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**Clinical Research Article**



# Magnesium Supplementation Modulates T-cell Function in People with Type 2 Diabetes and Low Serum Magnesium Levels

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## Abstract

**Context:** Low magnesium levels, which are common in people with type 2 diabetes, are associated with increased levels of proinflammatory molecules. It is unknown whether magnesium supplementation decreases this low-grade inflammation in people with type 2 diabetes.

**Objective:** We performed multidimensional immunophenotyping to better understand the effect of magnesium supplementation on the immune system of people with type 2 diabetes and low magnesium levels.

**Methods:** Using a randomized, double-blind, placebo-controlled, 2-period, crossover study, we compared the effect of magnesium supplementation (15 mmol/day) with placebo on the immunophenotype, including whole blood immune cell counts, T-cell and $CD14^+$ monocyte function after ex vivo stimulation, and the circulating inflammatory proteome.

**Results:** We included 12 adults with insulin-treated type 2 diabetes (7 males, mean ± SD age 67 ± 7 years, body mass index 31 ± 5 kg/$m^2$, $HbA_{1c}$ 7.5 ± 0.9%) and low magnesium levels (0.73 ± 0.05 mmol/L). Magnesium treatment significantly increased serum magnesium and urinary magnesium excretion compared with placebo. Interferon-γ production from phorbol myristate acetate/ionomycin stimulated $CD8^+$ T-cells and T-helper 1 cells, as well as interleukin (IL) 4/IL5/IL13 production from T-helper 2 cells was lower after treatment with magnesium compared with placebo. Magnesium supplementation did not affect immune cell numbers, ex vivo monocyte function, and circulating inflammatory proteins, although we found a tendency for lower high sensitivity C-reactive protein levels after magnesium supplementation compared with placebo.

**Conclusion:** In conclusion, magnesium supplementation modulates the function of $CD4^+$ and $CD8^+$ T-cells in people with type 2 diabetes and low serum magnesium levels.

**Key Words:** inflammation, magnesium, T-cells, type 2 diabetes

**Abbreviations:** CGM, continuous glucose monitoring; CRP, C-reactive protein; hs, high sensitivity; IFN, interferon; IL, interleukin; LPS, lipopolysaccharide; NKnatural killer; PMA, phorbol myristate acetate; TNF, tumor necrosis factor.

Type 2 diabetes is associated with a chronic low-grade inflammatory state, which may drive insulin resistance, the risk for atherosclerosis, and other diabetes-related complications (1). Low magnesium levels have been associated with a proinflammatory environment in people with type 2 diabetes (2, 3) and with micro/macrovascular complications of diabetes (4). It has been reported that hypomagnesemia affects up to 48% of people with type 2 diabetes compared with 2% of people without diabetes (2, 5).

Magnesium has been described as an anti-inflammatory ion and serves as a calcium channel blocker (6). Low extracellular magnesium levels activate the L-type calcium channel and N-methyl-D-aspartate receptor, which increases the intracellular calcium concentration. Intracellular calcium stimulates the production of substance P, activates NF-κβ, and promotes the secretion of tumor necrosis factor (TNF)-α and interleukin (IL)6, which promote the release of C-reactive protein (CRP) by the liver (6). Magnesium supplementation has been shown to decrease circulating levels of high sensitivity (hs)CRP (7), TNF-α (8), and IL6 (9) in people with type 2 diabetes. In people without diabetes, magnesium has been shown to alter the functionality of immune cells upon pathogenic stimulation. In vitro stimulation of immune cells with varying magnesium concentrations resulted in decreased TNF-α and IL6 production from monocytes (10), decreased IL4/IL5 production and increased interferon (IFN)-γ production from $CD4^+$ T-cells (11), and activation of $CD8^+$ T-cells (12).

Current evidence of a potential anti-inflammatory effect of magnesium supplementation in people with type 2 diabetes is very limited and studies have usually included people with

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normal serum magnesium levels. In this study, we performed multidimensional immunophenotyping to better understand the effect of magnesium supplementation on the immune system of people with type 2 diabetes and low magnesium levels.

