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Kidney Stones and Energy Drinks: A Literature Review

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Abstract
Kidney stones are common, painful, and expensive to treat. Several factors play a role in the development of stones, particularly the consumption of sugars such as fructose. As such, the consumption of sugary energy drinks contributes to the development of kidney stones. However, there is a lack of understanding behind the mechanism of kidney stone development and the role energy drinks play in stone development. This review analyzes the mechanism of kidney stone development and the effect energy drink consumption has on stone development. Here, we also detail the dietary roles calcium, oxalate, ascorbic acid, and animal protein have on stone development.

Introduction
Kidney stones are common, painful, and expensive to treat.[1] Kidney stones develop from the supersaturation of materials found in the urine, such as calcium, uric acid, cystine, and phosphate.[2,3] When these materials are overabundant in the urine, the kidneys are unable to excrete them. As the materials accumulate in the kidneys, they supersaturate into hardened deposits within the kidney. These hardened deposits continue to accumulate in the kidneys, eventually leading to the development of Randal's plaque where kidney stones attach.[2,4] Once attached, the kidney stones continue to accumulate until they detach from Randal's plaques and travel through the urinary system.

Because of the materials involved in kidney stone development, an individual's diet plays a large role in stone development. Of these materials, sugars have the largest involvement in kidney stone development. The common sugar that places individuals at risk for kidney stone development is fructose.[1,5-8] Fructose ingestion alters the body and contributes to kidney stone development.[1,5,6] These fructose alterations include increasing urinary uric acid, increasing urinary oxalate, increasing urinary calcium, reducing ionized calcium, increasing parathyroid hormone, lowering urinary pH, and reducing urinary magnesium.[1,5,6] However, despite progress on fructose and its role in kidney stone development, the exact mechanisms which fructose utilizes remains unclear.[1,6] Furthermore, a popular beverage type is energy drinks, and energy drinks are rich in fructose. Subsequently, one can presume an individual consuming energy drinks has a higher risk for kidney stones, due to energy drinks containing high amounts of fructose. However, energy drinks contain other ingredients that must be accounted for, such as caffeine, B vitamins, and sodium. Caffeine presents an interesting dilemma because caffeine increases urination and reduces urinary uric acid and oxalate, which all reduce the risk for kidney stones.[9,10] On the other hand, caffeine also increases urinary calcium and increased urinary calcium enhances the risk for stone development.[9,10] Moreover, the literature focuses on sugar free beverages such as coffee, and the results concerning these beverages display a reduced risk of kidney stone development.[9,10] As for B vitamins, energy drinks contain them in large amounts, but there is little research on B vitamins and their effect on kidney stone development. In fact, past research uncovered that vitamin B6 lessens the risk of kidney stone development.[11] Finally, a diet rich in sodium enhances the risk of kidney stone development.[12,13]

Energy drinks and fructose aside, other dietary factors such as calcium, oxalate, ascorbic acid, and animal protein are involved in the development of kidney stones. Calcium has the largest involvement in kidney stone development because the common substance comprising kidney stones is calcium.[2-4,14] Past recommendations involved a reduction in dietary calcium but current research reveals minimizing dietary intake of calcium increases the risk of stone development.[13-17] Calcium regulation within the body is complicated and involves several factors, meaning there is much to uncover on calcium regulation and its role in kidney stone development.[15] Oxalate is also an important dietary factor because the literature reveals it enhances stone development.[2,8,16,18] Unfortunately, it has been a challenge to understand the dietary role of oxalate on stone development because oxalate is also produced within the body.[18] Moreover, ascorbic acid and animal protein play contradictory roles in kidney stone development. Ascorbic acid raises the risk of kidney stone development, but diets rich in ascorbic acid contain factors which reduce the risk of kidney stone development.[6,8,16,19] As for animal protein, its metabolism in the body creates byproducts which increase the risk of stone development.[13,16,19] However, a concern with reduction of animal protein in the diet is that an individual will replace animal protein with another risk factor for kidney stones, such as fructose.[8] Another concern with animal protein is the current data. Current data is unable to associate animal protein and stones, but despite concerns with data, general recommendations include reducing animal protein intake to diminish the risk of kidney stones.[4,8,13,16]

