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Does drinking coffee reduce the risk of kidney stone formation?

Elwira Servaas

National Medical Institute of the Ministry of the Interior and Administration, Wołoska 137, 02-507 Warszawa

https://orcid.org/0009-0004-8432-7824

servaaselwira@gmail.com

Olga Grelewicz

National Medical Institute of the Ministry of the Interior and Administration, Wołoska 137, 02-507 Warszawa

https://orcid.org/0000-0001-5738-9262

olga.grelewicz@gmail.com

Adam Juśkiewicz

National Medical Institute of the Ministry of the Interior and Administration, Wołoska 137, 02-507 Warszawa

https://orcid.org/0000-0001-9884-3513

ad.juskiewicz@gmail.com

Mateusz Haber

Central Clinical Hospital in Warsaw

Banacha 1a, 02-097, Warszawa

https://orcid.org/0009-0002-8441-4931

mhaber.mateusz@gmail.com

Adrianna Czachor

Infant Jesus Clinical Hospital UCC MUW,

Lindleya 4, 02-005 Warszawa

https://orcid.org/0009-0001-8596-9341

adriannaczachor@gmail.com

Alicja Kotula

Infant Jesus Clinical Hospital UCC MUW,

Lindleya 4, 02-005 Warszawa

https://orcid.org/0009-0008-9718-1667

kotulaalicja5@gmail.com

Paula Kula

Central Clinical Hospital in Warsaw,

Banacha 1a, 02-097, Warszawa

https://orcid.org/0009-0004-7503-2602

paulakula98@gmail.com

Natalia Kucy

Infant Jesus Clinical Hospital UCC MUW,

Lindleya 4, 02-005 Warszawa

https://orcid.org/0009-0007-5468-6289

tusia.noelle@icloud.com

Robert Siemiątkowski

SPZOZ-ZZ Independent Public Health Care Center

Witosa 2, 02-600, Maków Mazowiecki

robert.siem98@gmail.com

https://orcid.org/0009-0009-1499-9242

Abstract

Introduction: Kidney stones, a prevalent urological issue affecting 2% to 15% of the global population, result from complex physicochemical processes in urine. Untreated stones can lead to severe complications like ureter blockage and kidney damage. Diet plays a crucial role in stone formation, with historical negative views on coffee consumption. However, new research shows potential benefits of coffee. The purpose of this review was to analyze the association between coffee consumption and the risk of developing kidney stones.

State of knowledge: Kidney stones develop as solid masses in the kidney's collecting system and can consist of various substances like calcium oxalate, calcium phosphate, uric acid, and cystine. Understanding the formation of kidney stones involves analyzing the role of crystal retention. Coffee consumption has shown potential benefits in reducing the risk of kidney stones by influencing urine composition. Additionally, oxalate and calcium are key dietary components to consider in kidney stone prevention strategies. Coffee has demonstrated diverse health benefits, including protection against cardiovascular disease, type 2 diabetes and neurodegenerative conditions. Its impact on blood pressure, glucose metabolism, and neuroprotection highlights its potential role in promoting overall well-being.

Conclusions: Coffee consumption, particularly due to its caffeine content and other compounds like chlorogenic acid, may reduce the risk of kidney stone formation. Caffeine has shown anti-lithogenic properties, decreasing oxalate excretion and increasing magnesium and potassium excretion, potentially preventing stone formation. A study by P. Peerapen and V. Thongboonkerd highlighted caffeine's role in reducing crystal adhesion to renal cells as a key mechanism in preventing kidney stones. In summary, coffee's diverse components could provide protection against kidney stone development.

Keywords: Kidney stones, nephrolithiasis, coffee, caffeine.

1. Introduction and purpose

Nephrolithiasis, commonly known as kidney stones, is one of the most frequent urological diseases, with a reported prevalence ranging from 2% to 15% worldwide. [1,2] The formation of stones is a complex process that arises from various physicochemical events, including supersaturation, nucleation, growth, aggregation, and the retention of urinary stone components within tubular cells. [3] Without adequate treatment, kidney stones may lead to ureter blockage, hematuria, recurrent urinary tract infections, vomiting, or painful urination, ultimately resulting in permanent kidney damage [2]. Diet composition is believed to be a key factor in the formation of urinary stones [1,4]. Coffee is one of the most frequently consumed beverages worldwide. Many studies have proven the beneficial effects of caffeine intake on neurological and metabolic diseases, including Parkinson's disease and type 2 diabetes. [5] The purpose of this review was to analyze the association between caffeine consumption and the risk of developing kidney stones.