## Materials and Methods

### Study Design and Procedure

This study is based on a prespecified secondary outcome and part of a clinical trial with a randomized, double-blind, placebo-controlled, 2-period, crossover study design that included 14 adults with insulin-treated type 2 diabetes (13). Briefly, every participant engaged in 2 treatment periods of 6 weeks (Fig. S1 (14)). The participants were randomly assigned to an order of the 2 possible treatment sequences using block randomization (ie, magnesium gluconate or matched placebo). Both treatments were administered orally as a liquid solution of 50 mL 3 times a day (ie, total daily dose of 150 mL, equivalent to 15 mmol magnesium or 360 mg magnesium). At the end of both treatment periods of 6 weeks, body weight was measured and blood was drawn under standardized fasting conditions for determination of magnesium, $HbA_{1c}$, and inflammatory markers. A urine sample was collected for determination of magnesium and creatinine. During the final week of each treatment period, participants wore a blinded continuous glucose monitoring (CGM) device (Dexcom G6; Dexcom Inc., San Diego, CA, USA).

### Measurements

#### Flow cytometry

Total white blood cell numbers were measured using Sysmex XN-450 (Sysmex Europe SE, Norderstedt, Germany) from whole blood samples. Functionality of monocytes, natural killer (NK) cells, and lymphocytes under pathogenic stimulations were assessed using flow cytometry. These peripheral blood mononuclear cells from whole blood were isolated using Ficoll and kept frozen at −80 °C until the day of the measurement. On the measurement day, 250 000 cells of peripheral blood mononuclear cells were stimulated for 6 hours using Pam3Cys (ie, toll-like receptor 2 agonist), lipopolysaccharide (LPS) (ie, TLR4 agonist), heat-killed *Staphylococcus aureus*, and *Mycobacterium tuberculosis* lysate to assess monocyte function. Furthermore, phorbol myristate acetate (PMA) (activates protein kinase C)/ionomycin (ie, calcium ionophore) was used to assess both NK cell and lymphocyte function. Brefeldin A was added 2 hours after the start of stimulation to inhibit Golgi activity and prevent secretion of cytokines. Stimulated cells were then fixated with 2% (v/v) formaldehyde and stained with antibodies to determine the intracellular production of cytokines from the $CD14^+$ monocytes (IL6/IL-1β/TNF/IL12), NK cells (IFN-γ), and lymphocytes (IL4/IL5/IL13/IL17/perforin/granzyme B/TNF/IFN-γ). Flow cytometry was performed using the CytoFLEX (Beckman Coulter Nederland B.V., Woerden, The Netherlands). Details on antibodies used and gating strategy can be found in Tables 1 and 2, and elsewhere (Figs. S2 and S3 (14)).

#### Plasma measurements

$HbA_{1c}$, magnesium, potassium, calcium, and creatinine were measured as described previously (13). Plasma hsCRP was assessed using sandwich enzyme-linked immunosorbent assay (R&D Duoset ELISA Systems) following the manufacturer's protocol. Readings above the detection limit (ie, >20 mg/L) were excluded from the analysis. Circulating plasma inflammatory proteins were measured using the Olink Proteomics AB Inflammation Panel (92 inflammatory proteins) (Uppsala, Sweden) (15). All samples were measured in 1 batch. Proteins that were not detectable in >75% of the samples were excluded from the final analysis. In the end, 77 out of 92 (83.7%) proteins were used for further analysis.

**Table 1. List of antibodies used for monocyte flow cytometry**

| Marker | Vendor | Cat# | RRID |
|---|---|---|---|
| IL10 | Biolegend | 501421 | AB_1089694 |
| CD14 | Biolegend | 367123 | AB_2716228 |
| CD16 | Biolegend | 302045 | AB_2561367 |
| IL-1β | Biolegend | 511705 | AB_1236434 |
| IL12 (p40/p70) | Miltenyi | 130-123-312 | AB_2921743 |
| IL6 | Biolegend | 501121 | AB_2810621 |
| HLA-DR | Biolegend | 307629 | AB_893575 |
| TNF | Biolegend | 502929 | AB_2204080 |

Abbreviations: HLA-DR, human leukocyte antigen-DR isotype; IL, interleukin; TNF, tumor necrosis factor.

