However, another study reported no significant differences in cardiovascular diseases, systolic and diastolic blood pressure, heart rate, total cholesterol, or LDL-c levels across various BMI categories in a Chinese population with impaired glucose tolerance (IGT) (Chu *et al*, 2023).

Dietary magnesium intake has been linked to a lower 10-year risk of atherosclerotic cardiovascular disease (Yang *et al*, 2024), with another study showing its role in improving vascular health and preventing plaque accumulation in the arteries (Wang *et al*, 2022). Association of plasma magnesium with cardiovascular risk factors was also found in study examining a general population in the Mediterranean region. A study found a statistically significant association between plasma magnesium concentrations, particularly in the highest quartile, and increased levels of total cholesterol (p-value <0.05) and LDL-cholesterol (p-value <0.05) (Barragán *et al*, 2020). These findings suggest that plasma magnesium levels may play a role in the lipid profile associated with cardiovascular risk.

Effects of magnesium on blood pressure

There are three article that discuss the results of research to blood pressure (Dominguez *et al*, 2020; Wang *et al*, 2022; Yang *et al*, 2024). In the SUN Project, a positive association of magnesium intake with the Mediterranean diet adherence score (r = 0.46; *p*-value <0.001) was found (Dominguez *et al*, 2020). However, low magnesium intake was similarly associated with approximately 50% higher relative risk of incident hypertension regardless of adherence levels to the Mediterranean diet (Dominguez *et al*, 2020).

A study evaluated the relationship between dietary magnesium intake and the 10-year risk of a first major atherosclerotic cardiovascular disease (ASCVD) event using 2,980 representative samples from NHANES 1999-2018 (Yang *et al*, 2024). The analysis showed that higher magnesium intake was associated with a lower risk of ASCVD events over 10 years. This relationship persisted even after adjusting for clinical risk factors, including age, sex, race, educational level, BMI, alcohol consumption, smoking, blood pressure (systolic and diastolic), hypertension treatment status, diabetes, LDL cholesterol, total energy intake, and dietary fiber (Yang *et al*, 2024).

Wang *et al* (2022) indicated that individuals with a lower dietary intake of magnesium (≤250 mg/day) faced an increased risk of mortality from all causes (Hazard Ratio (HR) = 1.56; 95% CI: 1.13-2.16) as well as mortality from other causes not related to cardiovascular disease or cancer (HR = 1.68; 95% CI: 1.09-2.60). All studies identified that dietary magnesium intake ranged from 250 to 1500 mg/day, indicating a wide variability in magnesium levels consumption observed across studies (Dominguez *et al*, 2020; Wang *et al*, 2022; Yang *et al*, 2024). This range reflects the differences in dietary habits and supplement use among different populations studied.

Magnesium intake recommendation for prevent metabolic syndrome

Magnesium-rich foods dietary intake, such as whole grains, nuts and seeds, legumes, and dark-green vegetables, is associated with a lower incidence of obesity, T2DM and metabolic syndrome (Lu *et al*, 2020). A balanced diet that includes adequate intake of meats, grains, vegetables, and fruits is essential to health. Beyond macronutrient quality, the quantity of minerals may help in different metabolism in carbohydrates and lipids that reduce the body fat, blood pressure, and glucose/ insulin response (Chu *et al*, 2023).

Individuals with magnesium intake less than 200 mg/day, compared to those consuming over 500 mg/day, were also more likely to have lower scores of adherences to the Mediterranean diet, less consumption of vegetables, fruit, legumes, cereals, whole cereals, nuts, olive oil, eggs, fish, whole and low-fat dairy, meat, coffee, total energy intake, and alcohol. They were more likely to have higher intakes of total fat and mono and saturated fatty acids, and lower intakes of vitamins C and D, iron from heme sources, folate, sodium, potassium, calcium, and dietary fiber (Dominguez *et al*, 2021).

Strength, weakness and limitations

One of the key strengths of this study lies in the thorough electronic search process, which utilized three major databases - PubMed, ScienceDirect, and Google Scholar. This approach involved using a wide range of search terms, ensuring comprehensive coverage, and maximizing the likelihood of identifying all relevant articles. The findings have practical implications for dietary recommendations and strategies to prevent or manage metabolic syndrome through magnesium intake. A weakness of this review is that the large portion of excluded articles during the selection process is recognized as a limitation, indicating the

importance of developing a more targeted and effective search strategy in future reviews.

However, this literature review has several limitations. Variability in study designs, populations, and interventions (*eg* dietary magnesium versus supplementation) can make it challenging to draw consistent conclusions. Many studies highlight associations but do not deeply explore the underlying biological mechanisms of how magnesium affects metabolic syndrome.

Significance/Implication of study

Highlighting the inverse relationship between magnesium intake and metabolic risk factors, it underscores the importance of adequate dietary magnesium in reducing the prevalence of metabolic syndrome.