We have made progress toward understanding the mechanisms of kidney stone development, the effect energy drinks have on kidney stone development, and the role various dietary factors play in kidney stone development. Our progress has improved treatments and recommendations involving kidney stones, dietary intake, and energy drinks. Despite our progress, knowledge gaps on kidney stone development and the effects of diet and energy drinks are present. However, we must strive to close knowledge gaps related to kidney stones, diet, and energy drinks, particularly as incident kidney stones rise, along with the popularity of energy drinks.[8,20,21] This review draws on the physiochemical mechanisms of kidney stone development, as well as the role that energy drinks and various dietary factors play. Primarily, we explore energy drinks effects on kidney stone development with a focus on fructose. However, we also explore other dietary factors that take part in stone development, such as calcium, oxalate, ascorbic acid, and animal protein.

Main Analysis

Kidney Stone Development

Kidney stones are solidified deposits made of minerals or chemical compounds already present in the urine.[2,3,14] The kidneys regulate excretion of these minerals or compounds via the urine. However, when the body is excreting excessive amounts of these minerals or compounds, they are able to harden and accumulate within the kidney. The imbalance stems from an excessive amount of these minerals or compounds in the urine, reduced volume of urine, or a mixture of both.[3] Moreover, other factors such as urinary pH and plaque development play important roles in kidney stone development because low urinary pH can lead to crystallization of urinary minerals, and plaque development is necessary for kidney stone attachment and growth.[2,4,6,8,22] Plaque development is critical for stone development because kidney stones need a site of attachment in order to grow (Figure 1B), and studies reveal stone attachment to interstitial plaque is the rule.[2,4] Within the thin loops of Henle, crystalline deposits first gather inside the interstitial space (Figure 1C), until the crystalline deposits accumulate enough to reach the surface of a renal papilla's urothelium (Figure 1D). Once on the surface, the accumulation of crystalline deposits (Figure 1A) present as a white plaque termed Randal's plaque.[4] Providers in the past focused on reducing kidney stone growth, but now this implies an additional clinical approach of reducing or preventing the plaque itself.[4]

Energy Drinks

Fructose

Energy drinks are rich in sugars, particularly fructose and sucrose. Both fructose and sucrose contribute to stone development, but due to the chemical structure of sucrose resembling fructose, we will focus on fructose.[1,6,7] The exact method which fructose raises the risk of stone development is unknown.[1,6] However, studies have been performed which reveal fructose ingestion causes certain alterations within the body that promote stone development.[1,5,6] These alterations include a rise in urinary uric acid, urinary oxalate, and urinary calcium, a reduction in ionized calcium but an increase in parathyroid hormone, a lowering of urinary pH, and a reduction in urinary magnesium.[1,5,6]

There are several factors which inhibit and promote kidney stone development, and an imbalance in inhibitors and promoters can lead to a heightened risk of stone development (Figure 2). Among these factors are the previous alterations that fructose causes within the body (Figure 2). Of these factors, citrate is of utmost importance. Fructose has been revealed to reduce urinary citrate, a common protector against kidney stone and plaque development.[4,6,19,22] Citrate performs its protective function by complexing with calcium in the urine, and this reduces supersaturation which then reduces calcium-oxalate and calcium-phosphate stones.[19,22]

Caffeine

Energy drinks are rich in caffeine, but caffeine's role in kidney stone development is overlooked. When caffeinated beverages such as coffee are consumed, the risk of kidney stone development is reduced.[9,10] Caffeine increases diuresis, which is a standard method of reducing the risk of kidney stones. When consuming beverages such as coffee, urinary volume is increased, urinary oxalate and urinary uric acid are reduced, and urinary calcium is increased.[9,10] The research surmised that heightened levels of urinary calcium would lead to increased stone development, but the increase in urinary volume decreased the amounts of supersaturated calcium, uric acid, and oxalate, thus reducing the likelihood of stone development.[9,10] However, this research focuses on coffee and coffee does not contain the high amounts of sugars that energy drinks contain. This is a limitation on our knowledge of energy drinks and stone development because the high amounts of sugars in energy drinks are not offset by the high amounts of caffeine present in energy drinks.