**Table 2. List of antibodies used for lymphocyte flow cytometry**

| Marker | Vendor | Cat# | RRID |
|---|---|---|---|
| Perforin | Biolegend | 308121 | AB_2566203 |
| CD56 | Biolegend | 362537 | AB_2565855 |
| CD8 | Biolegend | 301041 | AB_11125174 |
| CD69 | Biolegend | 310931 | AB_2561370 |
| IFN-γ | Biolegend | 502505 | AB_315230 |
| IL4 | Biolegend | 500808 | AB_315127 |
| IL5 | Biolegend | 500903 | AB_315138 |
| IL13 | Biolegend | 501903 | AB_315198 |
| Granzyme B | Biolegend | 372215 | AB_2728382 |
| CD4 | Biolegend | 344607 | AB_1953235 |
| TNF | Biolegend | 502929 | AB_2204080 |
| IL-17A | Biolegend | 512333 | AB_2563985 |
| CD3 | Biolegend | 300423 | AB_493740 |

Abbreviations: IL, interleukin; TNF, tumor necrosis factor.

#### Continuous glucose monitoring

Mean glucose concentration was calculated from the CGM data using R "One push-up" (R Foundation for Statistical Computing, Vienna, Austria).

### Statistical Analysis

Two participants were excluded from the analyses because they had an active inflammatory state on 1 of the measurement days (1 had gout, 1 a severe cold). Because of 3 missing samples, the flow cytometry analyses were performed on 9 participants, and the CGM data analyses included 11 participants because of 1 missing sample (Fig. S4 (14)). We used random effects models to account for the 2 measurements for each participant, with period and treatment as independent variables. Data that were not normally distributed were analyzed using the Wilcoxon signed rank test. Correlations

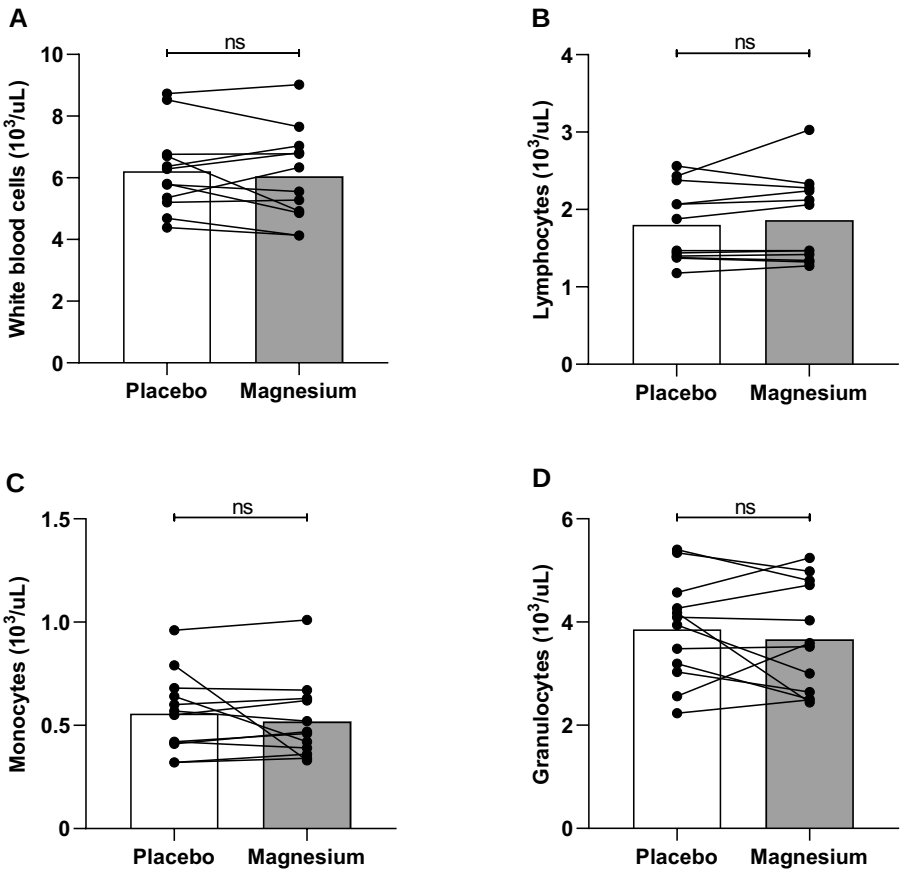


**Figure 1.** Counts ($10^3$/μL) of white blood cells (A), lymphocytes (B), monocytes (C), and granulocytes (D) after treatment with placebo (white) and magnesium (gray). ns, not significant. Data are presented as mean and individual values.

were analyzed using Spearman's rank-order test. Olink data were analyzed using linear modeling from the limma package in R and the inflammatory proteome analysis was corrected for multiple testing using the Benjamini–Hochberg method with a false discovery rate <0.05. Statistical analyses were performed using Stata version 17, IBM SPSS version 27, and R version 4.1.3 All data are expressed as mean ± SEM or median (interquartile range), unless otherwise specified. $P < .05$ was considered to be statistically significant.

