Dietary Magnesium Intake and Kidney Stone: The National Health and Nutrition Examination Survey 2011–2018

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ABSTRACT

BACKGROUND: The association between dietary magnesium intake (DMI) and kidney stone (KS) disease is not clear.

AIM: To determine the association between DMI and prevalent KS disease defined as self-report of any previous episode of KS.

METHODS: We examined The National Health and Nutrition Examination Survey (NHANES) 2011–2018 and used logistic regression analyses adjusting for demographics, BMI, histories of hypertension, diabetes, thiazide use, cigarette smoking, alcohol drinking, relevant dietary and supplemental intakes to determine the independent association between DMI and prevalent KS disease.

RESULTS: A total of 19,271 participants were eligible for the final analysis, including 1878 prevalent KS formers. Mean DMI among stone formers was 295.4 mg/day, as compared to 309.6 mg/day among non-stone formers (p=0.02). Higher DMI was strongly associated with lower odds of prevalent KS disease in univariate analysis regardless of when DMI was analyzed as a continuous variable (OR=0.94, 95% CI: 0.89–0.99, p=0.02) or when the extreme quartiles of DMI were compared (OR=0.74, 95% CI: 0.60–0.92, p=0.007). In the multivariable-adjusted regression analysis, those in the highest quartile of DMI compared to the lowest quartile (≥379 mg vs. <205 mg) had significantly reduced odds of prevalent KS (OR=0.70, 95% CI: 0.52–0.93, p=0.01). When DMI was analyzed as a continuous variable, there was a trend toward reduced odds of prevalent KS disease with higher DMI (OR=0.92 per 100 mg, 95% CI: 0.84–1.01, p=0.07).

CONCLUSIONS: Our study suggests that higher DMI is associated with a reduced risk of KS disease. Future prospective studies are needed to clarify the causal relationship between DMI and KS disease.

KEYWORDS: Dietary magnesium intake, renal stone, urolithiasis, nephrolithiasis

INTRODUCTION

Kidney stone (KS) disease is highly prevalent worldwide, with roughly 1 in every 11 people afflicted in the United States.[1] It carries significant morbidity and poses a huge economic burden to the society.[2,3] Calcium oxalate stone is by far the most common type, accounting for the vast majority of all stones identified.[4]

Magnesium (Mg) has long been thought to play a role in the formation of KS. In vitro studies have shown that Mg can inhibit each of the steps involved in formation of KS including supersaturation,[5] nucleation of calcium oxalate crystals,[6,7] aggregation,[8] as well as crystal growth.[6,9] Once formed, further growth of calcium oxalate monohydrate crystals occurs by adsorbing calcium and oxalate ions on its surface,[10] which promotes adhesion to renal epithelial cells.[11] Mg competitively gets adsorbed on calcium oxalate monohydrate crystals and has been shown to inhibit the adhesion of preformed calcium monohydrate crystals to renal cells.[12] In animal studies, hypomagnesemia has been associated with development of calcium oxalate monohydrate crystals.[13] Dietary Mg supplementation resulted in increased urinary Mg[14] and prevented the formation of calcium oxalate KS.[15]

It is well known from previous human studies that calcium stone formers tend to excrete less Mg in the urine than their non-stone forming counterparts, suggesting an inhibitory role of Mg in KS formation.[16-18] However, results from small interventional studies have been inconsistent in demonstrating reduction in urinary oxalate or reducing recurrence of KS disease.[19-24] Thus far, it remains unclear whether DMI modifies KS risk in humans.