2. State of knowledge

Mechanisms of kidney stones formation

Kidney stones are solid masses that develop in the kidney's collecting system. They typically consist of calcium oxalate monohydrate, calcium oxalate dehydrates, calcium phosphate, uric acid, cystine, among other substances, as well as organic matter or a combination of these elements. These stones form when crystals grow into larger masses. [6] The most common urinary stone components are as follows: calcium oxalate- CaOx (65.9%), carbapatite (15.6%), urate (12.4%), struvite (2.7%), and brushite (1.7%). CaOx and urate stones were more frequently found in males, whereas carbapatite and struvite were more common in females. CaOx stones and carbapatite were predominantly seen in individuals aged 30 to 50 years and 20 to 40 years, respectively. Brushite and struvite stones were most prevalent in those younger than 20 years and older than 70 years. Carbapatite, brushite, CaOx, and cystine stones were more frequently found in the kidney, whereas urate and struvite stones typically formed in the bladder. Kidney stones are categorized into calcium stones and non-calcium stones based on their calcium content. Calcium-containing stones are the most prevalent type, with a combination of calcium oxalate (CaOx) and calcium phosphate (CaP) making up approximately 80% of all kidney stones. [7] While the exact process of urinary stone formation remains unclear, it is widely thought to be associated with crystal formation, particularly in the initial phases. None of these crystals would lead to urinary stone formation if they were expelled by the flow of urine. Therefore, the retention of crystals is a crucial factor. Crystal retention occurs when crystals grow large enough to become lodged in the renal tubules or when they adhere to the urothelium before being excreted. [6]

Randall’s plaque

Randall’s plaque (RP) is considered a key factor in the pathogenesis of calcium oxalate (CaOx) kidney stones. First described by Alexander Randall in 1937, these plaques are subepithelial deposits of calcium phosphate (CaP) located in the renal papillae. Randall’s plaque originates in the basement membranes of the thin loops of Henle. [6] Scanning electron microscopy (SEM) analysis has revealed that Randall's plaques are composed of a combination of tubules with calcified walls and tubules blocked by calcium phosphate (CaP) plugs. RP consists of calcium phosphate crystals intermixed with an organic matrix containing

diverse proteins, lipids, membrane-bound vesicles or exosomes, collagen fibers, and other elements of the extracellular matrix. [2] The initial development of Randall's plaques resembles the process of ectopic calcification. Due to the compromised integrity of the urothelium, plaque regions become exposed to urine. Urine molecules, along with osteopontin, Tamm Horsfall protein, and crystals present in urine, influenced by supersaturation, interact with the exposed plaque. This interaction results in the formation of a ribbon consisting of alternating matrix and crystal layers through repeated coating and crystallization. Eventually, the crystallization process breaks free from the matrix modulation, allowing crystals to extend into the urine space and initiating the formation of a calcium oxalate stone. [6] Previously considered a passive phenomenon, it has recently been recognized as a regulated process. Crystal deposition in different parts of the body occurs due to an imbalance between factors that prevent crystal formation and those that encourage it. [2,6] (table 1)

Promoters of stone formation	**Inhibitors of stone formation**
Ions: calcium, oxalate, urate and phosphate	Anions: citrate
Proteins and glycosaminoglycan: CD44, nucleolin, hyaluronan (HA), heat shock protein 90 (HSP90), annexin II and osteopontin (OPN)	Cations: magnesium, potassium
High Vitamin D serum level	Macromolecules: Osteopentin (OPN), Tamm-Horsfall protein (THP), urinary prothrombin fragment 1 (UPTF-1), nephrocalcin (NC) and some subunits of the serum IαI
Low pH urine	
High-alkaline urine	
Lysozyme, lactoferrin	
Low urine volume	

Table 1. Promoters and inhibitors of stone formation.