We performed a sensitivity analysis where we excluded 3 additional participants because they had an infection or were vaccinated in the month before the blood draw, which did not materially change the results (data not shown).

## Results

Twelve adults with insulin-treated type 2 diabetes were included (7 males, mean ± SD age 67 ± 7 years, body mass index 31 ± 5 kg/m$^2$, magnesium 0.73 ± 0.05 mmol/L, $HbA_{1c}$ 7.5 ± 0.9% [58 ± 9 mmol/mol], diabetes duration 20 ± 8 years, insulin dose 55 ± 28 U/day). Serum magnesium was significantly higher after treatment with magnesium than with placebo (0.76 ± 0.02 vs 0.69 ± 0.02 mmol/L, $P < .001$), as was urinary magnesium excretion (magnesium/creatinine ratio 0.23 ± 0.03 vs 0.15 ± 0.02, $P = .006$). We found no difference in body mass index (30.6 ± 1.4 vs 30.7 ± 1.4 kg/m$^2$), $HbA_{1c}$ (7.49 ± 0.21 vs 7.49 ± 0.19%), mean glucose concentration (9.6 ± 0.5 vs 9.5 ± 0.3 mmol/L), serum potassium (4.2 ± 0.1 vs 4.1 ± 0.1 mmol/L), and calcium (corrected for serum albumin 2.4 ± 0.03 vs 2.4 ± 0.02 mmol/L) levels between both treatment arms (magnesium vs placebo respectively).

### Cell Count

Absolute numbers of white blood cells, lymphocytes, monocytes, and granulocytes after magnesium were similar to placebo treatment (Fig. 1). We found no correlation between the change in serum magnesium or change in urinary magnesium excretion with the change in immune cell counts after treatment with magnesium (Figs. S5 and S6 (14)).

### Cell Function

Magnesium supplementation lowered the ex vivo inflammatory functionality of lymphocytes compared with placebo (Fig. 2). IFN-γ production from stimulated CD8$^+$ T-cells and T-helper 1 cells was lower after treatment with magnesium than with placebo, as was IL4/IL5/IL13 production from T-helper 2 cells. There was no difference in these outcomes when comparing period 1 (5 participants magnesium, 4 placebo) with period 2 (4 participants magnesium, 5 placebo) (Fig. S7 (14)). Responses of other T-cell subsets did not differ between both treatment arms.

The ex vivo inflammatory functionality of monocytes (Fig. 3) and NK cells (Fig. S8 (14)) after magnesium was similar to placebo.

### Circulating Inflammatory Markers

Circulating inflammatory mediators, measured using a proteomics approach, did not differ after magnesium treatment