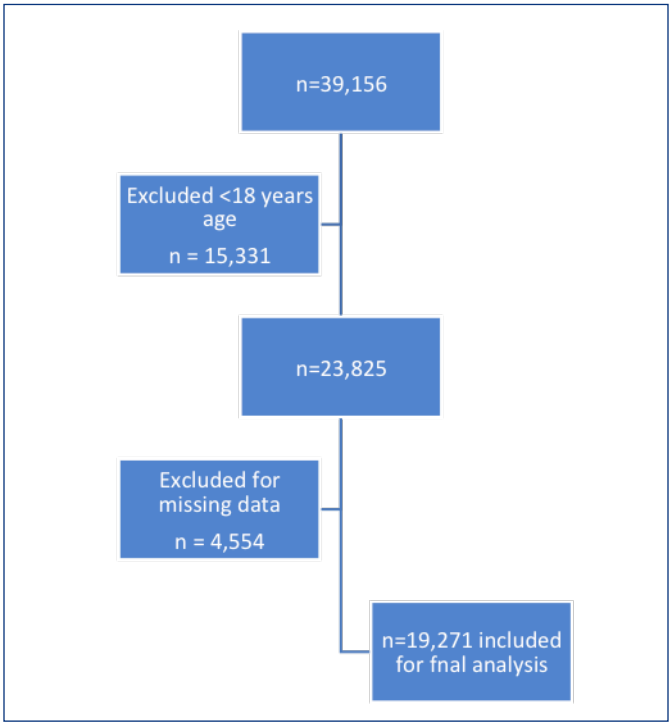
Here, we used a large US population survey database, the National Health and Nutrition Examination Survey (NHANES) from 2011 to 2018, to examine the independent association between DMI with KS disease.

METHODS

Study population

The NHANES is an ongoing series of cross-sectional assessments of the health and nutritional status of adults and children in the US. Since 1999, the program has been conducted continuously, with each two-year sample selected to represent the civilian non-institutionalized US population of all

Figure 1. Selection of study population



ages.[25] The survey collects demographic, socioeconomic, dietary, and health-related information, in addition to the examination and laboratory data obtained by highly trained medical personnel. A total of 39,156 participants were interviewed for NHANES from 2011 to 2018. Of these, our analysis included 19,271 participants aged 18 years or older with complete data on dietary Mg, history of KS, and the covariates of interest (**Figure 1**).

Primary exposure and outcome

The primary exposure was daily DMI, excluding intake specifically from supplements or antacids. DMI in mg/day was calculated by matching foods and beverages listed on the 24-hour dietary recall interview with the USDA's Food and Nutrient Database for Dietary Studies. Of the two 24-hour recall periods, only data from day one was included in the present analysis.

The primary outcome of interest, KS disease, was based on an affirmative response to the following question, "Have you ever had kidney stones?" Participants who refused to respond or did not know were excluded.

Covariates

Age, sex, race, history of diabetes, history of hypertension, thiazide use, and smoking status were obtained from questionnaires. Body mass index (BMI) was calculated from height and weight measured during the health examination. Information on alcohol and dietary intake of protein, sodium, calcium, vitamin D, zinc, and total calories were obtained from the same day one, 24-hour dietary recall interview when DMI was measured. Supplemental calcium, vitamin D, and zinc were measured by the corresponding day one, 24-hour supplement recall interview.

Analysis

Statistical analysis was performed with Stata MP version 18 (StataCorp, College Station, TX) using survey-specific procedures to accommodate the complex sampling design and estimate standard errors by Taylor linearization. Dietary intake day one sampling weights were divided by four to account for the combination of two-year survey cycles from 2011–2018. Logistic regression was applied to estimate crude and multivariable-adjusted odds ratios (OR) and 95% confidence intervals (CI) for DMI and prevalent KS disease. DMI was examined as both a continuous and a categorical predictor, with the latter variable created from quartiles of the DMI distribution. Deviations from a linear relationship between continuous DMI and KS disease were tested by including a quadratic term in the model, and interactions between DMI, sex, and age were evaluated by including product terms in the models. The multivariable models included the following covariates: sex, age (years), race (non-Hispanic White, non-Hispanic Black, Hispanic/Latino, Asian, Other), BMI (<25, 25–<30, 30+ kg/m^2), diabetes (no, borderline/yes), hypertension, thiazide diuretic use, smoking (never, former, current), daily alcohol consumption (none, some [<70g], heavy [70+ g]), dietary calories (kcal), dietary protein (g), water (g), dietary sodium (mg), dietary and supplemental calcium (mg), dietary and supplemental zinc (mg), and dietary and supplemental vitamin D (µg). National Center for Health Statistics guidelines for reporting statistical reliability of proportions were followed.[26]

RESULTS

A total of 19,271 participants were included in this analysis. Of these, 1,878 (10.0%, weighted) reported a history of stones. Mean DMI was 295.4 mg/day among stone formers and was significantly different as compared to 309.6 mg/day among non-stone formers. As shown in **Table 1**, stone formers tended to be older, male, non-Hispanic White, and had a higher BMI compared to non-stone formers. They were also more likely to have a history of diabetes, hypertension, and to use thiazide diuretics. Lastly, they were more likely to be smokers but less likely to drink alcohol.