Risk factors

Nephrolithiasis should be considered a systemic condition because it involves the interplay of various risk factors. [8] The development of kidney stones is linked among others to systemic disorders such as obesity, diabetes, cardiovascular diseases, hypertension, and metabolic syndrome. [2] A higher incidence of urolithiasis, exceeding 75%, is observed in overweight and obese individuals with metabolic syndrome compared to those with normal weight [9]. The underlying mechanisms of stone formation in obese patients are believed to be linked to insulin resistance and a lithogenic urinary profile. These patients frequently develop uric acid stones and calcium oxalate stones. Insulin resistance is thought to affect renal acid-base metabolism, leading to a lower urine pH and an increased risk of uric acid stone disease [9,10]. Additionally, obesity is associated with an excessive intake of lithogenic substances and a higher incidence of urinary tract infections. Recent studies have indicated that renal stone disease heightens the risk of myocardial infarction, the progression of chronic kidney disease, and diabetes. [10] Apart from metabolic syndrome components, there are many other typical yet equally significant risk factors for the development of kidney stones. Dehydration, whether due to a warm climate or other factors, contributes to urolithiasis. Low urinary volume and high urine osmolality lead to increased urinary calcium and oxalate levels [11]. Similarly, working in hot and humid conditions increases the likelihood of developing kidney stones. [11] Moreover, lack of physical activity plays a crucial role in the prevalence of kidney stones formation [9]. Risk factors for stone formation can also be hereditary or associated with certain diseases, such as idiopathic hypercalciuria, hyperoxalosis, Dent's disease, medullary sponge kidney, polycystic kidney disease, hyperparathyroidism, irritable bowel disease (IBD), renal tubular acidosis, or sarcoidosis. Individuals with a family history of nephrolithiasis have a 2.5 times higher risk of developing kidney stones. [22]. The list of risk factors reported in Table 2 was obtained using already published evidence [22].

Risk factors of kidney stone	
Genetic	Idiopathic hypercalciuria Cystinuria: Dent's disease Hyperoxalosis
Kidney disease related	Medullary sponge kidney Horseshoe PKD (10% develop stones) Metabolic causes: hypercalcemia, hyperparathyroidism, DM and obesity
Systemic disease	GI, Inflammatory bowel diseases (Ox and UA stones)
Renal tubular acidosis (RTA)	Hypercalcemic states, Ca phosphate
Climate	Heat, water loss, sweating
Dietary	Na Oxalate Protein (animal) Acid/ alkaline ash diet Fluid Potassium and citrate Fluid Vitamins (C, D) Ca supplement Low Ca diet High protein weight loss diet
Sarcoid	Hypercalciuria, CaOx stone

Table 2. Risk factors of stone formation.

The role of sex-hormones

Sex-specific differences in kidney stone disease, including variations in prevalence and composition of stones, are well-documented and are believed to be influenced by sex

hormones. [12] Urolithiasis is more prevalent in males, with incidence rates approximately three times higher than in females. [13] Androgens have been found to reduce levels of bone bridge proteins and increase the excretion of oxalate in urine, while estrogen has been observed to have the opposite effect. [2,7]. Moreover, androgens stimulate the synthesis of glycolate oxidase. Androgen receptor (AR) signaling directly enhances the transcription of hepatic glycolate oxidase and kidney epithelial nicotinamide adenine dinucleotide phosphate oxidase (NADPH), subunit p22-PHOX, thereby promoting oxalate production, which can ultimately contribute to the formation of kidney stones. [2,7]. The androgen receptor (AR) presents a promising theoretical target for novel therapeutic approaches aimed at suppressing kidney stone formation. [2] On the contrary, estrogen serves as a protective factor against kidney stones, although the precise mechanism remains unclear. Studies have indicated that two crystal receptors for calcium oxalate (CaOx) on the plasma membrane, annexin A1 and α-enolase, play roles in enhancing the binding ability of renal tubular cells to crystals. Estrogen has been shown to decrease the expression of these receptors and their ability to bind crystals, thereby influencing oxalate metabolism and ultimately exerting a protective effect against kidney stone formation. [7] All these findings help to explain the higher incidence of nephrolithiasis observed in males compared to females.

The impact of diet on kidney stones formation

Dietary habits significantly influence the formation, growth, and recurrence of kidney stones. [14] Dietary recommendations aim to mitigate most lithogenic risk factors by decreasing urine supersaturation, particularly of calcium oxalate, calcium phosphate, and uric acid. Current guidelines suggest increasing fluid intake, maintaining a balanced calcium intake, reducing sodium and animal protein consumption, and increasing the intake of fruits and fibers. [15]

- **Fluids including coffee**

Insufficient fluid intake is recognized as the primary dietary risk factor for urolithiasis. [14] In fact, Littlejohns et al. demonstrated a 13% reduction in the risk of stone formation for every 200 mL of fluids consumed daily. [16] Due to this evidence, individuals prone to kidney stones are advised to produce at least 2 to 2.5 liters of urine per day by increasing their oral fluid intake. Besides the volume of fluid intake, the type of beverages consumed is also likely

to affect stone recurrence prevention. Soft drinks, which are very popular among the general population, typically contain fructose, which may increase the excretion of calcium, oxalate, and uric acid, thereby elevating the risk of kidney stones. [17].