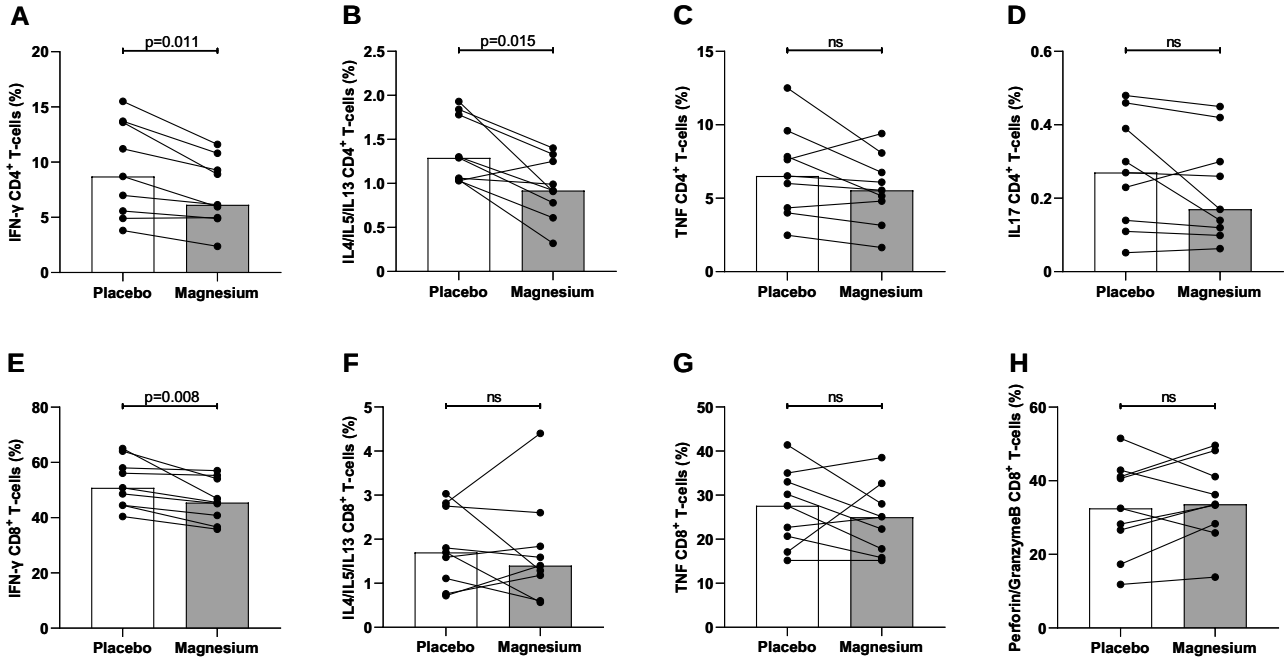


**Figure 2.** Percentage of IFN-γ producing $CD4^+$ T-cells (A), IL4/IL5/IL13 producing $CD4^+$ T-cells (B), TNF producing $CD4^+$ T-cells (C), IL17 producing $CD4^+$ T-cells (D), IFN-γ producing $CD8^+$ T-cells (E), IL4/IL5/IL13 producing $CD8^+$ T-cells (F), TNF producing $CD8^+$ T-cells (G), and perforin/granzyme B producing $CD8^+$ T-cells (H) under pathogenic stimulation with PMA/ionomycin after treatment with placebo (white) and magnesium (gray). ns, not significant. Data are presented as median and individual values.