B Vitamins

Energy drinks contain high amounts of B vitamins, but there are scant amounts of research on the effects of B vitamins and kidney stone development. One possible reason is that B vitamins are water-soluble, meaning it is difficult to ingest dangerous amounts, making research on them challenging or unnecessary. In fact, previous research illustrated vitamin B6 lessens the risk of kidney stone development by reducing the amount of oxalate excreted in the urine.[11] However, follow-up research on B vitamins and kidney stones is contradicting or lacking, making this another limitation on our knowledge of energy drinks and kidney stone development.

Sodium

Sodium rich diets are a common problem, particularly in the West.[23] Furthermore, beverages that contain moderate levels of sodium, such as energy drinks, contribute to the problem. In particular, sodium rich diets have been revealed to heighten the risk of kidney stone development.[12,13] Urinary sodium correlates with urinary calcium, which contributes to urinary supersaturation and calcium stone development.[12] Increased sodium intake causes higher amounts of calcium to be excreted, but increased sodium intake also reduces urinary citrate levels.[13] Urinary citrate is a known inhibitor of kidney stones because urinary citrate complexes with urinary calcium, inhibiting the supersaturation of calcium and calcium compounds.[19]

Dietary Factors

Calcium

Dietary factors have a large role in the development of kidney stones, particularly due to the main components of kidney stones, which are calcium, uric acid, cystine, and phosphate.[2,3] Calcium homeostasis involves interactions between the bones, kidneys, and intestines, but it is a complex process which we have yet to fully understand.[15] Old practice recommended a restriction of dietary calcium in order to avoid calcium forming stones, however, a dietary restriction of calcium has been revealed to increase the risk of calcium stone development.[13-16] Individuals whom restrict dietary calcium dysregulate calcium levels within their body and this can lead to bone demineralization, thus increasing calcium excretion which leads to an increase in plaque development and stone development.[4,15] Moreover, calcium is involved with oxalate absorption and reducing calcium intake will raise the amount of urinary oxalate, thus contributing to calcium-oxalate saturation and stone development.[13,18,24]

Stone formers present with much more calcium in their urine, in comparison to non-stone formers (Figure 3, top left). The increased urinary calcium fosters supersaturation of calcium-phosphate compounds (Figure 3, bottom right) and calcium-oxalate compounds (Figure 3, top right). The fact that calcium is present in both types of supersaturated compounds reinforces the role of calcium in kidney stone development.[4,13,15,18,24] Moreover, stone formers with higher amounts of calcium-phosphate supersaturation present in their urine leads to a higher number of stones comprised of calcium and phosphate (Figure 4, left), which can dictate the type of treatments or restrictions necessary with kidney stone development and the type of kidney stone.

Oxalate

Oxalate is one of the main components which enhances stone development, particularly calcium-oxalate stones.[2,8,16,18] In fact, studies have revealed that slight increases in urinary oxalate enhance the risk of calcium-oxalate stone development.[16,24] Despite these findings, it has been challenging to understand the role dietary oxalate plays in stone development because a primary source of urinary oxalate is the diet, but it is also produced within the body.[18] Despite the challenges associated with oxalate, research has revealed that increased dietary oxalate intake will enhance the urinary supersaturation of calcium-oxalate.[18] Moreover, findings reveal that a decrease in dietary calcium will increase urinary oxalate excretion and an increase in dietary calcium will decrease urinary oxalate excretion.[18] These findings reinforce the above mentioned role of dietary calcium, and why a balanced intake of calcium is necessary to decrease the risk of stone development.[4,13-16,18,24]

Stone formers contain higher amounts of oxalate supersaturation in their urine (Figure 3, top right), which reinforces the utility of oxalate in kidney stone development, and the importance of maintaining an appropriate balance of oxalate in the diet.[4,18] On the other hand, several limitations exist within current research, and two in particular stand out. First, several factors are involved with oxalate homeostasis which will affect results, and second, a more accurate method of dietary oxalate assessment is needed for future experiments.[18] Moreover, a contradiction about the importance of dietary oxalate in kidney stone development should be discussed. Urinary levels of oxalate did not significantly differ between non-stone formers and stone formers (Figure 3, top middle), but urinary calcium was increased in stone formers (Figure 3, top right). Despite this, supersaturation of calcium-oxalate (Figure 3, top right) was increased in stone formers, in addition to an increase in calcium-phosphate supersaturation (Figure 3, bottom right). Oxalate's contradiction reinforces dietary calcium's role in kidney stone development,[4] which will affect treatments and restrictions toward kidney stone development.