In the context of coffee consumption, high doses of caffeine were initially linked to increased urinary excretion of calcium, sodium, and chloride. [18] However, recent studies have shown that higher urine output in individuals with high consumption of both caffeinated and decaffeinated coffee is associated with a lower risk of kidney stones. [17,19] Caffeine appears to have anti-lithogenic properties, as it is connected to reduced urinary excretion of oxalate, increased excretion of magnesium and potassium, and greater urine volume. [17,19] Conversely, it has been demonstrated that higher caffeine intake is linked to a slightly increased urinary excretion of calcium. Despite this rise in urinary calcium, the study by P. M. Ferraro suggests that the overall effect of caffeine may lower urinary lithogenicity, as evidenced by the significant inverse relationship between caffeine intake and urinary supersaturation of calcium oxalate and uric acid. [19] Interestingly, this inverse relationship was also observed for decaffeinated coffee in two studies by G. C. Curhan [20,21], indicating that other components in these beverages, responsible for their antioxidant and anti-inflammatory properties, might help reduce the risk of stone formation. [19] Additionally, coffee is high in magnesium, which is known to inhibit stone formation. [2,19] Surprisingly, it was discovered that the link between caffeine intake and the risk of kidney stones varies with BMI, though the reason for this remains unclear. [19]

- **Oxalate**

Oxalate is a plant-derived molecule and a terminal toxic metabolite with no known physiological function in humans. [22,23] It has no nutritional role and is excreted by the kidneys. Urinary oxalate is a critical risk factor for calcium oxalate stone formation, as variations in its concentration can significantly increase the urinary supersaturation of calcium oxalate. [22,23] Oxalate is predominantly found in plants, which use it to manage excess of calcium from water. [15] Consequently, substantial amounts of oxalate are typically consumed daily, although it is challenging to estimate the precise amount. [15,17] Foods high in oxalate are listed in Table 3. [15,22,23,24] Despite efforts to limit oxalate intake, it is widely present in foods, making reduction difficult. Boiling food can reduce oxalate content, that is why food processing and preparation methods are crucial for managing oxalate levels. [23] Understanding the oxalate content in foods is essential for dietary therapy in patients

with calcium oxalate stones, particularly regarding beverages, as high fluid intake is a key nutritional strategy for preventing kidney stone recurrence.

- **Calcium**

Calcium is a crucial electrolyte involved in numerous biological processes, including muscle contraction, energy metabolism (glycolysis, gluconeogenesis), bone health and growth [17,24]. The majority of kidney stones consist of calcium salts and hypercalciuria is a significant risk factor for their formation. [23,25]. While reducing calcium intake might appear beneficial for preventing stones, its effectiveness is not fully established. [25] Restricting dietary calcium can lead to bone loss and increased absorption and excretion of oxalate. Lower intestinal calcium levels enhance the absorption of uncomplexed oxalate, which increases urinary oxalate excretion. [23] Calcium supplementation is recommended only for patients with enteric hyperoxaluria. [25] A randomized trial comparing a normal calcium (1200 mg/day), low salt, and low animal protein diet to a low calcium diet (400 mg/day) in hypercalciuric stone formers demonstrated that a balanced calcium diet reduced both urinary oxalate excretion and the risk of new stone formation by approximately 50% over five years. [26] Idiopathic calcium stone formers are advised to consume between 1000 to 1200 mg of calcium in their daily diet. [23] Products with high calcium content are listed in Table 3. [15, 25]

Products high in Oxalate	Products high in Calcium
Vegetables: soybeans, spinach, white beans, rhubarb, potatoes (with skin), beets, peas **Nuts:** almonds, hazelnuts, peanuts **Beverages:** black and green tea Cocoa powder Rice bran, cornmeal, whole-grain flour	**Dairy products:** Yogurt, milk, cheese **Fish:** sardines, salmon Almond and cashew milk