In the univariate analysis, higher DMI was strongly associated with lower odds of prevalent KS disease when DMI was analyzed as a continuous variable (OR=0.94, 95% CI: 0.89–0.99, p=0.02) or when the highest quartile of DMI was compared to the lowest (OR=0.74, 95% CI: 0.60–0.92, p=0.007). After adjustment for age, sex, race, BMI, histories of hypertension, diabetes, thiazide use, cigarette smoking, alcohol consumption, dietary intakes of calorie, protein,

Table 1. Baseline characteristics of the study population

	KS Former	Non-KS Former	p value
Total n, unweighted	1,878	17,393	
Male sex	53.8 (1,008)	47.7 (8,343)	0.006
Age (y)	53.7 ± 0.46	47.1 ± 0.34	<0.001
Race			<0.001
Non-Hispanic White	74.9 (961)	63.6 (6,392)	
Non-Hispanic Black	6.2 (271)	11.9 (4,122)	
Hispanic/Latino	12.1 (450)	15.2 (4,119)	
Asian	2.8 (121)	5.9 (2,127)	
Other	4.1 (75)	3.4 (633)	
BMI (kg/m2)			<0.001
<25.0	19.1 (357)	29.7 (5,106)	
25.0–<30.0	32.0 (617)	32.5 (5,571)	
30.0+	48.8 (904)	37.8 (6,716)	
History of diabetes	23.6 (507)	11.4 (2,645)	<0.001
History of hypertension	47.7 (966)	32.3 (6,307)	<0.001
Thiazide diuretic use	12.1 (231)	7.7 (1,570)	<0.001
Smoking status			<0.001
Never	50.2 (930)	57.2 (10,070)	
Former	30.8 (571)	24.1 (3,964)	
Current	19.0 (377)	18.7 (3,359)	
Alcohol consumption			0.02
None (0 g/d)	78.6 (1,536)	74.3 (13,386)	
Some (>0–<70g/d)	19.0 (297)	21.4 (3,317)	
Heavy (70+ g/d)	2.5 (45)	4.4 (690)	
Total calories (kcal)	2,116.6 ± 35.1	2,153.5 ± 9.3	0.31
Protein intake (g)	81.0 ± 1.7	83.1 ± 0.47	0.26
Water intake (g)	1,191.7 ± 36.8	1,244.5 ± 20.6	0.17
Dietary sodium (mg)	3,510.8 ± 68.0	3,555.8 ± 17.7	0.52
Dietary & supplemental calcium (mg)	1,079.6 ±23.2	1,110.8 ± 10.1	0.20
Dietary & supplemental zinc (mg)	15.9 ± 0.48	15.0 ± 0.14	0.08
Dietary & supplemental vitamin D (µg)	23.2 ± 2.6	19.2 ± 0.79	0.13
Dietary magnesium (mg)	295.4 ± 6.2	309.6 ± 2.2	0.02
Quartiles			0.01
0–204	27.8 (595)	25.2 (4,846)	
205–280	25.1 (481)	24.6 (4,308)	
281–378	26.1 (420)	24.6 (4,194)	
379–2,725	20.9 (382)	25.5 (4,045)	

Values are expressed as weighted means ± SE or % (unweighted n).
Abbreviations: BMI = body mass index, KS = kidney stone.

Table 2. Odds ratios of prevalent kidney stones according to dietary magnesium intake in the multivariable regression model

		Unadjusted Models		Adjusted Models*	
Dietary Magnesium Intake		OR (95% CI)	p value	OR (95% CI)	p value
Continuous variable, per 100 mg		0.94 (0.89–0.99)	0.02	0.92 (0.84–1.01)	0.07
Categorial variable	Quartile 1: 0–204 mg	REF		REF	
	Quartile 2: 205–280 mg	0.93 (0.79–1.09)	0.34	0.91 (0.77–1.08)	0.27
	Quartile 3: 281–378 mg	0.96 (0.82–1.13)	0.63	0.91 (0.75–1.10)	0.34
	Quartile 4: 379–2,725 mg	0.74 (0.60–0.92)	0.007	0.70 (0.52–0.93)	0.01