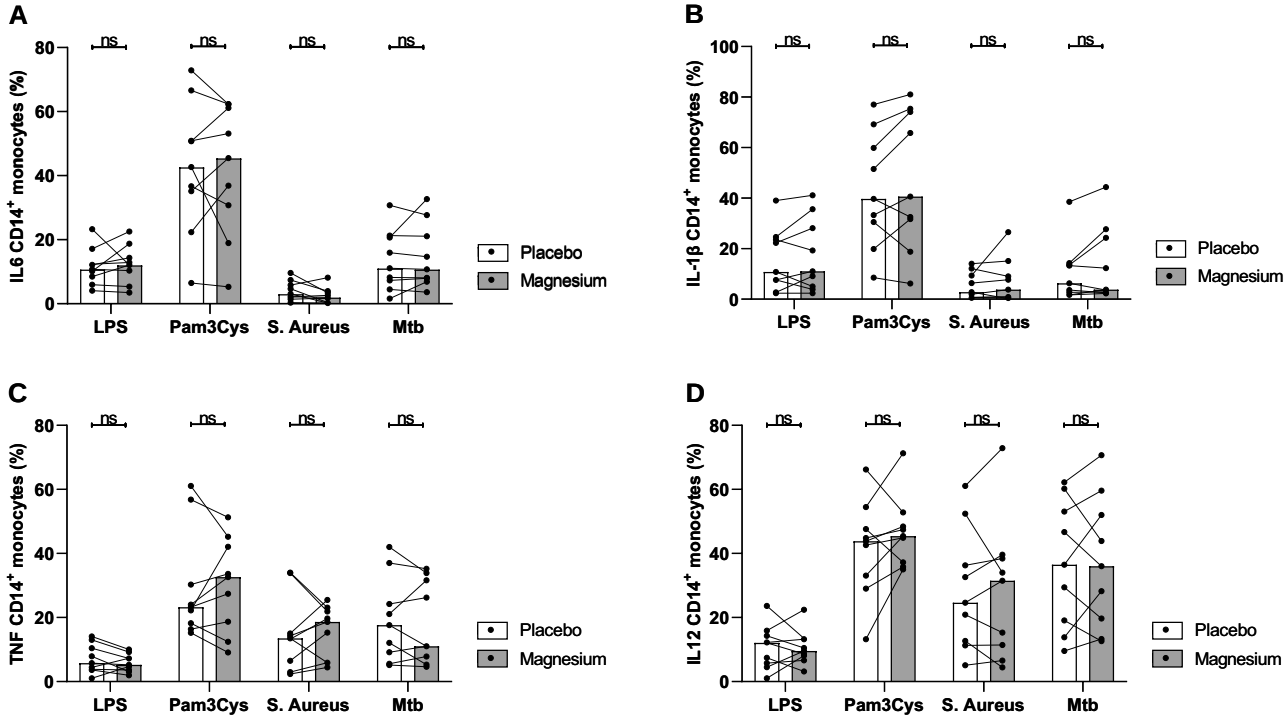


**Figure 3.** Percentage of IL6 (A), IL-1β (B), TNF (C), and IL12 producing $CD14^+$ monocytes (D) under pathogenic stimulation after treatment with placebo (white) and magnesium (gray). S. Aureus, *Staphylococcus aureus*; Mtb, *Mycobacterium tuberculosis*. Data are presented as median and individual values.

compared with placebo (Fig. S9 (14)). While hsCRP numerically decreased during treatment with magnesium compared with placebo (1.6 [1.0-3.5] vs 3.3 [0.9-6.7] mg/L), this did not attain formal statistical significance ($P = 0.062$) (Fig. 4). We found no correlation between the serum magnesium concentration or urinary magnesium excretion vs the circulating inflammatory mediators (Tables S1 and S2 (16)).

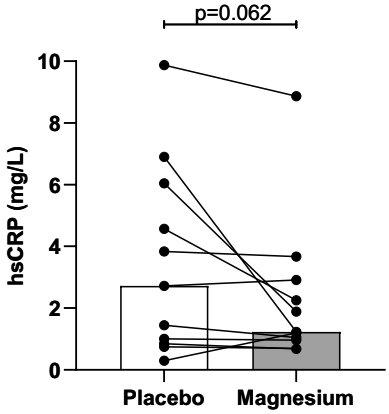


**Figure 4.** High sensitivity (hs) CRP level after treatment with placebo (white) and magnesium (gray). Data are presented as median and individual values.

## Discussion

The main finding of this study is that magnesium supplementation lowered the ex vivo inflammatory capacity of $CD8^+$ and $CD4^+$ T-cells in people with type 2 diabetes and low baseline magnesium levels, but it did not affect immune cell numbers or ex vivo monocyte function. Besides a tendency for lower hsCRP levels, magnesium did not affect levels of circulating inflammatory proteins. These results suggest a potential beneficial effect of modulating inflammatory responses of T-lymphocytes by correction of low magnesium levels in people with type 2 diabetes.

Our results show that the functionality of T-cells was modulated by magnesium supplementation, as shown by lower cytokine production upon pathogenic stimulation. Two previous reports support the relevance of extracellular magnesium levels for $CD4^+$ and $CD8^+$ T-cell function (11, 12). Liang et al investigated the effect of magnesium-supplemented medium on the ex vivo cytokine production of $CD4^+$ lymphocytes in people with acute asthma (11). Similar to our results, they found a decrease in IL5/IL13 production of T-helper 2 cells but, contrary to our findings, an increase in IFN-γ production of T-helper 1 cells when using magnesium concentrations up to 20 mmol/L, both after pathogenic stimulation. However, this may merely reflect a short-term, direct effect of extracellular magnesium on immune cell function using a magnesium concentration that far surpasses the physiological range and complicates translation to the in vivo condition, explaining the difference with our results.