Table 3. Products high in oxalate/calcium

The impact of coffee and caffeine on the human body

Coffee is one of the most widely consumed beverages worldwide. [27] This beverage is recognized for its caffeine content, often associated with its stimulating properties. However, coffee is not solely defined by caffeine. While many chemical compounds in coffee remain unidentified and the mechanisms of most known compounds are not fully understood, the biological properties of coffee are also attributed to other well-known compounds such as chlorogenic acid, trigonelline, cafestol, kahweol, and ferulic acid. [27, 28] Over the years, coffee has transitioned towards a more favorable perception in terms of health, propelled by a growing understanding of its pharmacological properties. [27,28]. Regular coffee consumption may help protect against various chronic conditions, including cardiovascular disease, type 2 diabetes, obesity, neurodegenerative conditions, as well as kidney malfunctions. [27,28,29]. Caffeine primarily functions, in the typical human intake range, by acting as an antagonist to adenosine receptors. Structurally resembling adenosine, the caffeine molecule can effectively inhibit adenosine's impact on A2A and A1 receptor types even at low concentrations following the consumption of just one cup of coffee. The blockage of these receptors by caffeine may contribute to coffee's protective effect against cardiovascular disease. [28,29]. Regular moderate coffee consumption (1-3 cups per day) may lower blood pressure and reduce the risk of developing hypertension by altering total peripheral resistance, diuresis, and heart rate. [28] Additionally, chlorogenic acids and their metabolites reduce oxidative stress (reactive oxygen species), leading to lower blood pressure by enhancing endothelial function and increasing nitric oxide bioavailability in the arteries. [29] Many studies show that moderate consumption of coffee (maximum 4 cups per day) is associated with inverse relationship with the development of heart failure and lower rates of atrial fibrillation. [30] Moreover coffee promotes the body loss. Caffeine inhibits phosphodiesterase, preventing cAMP degradation and leading to the accumulation of cAMP. This stimulates the release of hormones and neurotransmitters like dopamine and catecholamines (epinephrine and norepinephrine), which, in turn, enhance beta-adrenergic receptor stimulation, increasing fat breakdown and fatty acid oxidation. [31] Prospective epidemiological studies consistently show a link between regular coffee consumption and a reduced risk of type 2 diabetes. [32] Clinical studies have proved that coffee's ability to lower blood sugar depends not only on caffeine but also on other components, likely chlorogenic acid. Chlorogenic acid has

antioxidant and anti-inflammatory properties and can influence glucose and lipid metabolism. [33] However, the exact mechanisms behind coffee's diabetes-preventive effects remain unclear. [29,32]. Additionally, coffee and its components possess various neuroprotective properties that reduce the risk of cognitive decline and other neurodegenerative diseases such as Alzheimer's disease (AD) and Parkinson's disease. [34] AD is the most prevalent cause of dementia. Coffee appears to exert a beneficial influence on the progression of this condition by the impact of caffeine and chlorogenic acid on adenosine receptors, which ultimately contribute to the prevention of toxic β-amyloid peptide accumulations in the brain. [34] Interestingly, caffeine has also been demonstrated to enhance the sensitivity of ryanodine channels to calcium ions. Elevated levels of calcium ions can be detrimental to motor neurons in individuals with amyotrophic lateral sclerosis. [35] Moreover, moderate coffee consumption has indeed been linked to a reduced risk of chronic kidney disease (CKD). However, the precise biological mechanisms driving this association remain unclear. [36]

What is the mechanism by which coffee reduces the risk of kidney stone formation?

Many studies have shown a link between coffee consumption and increased risk of kidney stones. [17,18, 37] It was mostly contributed to the caffeine influence on the concentration of urine components and other compounds of coffee, which mechanism of action is not fully understood. [17,18]

In 2016 P. Peerapen and V. Thongboonkerd conducted an in vitro study to prove the positive effects of caffeine on calcium oxalate monohydrate (COM) kidney stone formation, using crystallization, crystal growth, cell-crystal adhesion, Western blotting, and immunofluorescence assays. [38] The study found that caffeine had contrasting effects on crystal properties. While it reduced the number of crystals, it simultaneously increased their size, resulting in an overall unchanged crystal mass. Interestingly, caffeine did not impact crystal growth. However, it significantly decreased the ability of MDCK renal tubular cells to bind crystals in a dose-dependent manner. Further analysis revealed that caffeine treatment led to decreased levels of annexin A1 on the apical surface of cells, with translocation into the cytoplasm. Notably, other COM crystal-binding proteins (annexin A2, α-enolase, HSP70, and HSP90) remained unaffected. [38] The study provided a new in vitro evidence supporting caffeine’s protective mechanism against kidney stone formation. It revealed that caffeine facilitates the translocation of annexin A1 from the apical surface to the cytoplasm, thereby

reducing the crystal-binding capacity of renal tubular epithelial cells, which seems to be the main mechanism in which coffee reduces the risk of kidney stone formation [38].