Abbreviations: OR = odds ratio, CI = confidence interval.
*Multivariable model included age, sex, race, BMI, histories of hypertension, diabetes, thiazide use, cigarette smoking, alcohol consumption, dietary intakes of calorie, protein, water, sodium, and both dietary and supplemental intakes of calcium, zinc, and vitamin D.

water, sodium, and both dietary and supplemental intakes of calcium, zinc, and vitamin D, higher DMI had a trend toward an association with reduced odds of prevalent KS disease (OR 0.92 per 100 mg increase, 95% CI: 0.84–1.01, p=0.07). No deviation from a linear relationship between DMI and odds of KS disease was observed. In addition, we evaluated KS risk associated with extreme categories of DMI. We divided DMI into quartiles. Among stone formers, there were 595 participants in quartile 1 (<204 mg/day), 481 participants in quartile 2 (205–280 mg/day), 420 participants in quartile 3 (281–378 mg/day), and 382 participants in quartile 4 (≥379 mg/day), whereas among non-stone formers, the corresponding numbers of participants were 4846, 4308, 4194 and 4045 in each respective quartile. The multivariate-adjusted OR for stone formation was 0.70 (95% CI: 0.52–0.93, p = 0.01) in those who consumed ≥ 379 mg/day Mg compared to those with <205 mg/day of DMI (**Table 2**). There was no two-way interaction effect of age x DMI or of sex x DMI on KS formation. Also, no three-way interaction effect of age x sex x DMI on KS formation was noted.

In our multivariate logistic regression analyses, the following variables were found to have significant associations with increased odds of prevalent KS disease (**Table 3**): age, male sex, BMI, diabetes, hypertension, and increasing caloric intake. In contrast, non-Hispanic White, heavy alcohol intake, and dietary calcium intake were associated with lower odds of prevalent KS disease. The estimated associations were similar when DMI was modeled as a continuous variable or in quartiles.

Table 3. Multivariate-adjusted OR of covariates from the model with categorized DMI

	Model with DMI quartiles	
	OR (95% CI)	p value
Male sex	1.27 (1.03–1.56)	0.03
Age (y)*	1.02 (1.01–1.02)	<0.001
Race		
Non-Hispanic White	REF	
Non-Hispanic Black	0.41 (0.34–0.50)	<0.001
Hispanic/Latino	0.75 (0.63–0.89)	0.001
Asian	0.50 (0.37–0.68)	<0.001
Other	1.00 (0.71–1.41)	0.99
BMI (kg/m2)		
<25.0	REF	
25.0–<30.0	1.27 (1.06–1.52)	0.009
30.0+	1.55 (1.29–1.87)	<0.001
History of diabetes	1.67 (1.38–2.01)	<0.001
History of hypertension	1.26 (1.07–1.49)	0.007
Thiazide diuretic use	1.03 (0.78–1.36)	0.82
Smoking status		
Never	REF	
Former	1.08 (0.89–1.31)	0.43
Current	1.18 (0.95–1.46)	0.14
Alcohol consumption		
None (0 g/d)	REF	
Some (>0-<70g/d)	0.85 (0.69–1.06)	0.15
Heavy (70+ g/d)	0.50 (0.30–0.82)	0.007
Total calories (kcal)*	1.00 (1.00–1.00)	0.04
Protein intake (g)*	0.99 (0.99–1.01)	0.89
Water intake (g)*	1.00 (1.00–1.00)	0.24
Dietary sodium (mg)*	0.99 (0.99–1.00)	0.72
Dietary & supplemental calcium (mg)*	0.99 (0.99–0.99)	0.02
Dietary & supplemental zinc (mg)*	1.00 (0.99–1.01)	0.23
Dietary & supplemental vitamin D (µg)*	1.00 (0.99–1.00)	0.66

Abbreviations: DMI = dietary magnesium intake, BMI = body mass index, OR = odds ratio, CI = confidence interval. *OR per unit increase for continuous variables. OR and CI bounds may be the same due to rounding.

DISCUSSION

Mg is involved in multiple cellular activities and is important for bone mineral metabolism. Its role in KS formation remains unclear. Here, we analyzed a large US population cohort and showed a strong association between DMI and the odds of prevalent KS. To the best of our knowledge, it is the largest population study examining the effect of DMI on risk of KS formation independent of other known confounders for KS disease.