Ascorbic Acid

Ascorbic acid plays a contradictory role in kidney stone development. Ascorbic acid has been revealed to increase the potential for kidney stone development due to higher levels of urinary oxalate excretion.[8,13,16] Moreover, foods rich in ascorbic acid are also rich in oxalate.[16] However, there are three dietary factors that negate ascorbic acid's contribution to stone development. First, diets rich in ascorbic acid are rich in magnesium and magnesium lessens the risk of stone development by reducing urinary oxalate excretion.[8,16] Second, diets rich in ascorbic acid are also rich in potassium and potassium also lessens the risk of stone development by reducing urinary calcium excretion, thus reducing supersaturation of calcium-oxalate.[8,16] Third, ascorbic acid is present in fruits and vegetables, as is oxalate, but fruits and vegetables also contain citrate which is an important inhibitor in kidney stones, specifically calcium stones.[6,8,16,19] Individuals whom reduce fruits and vegetables in their diets will reduce urinary oxalate, but these individuals will also decrease urinary citrate and increase urinary supersaturation of calcium-oxalate, thus increasing the risk for kidney stones.[8,]

Nevertheless, the type of dietary ascorbic acid plays a part in kidney stone development. Mentioned above are dietary sources of ascorbic acid, but when supplemental ascorbic acid is taken, the risk of kidney stones increases.[16] Unfortunately, the research behind ascorbic acid has its limitations. These limitations include contradicting or weak results, unknown dietary factors affecting results, and lacking research on dietary and supplementary ascorbic acid's effects on kidney stone development.[8,16]

Animal Protein

Animal protein displays yet another contradictory role in kidney stone development. First and foremost, the type of protein is important because animal protein has specific effects related to kidney stone development, in comparison to plant protein. These effects are due to the metabolism of animal protein, which generates acidic byproducts that increase urinary calcium, reduce urinary citrate, reduce urinary pH, and increase urinary uric acid, which all contribute to stone development.[13,16,19] However, the data is lacking or conflicting, as studies have failed to uncover associations between animal protein and kidney stones, while other studies have not revealed associations between animal protein and stones.[16] In addition, if a person decreases their dietary intake of animal protein, they could end up increasing intake of something else which increases stone development risk, such as fructose.[16] Despite the conflicts associated with animal protein, general recommendations include reducing animal protein intake to lessen the risk of kidney stone development.[4,8,13]

Conclusion

Rates of incident kidney stones have steadily increased over the years. Furthermore, the popularity of energy drinks has also increased. Energy drinks have been revealed to increase the risk of kidney stone development, due to the high amounts of sugars present. The common sugar at fault is fructose, and fructose alters the body via several different mechanisms, which all enhance the risk of kidney stone development. Moreover, energy drinks contain moderate to high amounts of caffeine and sodium, which are believed to play a part in stone development. However, energy drinks also contain ingredients such as B vitamins and citric acid, which have been revealed to lessen the risk of stones. In addition, the consumption of energy drinks enhances diuresis and diuresis decreases the risk of stone development. Nevertheless, despite B vitamins, citric acid, and increased diuresis, the consumption of energy drinks increases the risk of kidney stone development.

Energy drinks aside, other dietary factors take part in kidney stone development. We found that calcium, oxalate, ascorbic acid, and animal protein also play a large part in the development of kidney stones. However, despite calcium stones being the common category of stones, a balanced amount of calcium intake decreases the chance for stone development because if the regulation of calcium is disrupted, this enhances calcium excretion, thus heightening the likelihood of stone development. As for oxalate, ascorbic acid, and animal protein, the literature reveals that reducing dietary oxalate and animal protein will reduce a person’s risk for stone development. On the other hand, ascorbic acid increases the risk for stones when supplemented, but from a dietary perspective, the types of food that contain ascorbic acid are rich in magnesium, potassium, and citrate, which all decrease the possibility of urinary supersaturation and stone development. This specifies that with ascorbic acid, similarly to calcium, maintaining an appropriate dietary balance of ascorbic acid is essential to reducing the risk of stone development.