3. Summary

Coffee consumption has been linked to various positive health effects, including potentially reducing the risk of kidney stone formation. Studies have shown that caffeine, a key component of coffee, may have anti-lithogenic properties that could help lower the risk of kidney stones. Caffeine intake has been associated with reduced urinary excretion of oxalate, increased excretion of magnesium and potassium, and greater urine volume, all of which may contribute to preventing kidney stone formation. Additionally, components in coffee other than caffeine, such as chlorogenic acid, trigonelline, cafestol, and kahweol, may play a role in reducing the risk of stone formation by providing antioxidant and anti-inflammatory properties. One particular study by P. Peerapen and V. Thongboonkerd demonstrated that caffeine had contrasting effects on crystal properties related to kidney stone formation. Caffeine treatment decreased the ability of renal tubular cells to bind crystals, mainly by facilitating the translocation of annexin A1. This mechanism seems to be the primary way in which coffee reduces the risk of kidney stone formation. Overall, the evidence suggests that coffee consumption, particularly due to its caffeine content and other beneficial compounds, may have a protective effect against kidney stone formation.

Author's contribution:

Conceptualization: Elwira Servaas and Paula Kula
Methodology: Olga Grelewicz and Adam Juśkiewicz
Software: Mateusz Haber and Robert Siemiątkowski
Check: Adrianna Czachor and Robert Siemiątkowski
Formal analysis: Natalia Kucy and Alicja Kotula
Investigation: Elwira Servaas and Mateusz Haber
Resources: Alicja Kotula and Olga Grelewicz
Data curation: Adam Juśkiewicz and Adrianna Czachor
Writing -rough preparation: Elwira Servaas and Olga Grelewicz
Writing -review and editing: Paula Kula and Alicja Kotula
Supervision: Natalia Kucy and Robert Siemiątkowski
Project administration: Adrianna Czachor and Mateusz Haber
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References

1. Tamborino, F., Cicchetti, R., Mascitti, M., Litterio, G., Orsini, A., Ferretti, S., Basconi, M., De Palma, A., Ferro, M., Marchioni, M., & Schips, L. (2024). Pathophysiology and Main Molecular Mechanisms of Urinary Stone Formation and Recurrence. *International journal of molecular sciences*, *25*(5), 3075. https://doi.org/10.3390/ijms25053075

2. Wang, Z., Zhang, Y., Zhang, J., Deng, Q., & Liang, H. (2021). Recent advances on the mechanisms of kidney stone formation (Review). *International journal of molecular medicine*, *48*(2), 149. https://doi.org/10.3892/ijmm.2021.4982

3. Alelign, T., & Petros, B. (2018). Kidney Stone Disease: An Update on Current Concepts. *Advances in urology*, *2018*, 3068365. https://doi.org/10.1155/2018/3068365

4. Legay, C., Haeusermann, T., Pasquier, J., Chatelan, A., Fuster, D. G., Dhayat, N., Seeger, H., Ritter, A., Mohebbi, N., Ernandez, T., Chopard, C. S., Buchkremer, F., Segerer, S., Wuerzner, G., Ammor, N., Roth, B., Wagner, C. A., Bonny, O., & Bochud, M. (2023). Differences in the Food Consumption Between Kidney Stone Formers and Nonformers in the Swiss Kidney Stone Cohort. *Journal of renal nutrition : the official journal of the Council on Renal Nutrition of the National Kidney Foundation*, *33*(4), 555–565. https://doi.org/10.1053/j.jrn.2023.04.007

5. Safe, S., Kothari, J., Hailemariam, A., Upadhyay, S., Davidson, L. A., & Chapkin, R. S. (2023). Health Benefits of Coffee Consumption for Cancer and Other Diseases and Mechanisms of Action. *International journal of molecular sciences*, *24*(3), 2706. https://doi.org/10.3390/ijms24032706

6. Chung H. J. (2014). The role of Randall plaques on kidney stone formation. *Translational andrology and urology*, *3*(3), 251–254. https://doi.org/10.3978/j.issn.2223-4683.2014.07.03

7. Xu, Z., Yao, X., Duan, C., Liu, H., & Xu, H. (2023). Metabolic changes in kidney stone disease. *Frontiers in immunology*, *14*, 1142207. https://doi.org/10.3389/fimmu.2023.1142207

8. Cicerello, E., Ciaccia, M., Cova, G. D., & Mangano, M. S. (2021). The new patterns of nephrolithiasis: What has been changing in the last millennium?. *Archivio italiano di urologia, andrologia : organo ufficiale [di] Societa italiana di ecografia urologica e nefrologica*, *93*(2), 195–199. https://doi.org/10.4081/aiua.2021.2.195

9. Wong, Y. V., Cook, P., & Somani, B. K. (2015). The association of metabolic syndrome and urolithiasis. *International journal of endocrinology*, *2015*, 570674. https://doi.org/10.1155/2015/570674