KS formation involves several key steps, including over secretion of stone forming minerals including calcium and oxalate, ultimately reaching a supersaturation point. It is followed by crystal nucleation, aggregation, and ultimately stone growth. Mg can affect KS formation in many different ways. When bound in the urinary space, magnesium oxalate is 100 times more soluble than calcium oxalate, therefore lowering the urinary saturation of calcium oxalate.[27] Indeed, in an artificial urine environment at acidic pH, Mg has not only been shown to bind with oxalate reducing supersaturation but also reduces time to supersaturation.[5] Using a mixed suspension crystallizer and scanning electron microscopy, investigators showed that Mg decreased both nucleation and growth rates of calcium oxalate crystals in physiological concentrations.[6] These findings were confirmed by other in vitro studies.[7,28-31] Once calcium oxalate crystals are formed, Mg can still slow down their growth.[9] Furthermore, using radioactive C-14, Lieske et al showed that increasing concentrations of Mg prevented adhesion of calcium oxalate monohydrate crystals to cultured kidney cells[12] which serves as the crystallization surface, and therefore blocking the final step of KS formation. In addition to its direct effect on stone formation, Mg can bind to oxalate in the gut and reduce its absorption,[32,33] further reducing the crystallization potential of calcium oxalate.[30]

In humans, calcium stone formers tend to excrete less urinary Mg than their non-stone forming counterparts[16,17,34] and presence of low urine Mg has been associated with high oxalate concentration.[35] Urinary Mg can be a surrogate of dietary Mg as supplementation leads to increased renal excretion in a state of normal total body Mg.[36] This suggests a role of dietary Mg in KS formation. This was also clinically demonstrated in an interventional study by Kato et al where dietary Mg supplementation with Mg oxide tablet raised urinary Mg and reduced urinary oxalate.[37]

However, despite favorable urinary biochemical changes associated with DMI, its effect on actual stone prevention remains unclear. Interventional trials have shown conflicting results. In 1980, Johansson et al examined the role of Mg supplementation in 56 stone formers without signs of Mg deficiency. They found that 500mg of oral Mg dihydroxide daily for 2–4 years led to a reduction in stone recurrence in 80–86% of patients as compared to controls who did not receive Mg supplement.[21,22] Ettinger et al reported similar findings in 64 recurrent stone formers. They observed an 85% reduced risk of stone recurrence after daily supplementation of potassium Mg citrate for three years when compared to controls.[24] However, results from other interventional studies contradict these findings. In a study of 75 KS formers, supplementation with 1300mg of Mg oxide did not reduce the rate of KS recurrence when compared with placebo.[19] Unfortunately, all these interventional studies were limited by small number of participants and the use of different Mg preparations with unpredictable bioavailability.[38]

Our study has several limitations. First, we used DMI as a marker of body Mg store, assuming a steady state is reached. However, potential gastrointestinal malabsorption (especially among elderly) should be considered, as it may misclassify individuals into different categories of Mg intake. Second, this study is cross-sectional and involves prevalent KS cases, a causal or temporal relationship cannot be established. However, it is very unlikely that stone formers increase their Mg intake for secondary stone prevention as existing studies have conflicting results, and no clinical guidelines to date recommend Mg intake for stone prevention. Third, the prevalent KS cases were self-reported, and some participants may have KS disease without self-awareness or clinical diagnosis. This may have led to potential misclassification but should be non-selective with regard to Mg intake. Therefore, if this misclassification exists, the results should be biased toward null. Fourth, we were unable to evaluate the effects of higher DMI on urine stone risk profile since these urine studies were not performed in NHANES 2011-2018. Finally, we do not have information on stone composition, although the vast majority of kidney stones in the general population reflected by NHANES are calcium-based.

CONCLUSION

Our study demonstrates that higher DMI is associated with a reduced prevalence of KS disease. Future prospective studies are needed to clarify the causal relationship and underlying mechanism.