We found no effect of magnesium treatment on an extensive explorative panel of circulating inflammatory proteins, although hsCRP levels were numerically lower after magnesium supplementation compared with placebo with borderline significance. Previous meta-analyses and systematic reviews have shown an inverse association between dietary magnesium intake and hsCRP (17) and a CRP-lowering effect of magnesium supplementation (18) in mixed populations, including participants without diabetes. In people with type 2 diabetes alone, a decrease in circulating hsCRP, TNF-α, and IL6 was found after magnesium supplementation (7-9). None of these studies used such an extensive proteomic approach as we did and were less selective with respect to low magnesium levels at study entry. One study included people undergoing hemodialysis, which limits generalizability (7). The lack of significant findings in our study may simply be a matter of power. Furthermore, we cannot exclude that higher dosed supplementation may have a more pronounced effect on the hsCRP level, although reaching this seems difficult due to concomitant greater urinary magnesium loss and gastrointestinal side effects.

We found no effect of magnesium supplementation on monocyte and lymphocyte cell count, nor on monocyte and NK cell function. This latter might suggest a specific effect of magnesium supplementation on parts of the adaptive immune system instead of an effect on the innate immune system. Literature regarding the effect of magnesium (supplementation) on different immune cell subsets, particularly monocytes, is scarce. Literature highlights differences in the identity of magnesium-specific ion channels in the innate and adaptive immune system (19, 20). This may contribute to the different effect of magnesium on the functionality of monocytes and lymphocytes found in our study, especially since cytokine production is mediated by the intracellular magnesium level (10). One could hypothesize that the uptake of magnesium varies across different immune cell subsets, which can differentially affect the cell's capacity of producing and secreting cytokines, which may explain the different effect of magnesium on monocytes and lymphocytes. In clinical practice, serum magnesium is still used to assess magnesium status, sometimes combined with the urinary magnesium excretion (21, 22). In our study, serum magnesium increased after supplementation, as did urinary magnesium excretion, which may reflect an adequate whole-body magnesium status. We did not measure the intracellular magnesium concentration of different cell types. Further research needs to elucidate whether this explains the T-cell–specific altered immune function after magnesium supplementation. Furthermore, based on our data, we can conclude that oral magnesium supplementation impacts IFN-γ production upon PMA/ionomycin stimulation of T-cells, yet whether longer or different types of T-cell stimulation would impact on other T-cell functions including proliferation is currently unknown. Therefore, since we found this T-cell–specific effect of magnesium supplementation upon PMA/ionomycin stimulation, it may be important to gain more insight in T-cell dynamics and therefore study the effect of magnesium on different T-cell subpopulations.

In conclusion, magnesium supplementation lowers ex vivo IFN-γ production of $CD8^+$ and $CD4^+$ T-cells as well as cytokine production of T-helper 2 cells after pathogenic stimulation in people with type 2 diabetes having low magnesium levels. Furthermore, magnesium supplementation tends to decrease hsCRP levels in this group. These results provide preliminary evidence for a potential beneficial effect of magnesium supplementation on the immune function in this population. However, larger trials and studies exploring the underlying mechanisms are required to support the potential benefits of magnesium supplementation on (low-grade) inflammation in people with type 2 diabetes.

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involved in the collection, analyses, and interpretation of data, nor in writing the report and the decision to submit for publication.

## Disclosures

The authors have no other conflicts to disclose that are relevant to this manuscript.

## Author Contributions

All authors designed the study. L.C.A.D. recruited the participants and collected the data. M.A. performed the laboratory experiments. L.C.A.D. and M.A. performed the statistical analyses and wrote the first version of the manuscript. All authors discussed the results and implications, commented on the manuscript at all stages and approved the final version of the manuscript. R.S. is the guarantor of this work and, as such, had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

## Data Availability

Original data generated and analyzed during this study are included in this published article or in the data repositories listed in the references.

## Clinical Trial Information

Trial registry number: EudraCT 2021-001243-27 (registered December 9, 2021).