10. Carbone, A., Al Salhi, Y., Tasca, A., Palleschi, G., Fuschi, A., De Nunzio, C., Bozzini, G., Mazzaferro, S., & Pastore, A. L. (2018). Obesity and kidney stone disease: a systematic review. *Minerva urologica e nefrologica = The Italian journal of urology and nephrology*, *70*(4), 393–400. https://doi.org/10.23736/S0393-2249.18.03113-2

11. Strohmaier, W. L., Hörmann, M., & Schubert, G. (2013). Papillary calcifications: a new prognostic factor in idiopathic calcium oxalate urolithiasis. *Urolithiasis*, *41*(6), 475–479. https://doi.org/10.1007/s00240-013-0606-3

12. Fuster, D. G., Morard, G. A., Schneider, L., Mattmann, C., Lüthi, D., Vogt, B., & Dhayat, N. A. (2022). Association of urinary sex steroid hormones with urinary calcium, oxalate and citrate excretion in kidney stone formers. *Nephrology, dialysis, transplantation : official publication of the European Dialysis and Transplant Association - European Renal Association*, *37*(2), 335–348. https://doi.org/10.1093/ndt/gfaa360

13. Gupta, K., Gill, G. S., & Mahajan, R. (2016). Possible role of elevated serum testosterone in pathogenesis of renal stone formation. *International journal of applied & basic medical research*, *6*(4), 241–244. https://doi.org/10.4103/2229-516X.192593

14. Yitgin, Y., Asrak, H., & Tefik, T. (2023). Role, importance and assessment of dietary habits in urolithiasis patient. *World journal of urology*, *41*(5), 1229–1233. https://doi.org/10.1007/s00345-023-04277-3

15. Ferraro, P. M., Bargagli, M., Trinchieri, A., & Gambaro, G. (2020). Risk of Kidney Stones: Influence of Dietary Factors, Dietary Patterns, and Vegetarian-Vegan Diets. *Nutrients*, *12*(3), 779. https://doi.org/10.3390/nu12030779

16. Littlejohns, T. J., Neal, N. L., Bradbury, K. E., Heers, H., Allen, N. E., & Turney, B. W. (2020). Fluid Intake and Dietary Factors and the Risk of Incident Kidney Stones in UK Biobank: A Population-based Prospective Cohort Study. *European urology focus*, *6*(4), 752–761. https://doi.org/10.1016/j.euf.2019.05.002

17. Ferraro, P. M., & Bargagli, M. (2021). Dietetic and lifestyle recommendations for stone formers. Consejos dietéticos y de estilo de vida en pacientes con litiasis urinarias. *Archivos espanoles de urologia*, *74*(1), 112–122.

18. Massey, L.K. and Wise, K.J. (1992) Impact of Gender and Age on Urinary Water and Mineral Excretion Responses to Acute Caffeine Doses. Nutrition Research, 12, 605-612. https://doi.org/10.1016/S0271-5317(05)80030-2

19. Ferraro, P. M., Taylor, E. N., Gambaro, G., & Curhan, G. C. (2014). Caffeine intake and the risk of kidney stones. *The American journal of clinical nutrition*, *100*(6), 1596–1603. https://doi.org/10.3945/ajcn.114.089987

20. Curhan, G. C., Willett, W. C., Rimm, E. B., Spiegelman, D., & Stampfer, M. J. (1996). Prospective study of beverage use and the risk of kidney stones. *American journal of epidemiology*, *143*(3), 240–247. https://doi.org/10.1093/oxfordjournals.aje.a008734

21. Curhan, G. C., Willett, W. C., Speizer, F. E., & Stampfer, M. J. (1998). Beverage use and risk for kidney stones in women. *Annals of internal medicine*, *128*(7), 534–540. https://doi.org/10.7326/0003-4819-128-7-199804010-00003

22. Bargagli, M., Tio, M. C., Waikar, S. S., & Ferraro, P. M. (2020). Dietary Oxalate Intake and Kidney Outcomes. *Nutrients*, *12*(9), 2673. https://doi.org/10.3390/nu12092673

23. Siener R. (2021). Nutrition and Kidney Stone Disease. *Nutrients*, *13*(6), 1917. https://doi.org/10.3390/nu13061917

24. Han, H., Segal, A. M., Seifter, J. L., & Dwyer, J. T. (2015). Nutritional Management of Kidney Stones (Nephrolithiasis). *Clinical nutrition research*, *4*(3), 137–152. https://doi.org/10.7762/cnr.2015.4.3.137