References

1. Scales CD, Jr., Smith AC, Hanley JM, Saigal CS, Urologic Diseases in America P. Prevalence of kidney stones in the United States. Eur Urol 2012;62(1):160-5. PMID: 22498635.
2. Tang J, Mettler P, McFann K, Chonchol M. The association of prevalent kidney stone disease with mortality in US adults: the National Health and Nutrition Examination Survey III, 1988-1994. Am J Nephrol 2013;37(5):501-6. PMID: 23635714.
3. Dhondup T, Kittanamongkolchai W, Vaughan LE, et al. Risk of ESRD and Mortality in Kidney and Bladder Stone Formers. Am J Kidney Dis 2018;72(6):790-797. PMID: 30146423.
4. Lieske JC, Rule AD, Krambeck AE, et al. Stone composition as a function of age and sex. Clin J Am Soc Nephrol 2014;9(12):2141-6. PMID: 25278549.
5. Grases F, Rodriguez A, Costa-Bauza A. Efficacy of Mixtures of Magnesium, Citrate and Phytate as Calcium Oxalate Crystallization Inhibitors in Urine. Journal of Urology 2015;194(3):812-819. PMID: 25818031.
6. Kohri K, Garside J, Blacklock NJ. The Role of Magnesium in Cacium Oxalate Urolithiasis. British Journal of Urology 1988;61(2):107-115. PMID: 3349276.
7. Hsu Y-C, Lin Y-H, Shiau L-D. Effects of Various Inhibitors on the Nucleation of Calcium Oxalate in Synthetic Urine. Crystals 2020;10(4):333. PMID: doi:10.3390/cryst10040333.
8. Ryall RL, Harnett RM, Marshall VR. The effect of urine, pyrophosphate, citrate, magnesium and glycosaminoglycans on the growth and aggregation of calcium oxalate crystals in vitro. Clinica Chimica Acta 1981;112(3):349-356. PMID: 6263523.
9. Desmars JF, Tawashi R. Dissolution and growth of calcium oxalate monohydrate I. Effect of magnesium and pH. Biochimica et Biophysica Acta (BBA) - General Subjects 1973;313(2):256-267. PMID: 4741585.
10. Cho KR, Lee J-H, Seo H-S, et al. Mechanistic Pathways for the Molecular Step Growth of Calcium Oxalate Monohydrate Crystal Revealed by In Situ Liquid-Phase Atomic Force Microscopy. ACS Applied Materials & Interfaces 2021;13(31):37873-37882. PMID: 34327985.
11. Rabinovich YI, Esayanur M, Daosukho S, Byer KJ, El-Shall HE, Khan SR. Adhesion force between calcium oxalate monohydrate crystal and kidney epithelial cells and possible relevance for kidney stone formation. Journal of Colloid and Interface Science 2006;300(1):131-140. PMID: 16677664.
12. Lieske JC, Farell G, Deganello S. The effect of ions at the surface of calcium oxalate monohydrate crystals on cell-crystal interactions. Urol Res 2004;32(2):117-23. PMID: 14663633.
13. Rushton HG, Spector M. Effects of Magnesium Deficiency on Intratubular Calcium Oxalate Formation and Crystalluria in Hyperoxaluric Rats. Journal of Urology 1982;127(3):598-604. PMID: 7062446.
14. Corre T, Olinger E, Harris SE, et al. Common variants in CLDN14 are associated with differential excretion of magnesium over calcium in urine. Pflugers Arch 2017;469(1):91-103. PMID: 27915449.
15. Khan SR, Shevock PN, Hackett RL. Magnesium Oxide Administration and Prevention of Calcium Oxalate Nephrolithiasis. Journal of Urology 1993;149(2):412-416. PMID: 8426432.
16. Atakan IH, Kaplan M, Seren G, Aktoz T, Gül H, Inci O. Serum, urinary and stone zinc, iron, magnesium and copper levels in idiopathic calcium oxalate stone patients. Int Urol Nephrol 2007;39(2):351-6. PMID: 17203355.
17. Childs MA, Mynderse LA, Rangel LJ, Wilson TM, Lingeman JE, Krambeck AE. Pathogenesis of bladder calculi in the presence of urinary stasis. J Urol 2013;189(4):1347-51. PMID: 23159588.
18. Robertson WG. A risk factor model of stone-formation. Front Biosci 2003;8:s1330-8. PMID: 12957848.
19. Massey L. Magnesium therapy for nephrolithiasis. Magnes Res 2005;18(2):123-6. PMID: 16100850.
20. Gupta M, Gallante B, Bamberger JN, et al. Prospective Randomized Evaluation of Idiopathic Hyperoxaluria Treatments. J Endourol 2021;35(12):1844-1851. PMID: 34254834.
21. Johansson G, Backman U, Danielson BG, Fellström B, Ljunghall S, Wikström B. Biochemical and Clinical Effects of the Prophylactic Treatment of Renal Calcium Stones with Magnesium Hydroxide. Journal of Urology 1980;124(6):770-774. PMID: 7441826.
22. Johansson G, Backman U, Danielson BG, Fellström B, Ljunghall S, Wikström B. Effects of magnesium hydroxide in renal stone disease. J Am Coll Nutr 1982;1(2):179-85. PMID: 6764473.
23. Ettinger B, Citron John T, Livermore B, Dolman Loren I. Chlorthalidone Reduces Calcium Oxalate Calculous Recurrence but Magnesium Hydroxide Does Not. Journal of Urology 1988;139(4):679-684. PMID: 3280829.
24. Ettinger B, Pak Charles YC, Citron John T, Thomas C, Adams-Huet B, Vangessel A. Potassium-magnesium citrate is an effective prophylaxis against recurrent calcium oxalate nephrolithiasis. Journal of Urology 1997;158(6):2069-2073. PMID: 9366314.
25. Statistics NCfH. Continuous NHANES. CDC. 8/19/23 (https://wwwn.cdc.gov/nchs/nhanes/continuousnhanes/default.aspx).
26. Parker JD, Talih M, Malec DJ, et al. National Center for Health Statistics Data Presentation Standards for Proportions. Vital Health Stat 2 2017(175):1-22. PMID: 30248016.
27. Israr B, Frazier RA, Gordon MH. Effects of phytate and minerals on the bioavailability of oxalate from food. Food Chem 2013;141(3):1690-3. PMID: 23870879.