The literature is promising, but not without flaws. The method of kidney stone development is well understood, but not fully understood. The same is true of the mechanisms which energy drinks and fructose heighten the risk of stone development. Despite the unknowns behind energy drinks and fructose, a general recommendation of reducing intake of energy drinks and fructose will reduce the risk for kidney stones. As for the diet, there are several knowledge gaps present, in addition to contradictions, when analyzing diet and its effect on kidney stone development. Nevertheless, a balanced diet of calcium, oxalate, and ascorbic acid reduces the risk for kidney stones, while an appropriate reduction in animal protein intake will also lessen the risk for kidney stones.

More research is needed to continue expanding our knowledge of kidney stone development and the factors involved. Moreover, energy drinks branded as “healthy” have begun entering the market and gaining popularity. These healthy energy drinks pose new dilemmas to our current understanding of energy drinks and their effect on kidney stone development. Healthy energy drinks pose dilemmas because they do not contain the typical high amounts of sugars and sodium. In addition, these healthy energy drinks, such as Bang, contain large amounts of kidney stone inhibiting ingredients. Apart from the high amounts of caffeine, one can argue that healthy energy drinks are indeed healthy. Due to this, it is essential that we also begin research on healthy energy drinks, in order to begin understanding the effects they can have on kidney stone development, as well as the rest of the body.