25. Wang, X., & Wang, Q. (2024). Current Dietary and Medical Prevention of Renal Calcium Oxalate Stones. *International journal of general medicine*, *17*, 1635–1649. https://doi.org/10.2147/IJGM.S459155

26. Borghi, L., Schianchi, T., Meschi, T., Guerra, A., Allegri, F., Maggiore, U., & Novarini, A. (2002). Comparison of two diets for the prevention of recurrent stones in idiopathic hypercalciuria. *The New England journal of medicine*, *346*(2), 77–84. https://doi.org/10.1056/NEJMoa010369

27. Socała, K., Szopa, A., Serefko, A., Poleszak, E., & Wlaź, P. (2020). Neuroprotective Effects of Coffee Bioactive Compounds: A Review. *International journal of molecular sciences*, *22*(1), 107. https://doi.org/10.3390/ijms22010107

28. Surma, S., & Oparil, S. (2021). Coffee and Arterial Hypertension. *Current hypertension reports*, *23*(7), 38. https://doi.org/10.1007/s11906-021-01156-3

29. Nieber K. (2017). The Impact of Coffee on Health. *Planta medica*, *83*(16), 1256–1263. https://doi.org/10.1055/s-0043-115007

30. Mendoza, M. F., Sulague, R. M., Posas-Mendoza, T., & Lavie, C. J. (2023). Impact of Coffee Consumption on Cardiovascular Health. *Ochsner journal*, *23*(2), 152–158. https://doi.org/10.31486/toj.22.0073

31. Antonio, J., Newmire, D. E., Stout, J. R., Antonio, B., Gibbons, M., Lowery, L. M., Harper, J., Willoughby, D., Evans, C., Anderson, D., Goldstein, E., Rojas, J., Monsalves-Álvarez, M., Forbes, S. C., Gomez Lopez, J., Ziegenfuss, T., Moulding, B. D., Candow, D., Sagner, M., & Arent, S. M. (2024). Common questions and misconceptions about caffeine supplementation: what does the scientific evidence really show?. *Journal of the International Society of Sports Nutrition*, *21*(1), 2323919. https://doi.org/10.1080/15502783.2024.2323919

32. Kolb, H., Martin, S., & Kempf, K. (2021). Coffee and Lower Risk of Type 2 Diabetes: Arguments for a Causal Relationship. *Nutrients*, *13*(4), 1144. https://doi.org/10.3390/nu13041144

33. Sirotkin, A. V., & Kolesárová, A. (2021). The anti-obesity and health-promoting effects of tea and coffee. *Physiological research*, *70*(2), 161–168. https://doi.org/10.33549/physiolres.934674

34. Wasim, S., Kukkar, V., Awad, V. M., Sakhamuru, S., & Malik, B. H. (2020). Neuroprotective and Neurodegenerative Aspects of Coffee and Its Active Ingredients in View of Scientific Literature. *Cureus*, *12*(8), e9578. https://doi.org/10.7759/cureus.9578

35. Ladewig, T., Kloppenburg, P., Lalley, P. M., Zipfel, W. R., Webb, W. W., & Keller, B. U. (2003). Spatial profiles of store-dependent calcium release in motoneurones of the nucleus hypoglossus from newborn mouse. *The Journal of physiology*, *547*(Pt 3), 775–787. https://doi.org/10.1113/jphysiol.2002.033605

36. He, W. J., Chen, J., Razavi, A. C., Hu, E. A., Grams, M. E., Yu, B., Parikh, C. R., Boerwinkle, E., Bazzano, L., Qi, L., Kelly, T. N., Coresh, J., & Rebholz, C. M. (2021). Metabolites Associated with Coffee Consumption and Incident Chronic Kidney Disease. *Clinical journal of the American Society of Nephrology : CJASN*, *16*(11), 1620–1629. https://doi.org/10.2215/CJN.05520421

37. Geng, J., Qiu, Y., Kang, Z., Li, Y., Li, J., Liao, R., Qin, Z., Yang, Q., & Su, B. (2022). The association between caffeine intake and risk of kidney stones: A population-based study. *Frontiers in nutrition*, *9*, 935820. https://doi.org/10.3389/fnut.2022.935820

38. Peerapen, P., & Thongboonkerd, V. (2016). Caffeine prevents kidney stone formation by translocation of apical surface annexin A1 crystal-binding protein into cytoplasm: In vitro evidence. *Scientific reports*, *6*, 38536. https://doi.org/10.1038/srep38536