28. Kulaksizoglu S, Sofikerim M, Cevik C. Impact of various modifiers on calcium oxalate crystallization. Int J Urol 2007;14(3):214-8. PMID: 17430258.
29. Ibis F, Yu TW, Penha FM, et al. Nucleation kinetics of calcium oxalate monohydrate as a function of pH, magnesium, and osteopontin concentration quantified with droplet microfluidics. Biomicrofluidics 2021;15(6):064103. PMID: 34853626.
30. Riley JM, Kim H, Averch TD, Kim HJ. Effect of magnesium on calcium and oxalate ion binding. J Endourol 2013;27(12):1487-92. PMID: 24127630.
31. Guerra A, Meschi T, Allegri F, et al. Concentrated urine and diluted urine: the effects of citrate and magnesium on the crystallization of calcium oxalate induced in vitro by an oxalate load. Urol Res 2006;34(6):359-64. PMID: 16953377.
32. Voss S, Zimmermann DJ, Hesse A, von Unruh GE. The effect of oral administration of calcium and magnesium on intestinal oxalate absorption in humans. Isotopes Environ Health Stud 2004;40(3):199-205. PMID: 15370283.
33. Zimmermann DJ, Voss S, von Unruh GE, Hesse A. Importance of magnesium in absorption and excretion of oxalate. Urol Int 2005;74(3):262-7. PMID: 15812215.
34. Schwartz BF, Bruce J, Leslie S, Stoller ML. Rethinking the role of urinary magnesium in calcium urolithiasis. J Endourol 2001;15(3):233-5. PMID: 11339386.
35. Eisner BH, Sheth S, Dretler SP, Herrick B, Pais VM, Jr. High dietary magnesium intake decreases hyperoxaluria in patients with nephrolithiasis. Urology 2012;80(4):780-3. PMID: 22921695.
36. White J, Massey L, Gales SK, Dittus K, Campbell K. Blood and urinary magnesium kinetics after oral magnesium supplements. Clin Ther 1992;14(5):678-87. PMID: 1468087.
37. Kato Y, Yamaguchi S, Yachiku S, et al. Changes in urinary parameters after oral administration of potassium-sodium citrate and magnesium oxide to prevent urolithiasis. Urology 2004;63(1):7-11; discussion 11-2. PMID: 14751336.
38. Siener R, Jahnen A, Hesse A. Bioavailability of magnesium from different pharmaceutical formulations. Urol Res 2011;39(2):123-7. PMID: 20862466.

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Conflict of Interest

Authors declare that they have no competing interests.

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