Recommendations

Public health initiatives could focus on promoting the consumption of magnesium-rich foods such as whole grains, nuts, seeds, green leafy vegetables, and legumes as part of a healthy diet to help reduce the risk of metabolic syndrome. In addition, increasing public awareness about the role of magnesium in metabolic health may be particularly beneficial for populations at higher risk of obesity, diabetes, and cardiovascular disease.

In conclusion, the benefits of magnesium intake on glycemic profile have been found in many but not all studies. Differences in baseline magnesium levels and metabolic control may help to explain the differences across studies. Therefore, prospective studies are thus still needed to support the potential role of dietary magnesium intake as a possible public health strategy to reduce obesity, T2DM, and the metabolic syndrome risk in the general population.

ACKNOWLEDGMENTS

We express our gratitude for the valuable contributions and efforts of each member of the research team, whose dedication and hard work made this project possible.

CONFLICT OF INTEREST DISCLOSURE

The authors declare no conflicts of interest.

REFERENCES

Ashique S, Kumar S, Hussain A, *et al*. A narrative review on the role of magnesium in immune regulation, inflammation, infectious diseases, and cancer. *J Health Popul Nutr* 2023; 42(1): 74.

Barragán R, Llopis J, Portolés O, *et al*. Influence of demographic and lifestyle variables on plasma magnesium concentrations and their associations with cardiovascular risk factors in a mediterranean population. *Nutrients* 2020; 12(4): 1018.

Blüher M. Obesity: global epidemiology and pathogenesis. *Nat Rev Endocrinol* 2019; 15(5): 288-98.

Briawan D, Khomsan A, Alfiah E, Nasution Z, Putri PA. Preference for and consumption of traditional and fast foods among adolescents in Indonesia. *Food Res* 2023; 7(4), 211-26.

Chu N, Chan TY, Chu YK, *et al*. Higher dietary magnesium and potassium intake are associated with lower body fat in people with impaired glucose tolerance. *Front Nutr* 2023; 10: 1169705.

Cruz KJC, de Oliveira ARS, de Freitas ST, Henriques GS, do Nascimento Marreiro D. Hypomagnesemia in obese subjects: evidence of

systematic review and meta-analysis. *Curr Nutr Food Sci* 2019; 16(7): 1044-51.

Dibaba DT, Xun P, He K. Dietary magnesium intake is inversely associated with serum C-reactive protein levels: meta-analysis and systematic review. *Eur J Clin Nutr* 2014; 68(4): 510-6.

Dominguez LJ, Gea A, Ruiz-Estigarribia L, *et al*. Low dietary magnesium and overweight/obesity in a mediterranean population: a detrimental synergy for the development of hypertension. The SUN project. *Nutrients* 2020; 13(1): 125.

Dos Santos LR, Melo SRS, Severo JS, *et al*. Cardiovascular diseases in obesity: what is the role of magnesium? *Biol Trace Elem Res* 2021; 199(11): 4020-7.

Drenthen LCA, Ajie M, de Baaij JHF, Tack CJ, de Galan BE, Stienstra R. Magnesium supplementation modulates T-cell function in people with type 2 diabetes and low serum magnesium levels. *J Clin Endocrinol Metab* 2024; 109(12): e2240-5.

Fang X, Wang K, Han D, *et al*. Dietary magnesium intake and the risk of cardiovascular disease, type 2 diabetes, and all-cause mortality: a dose-response meta-analysis of prospective cohort studies. *BMC Med* 2016; 14(1): 210.

Gröber U, Schmidt J, Kisters K. Magnesium in prevention and therapy. *Nutrients* 2015; 7(9): 8199-226.

Hamedifard Z, Farrokhian A, Reiner Ž, *et al*. The effects of combined magnesium and zinc supplementation on metabolic status in patients with type 2 diabetes mellitus and coronary heart disease. *Lipids Health Dis* 2020; 19(1): 112.

Hassan SAU, Ahmed I, Nasrullah A, *et al*. Comparison of serum magnesium levels in overweight and obese children and normal weight children. *Cureus* 2017; 9(8): e1607.

Hoffman DJ, Powell TL, Barrett ES, Hardy DB. Developmental origins of metabolic diseases. *Physiol Rev* 2021; 101(3): 739-95.

Institute of Medicine. Dietary reference intakes: calcium, phosphorus, magnesium, vitamin d and fluoride, 1997 [cited 2024 Jun 26]. Available from: URL: https://nap.nationalacademies.org/read/5776/chapter/1

International Diabetes Federation (IDF). IDF Diabetes Atlas, 10th ed, 2022 [cited 2024 Jun 26]. Available from: URL: https://diabetesatlas.org/atlas/tenth-edition/

Jiang S, Ma X, Li M, *et al*. Association between dietary mineral nutrient intake, body mass index, and waist circumference in U.S. adults using quantile regression analysis NHANES 2007-2014. *PeerJ* 2020; 8: e9127.