## References


1. Esser N, Legrand-Poels S, Piette J, Scheen AJ, Paquot N. Inflammation as a link between obesity, metabolic syndrome and type 2 diabetes. *Diabetes Res Clin Pract*. 2014;105(2):141-150.
2. Oost LJ, Tack CJ, de Baaij JHF. Hypomagnesemia and cardiovascular risk in type 2 diabetes. *Endocr Rev*. 2023;44(3):357-378.
3. Kostov K. Effects of magnesium deficiency on mechanisms of insulin resistance in type 2 diabetes: focusing on the processes of insulin secretion and signaling. *Int J Mol Sci*. 2019;20(6):1351.
4. Oost LJ, van der Heijden A, Vermeulen EA, *et al*. Serum magnesium is inversely associated with heart failure, atrial fibrillation, and microvascular complications in type 2 diabetes. *Diabetes Care*. 2021;44(8):1757-1765.
5. Simmons D, Joshi S, Shaw J. Hypomagnesaemia is associated with diabetes: not pre-diabetes, obesity or the metabolic syndrome. *Diabetes Res Clin Pract*. 2010;87(2):261-266.
6. Nielsen FH. Magnesium deficiency and increased inflammation: current perspectives. *J Inflamm Res*. 2018;11:25-34.
7. 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):809-817.
8. Zghoul N, Alam-Eldin N, Mak IT, Silver B, Weglicki WB. Hypomagnesemia in diabetes patients: comparison of serum and intracellular measurement of responses to magnesium supplementation and its role in inflammation. *Diabetes Metab Syndr Obes*. 2018;11:389-400.
9. Rashvand S, Mobasseri M, Tarighat-Esfanjani A. The effects of choline and magnesium co-supplementation on metabolic parameters, inflammation, and endothelial dysfunction in patients with type 2 diabetes mellitus: a randomized, double-blind, placebo-controlled trial. *J Am Coll Nutr*. 2019;38(8):714-721.
10. Sugimoto J, Romani AM, Valentin-Torres AM, *et al*. Magnesium decreases inflammatory cytokine production: a novel innate immunomodulatory mechanism. *J Immunol*. 2012;188(12):6338-6346.
11. Liang RY, Wu W, Huang J, Jiang SP, Lin Y. Magnesium affects the cytokine secretion of $CD4^+$ T lymphocytes in acute asthma. *J Asthma*. 2012;49(10):1012-1015.
12. Lötscher J, Martí ILAA, Kirchhammer N, *et al*. Magnesium sensing via LFA-1 regulates CD8(+) T cell effector function. *Cell*. 2022;185(4):585-602.e29.
13. Drenthen LCA, de Baaij JHF, Rodwell L, van Herwaarden AE, Tack CJ, de Galan BE. Oral magnesium supplementation does not affect insulin sensitivity in people with insulin-treated type 2 diabetes and a low serum magnesium: a randomised controlled trial. *Diabetologia*. 2024;67(1):52-61.
14. Drenthen LCA, Ajie A, de Baaij JHF, Tack CJ, de Galan BE, Stienstra R. Supplemental figure 1–9: data from magnesium supplementation modulates T-cell function in people with type 2 diabetes and low serum magnesium levels. Figshare. doi:10.6084/m9.figshare.24534604. Date of deposit 9 November 2023.
15. Assarsson E, Lundberg M, Holmquist G, *et al*. Homogenous 96-plex PEA immunoassay exhibiting high sensitivity, specificity, and excellent scalability. *PLoS One*. 2014;9(4):e95192.
16. Drenthen LCA, Ajie A, de Baaij JHF, Tack CJ, de Galan BE, Stienstra R. Supplemental table 1–2: Data from magnesium supplementation modulates T-cell function in people with type 2 diabetes and low serum magnesium levels. Figshare. doi:10.6084/m9.figshare.24534661. Date of deposit 9 November 2023.
17. 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):510-516.
18. Mazidi M, Rezaie P, Banach M. Effect of magnesium supplements on serum C-reactive protein: a systematic review and meta-analysis. *Arch Med Sci*. 2018;14(4):707-716.
19. Brandao K, Deason-Towne F, Perraud AL, Schmitz C. The role of Mg2+ in immune cells. *Immunol Res*. 2013;55(1-3):261-269.
20. Feske S, Wulff H, Skolnik EY. Ion channels in innate and adaptive immunity. *Annu Rev Immunol*. 2015;33(1):291-353.
21. Huijgen HJ, Soesan M, Sanders R, Mairuhu WM, Kesecioglu J, Sanders GT. Magnesium levels in critically ill patients. What should we measure? *Am J Clin Pathol*. 2000;114(5):688-695.
22. de Baaij JH, Hoenderop JG, Bindels RJ. Magnesium in man: implications for health and disease. *Physiol Rev*. 2015;95(1):1-46.