Kocyigit E, Akturk M, Koksal E. Relationships between serum and dietary magnesium, calcium, and metabolic parameters in women with type 2 diabetes mellitus. *Clin Nutr ESPEN* 2023; 54: 304-10.

Liu L, Luo P, Wen P, Xu P. The role of magnesium in the pathogenesis of osteoporosis. *Front Endocrinol* 2024; 15: 1406248.

Lötscher J, Martí I Líndez AA, Kirchhammer N, *et al*. Magnesium sensing via LFA-1 regulates CD8+ T cell effector function. *Cell* 2022; 185(4): 585-602.e29.

Lu L, Chen C, Yang K, *et al*. Magnesium intake is inversely associated with risk of obesity in a 30-year prospective follow-up study among American young adults. *Eur J Nutr* 2020; 59(8): 3745-53.

Morais JB, Severo JS, Santos LR, *et al*. Role of magnesium in oxidative stress in individuals with obesity. *Biol Trace Elem Res* 2017; 176(1): 20-6.

Naseeb M, Bruneau ML, Milliron BJ, *et al*. Changes in dietary magnesium intake and risk of type 2 diabetes mellitus in middle school

students: using data from the HEALTHY Study. *J Nutr* 2021; 151(11): 3442-9.

Pethő ÁG, Fülöp T, Orosz P, Tapolyai M. Magnesium is a vital ion in the body - it is time to consider its supplementation on a routine basis. *Clin Pract* 2024; 14(2): 521-35.

Pitzer Mutchler A, Huynh L, Patel R, *et al*. The role of dietary magnesium deficiency in inflammatory hypertension. *Front Physiol* 2023; 14: 1167904.

Piuri G, Zocchi M, Della Porta M, *et al*. Magnesium in obesity, metabolic syndrome, and type 2 diabetes. *Nutrients* 2021; 13(2): 320.

Ruze R, Liu T, Zou X, *et al*. Obesity and type 2 diabetes mellitus: connections in epidemiology, pathogenesis, and treatments. *Front Endocrinol* 2023; 14: 1161521.

Saltiel AR, Olefsky JM. Inflammatory linking obesity and metabolic disease and metabolic disease. *J Clin Invest* 2017; 127(1): 1-4.

Schwalfenberg GK, Genuis SJ. The importance of magnesium in clinical healthcare. *Scientifica* 2017; 2017: 4179326.

Shamnani G, Rukadikar CA, Gupta V, *et al*. Serum magnesium in relation with obesity. *Nat J Physiol Pharm Pharmacol* 2018; 8(7): 1074-7.

Solati M, Kazemi L, Shahabi Majd N, Keshavarz M, Pouladian N, Soltani N. Oral herbal supplement containing magnesium sulfate improve metabolic control and insulin resistance in non-diabetic overweight patients: a randomized double blind clinical trial. *Med J Islam Repub Iran* 2019; 33: 2.

Talari HR, Zakizade M, Soleimani A, *et al*. Effects of magnesium supplementation on carotid intima–media thickness and metabolic profiles in diabetic haemodialysis patients: a randomised, double-blind, placebo-controlled trial. *Br J Nutr* 2019; 121(7): 809-17.

The Joanna Briggs Institute. The Joanna Briggs Institute Critical Appraisal tools for use in JBI Systematic Reviews: checklist for analytical cross sectional studies, 2017 [cited 2024 Aug 20]. Available from: URL: https://jbi.global/sites/default/files/2019-05/JBI_Critical_Appraisal-Checklist_for_Analytical_Cross_Sectional_Studies2017_0.pdf

Veronese N, Dominguez LJ, Pizzol D, Demurtas J, Smith L, Barbagallo M. Oral magnesium supplementation for treating glucose metabolism parameters in people with or at risk of diabetes: a systematic review and meta-analysis of double-blind randomized controlled trials. *Nutrients* 2021; 13(11): 4074.

Wang HW, Huang YT, Jiang MY. Association of dietary magnesium intake and glycohemoglobin with mortality risk in diabetic patients. *PLoS One* 2022; 17(12): e0277180.

World Health Organization (WHO). Obesity and overweight, 2024 [cited 2024 Dec 20]. Available from: URL: https://www.who.int/news-room/fact-sheets/detail/obesity-and-overweight

Yang N, He L, Li Y, *et al*. Reduced insulin resistance partly mediated the association of high dietary magnesium intake with less metabolic syndrome in a large chinese population. *Diabetes Metab Syndr Obes* 2020; 13: 2541-50.

Yang Z, Zhang Y, Gao J, Yang Q, Qu H, Shi J. Association between dietary magnesium and 10-year risk of a first hard atherosclerotic cardiovascular disease event. *Am J Med Sci* 2024; 368(4): 355-60.