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Figures

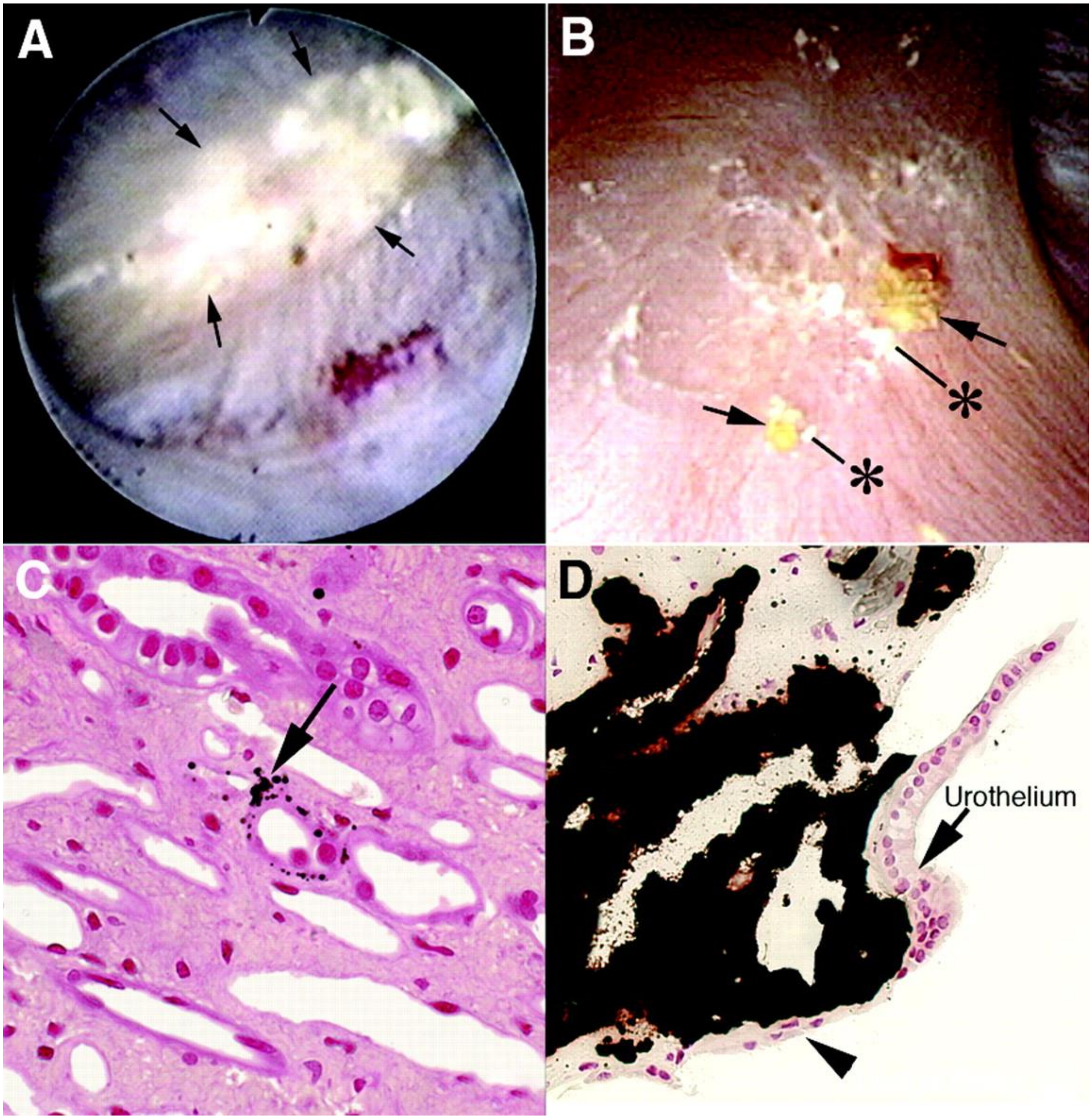

Figure 1.

Endoscopic and microscopic views of plaque in individuals with calcium-oxalate kidney stones. (A) Renal papilla with Randal's plaque (black arrows). (B) Kidney stones (asterisks), attached to Randal's plaque (black arrows). (C) Histologic view of a renal papilla, with plaques comprised of crystallized and hardened material (black arrow). (D) Urothelial covering of a renal papilla (black arrows), displaying deposits of accumulated crystallized and hardened material over time. Adapted from reference 4.

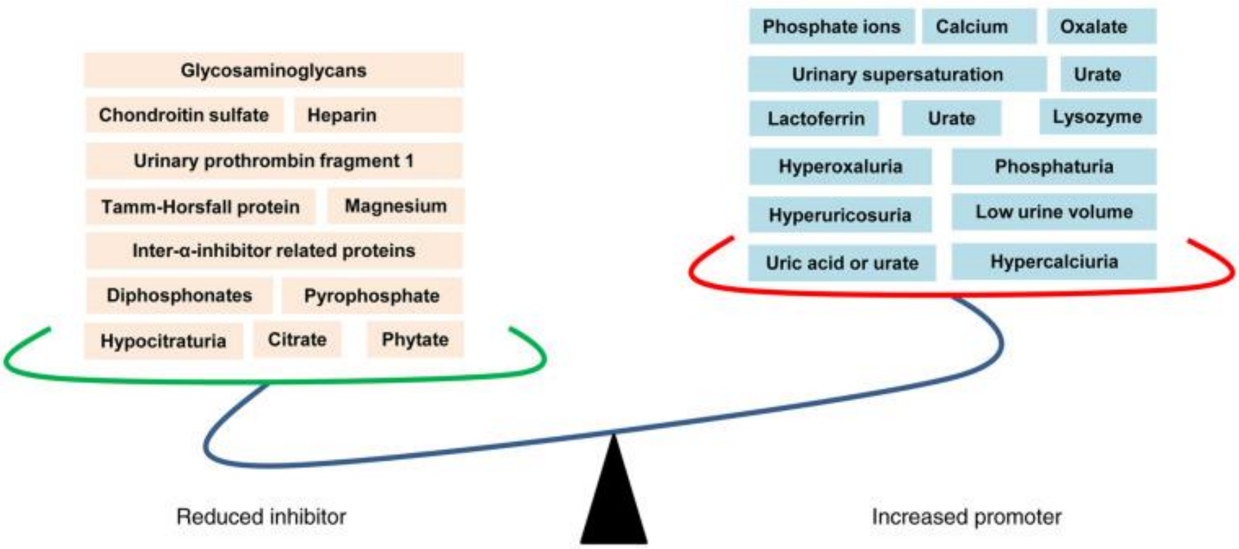

Figure 2.

Physiological and chemical means of kidney stone development. The scale displays inhibitors of kidney stone development (left panel) and promoters of kidney stone development (right panel). The illustration displays a “tipping of the scale” when there is a rise in the promoters of kidney stone development and a reduction in the inhibitors of kidney stone development. When inhibitors and promoters of kidney stones are unbalanced in this way, kidney stones are more likely to form. Adapted from reference 2.

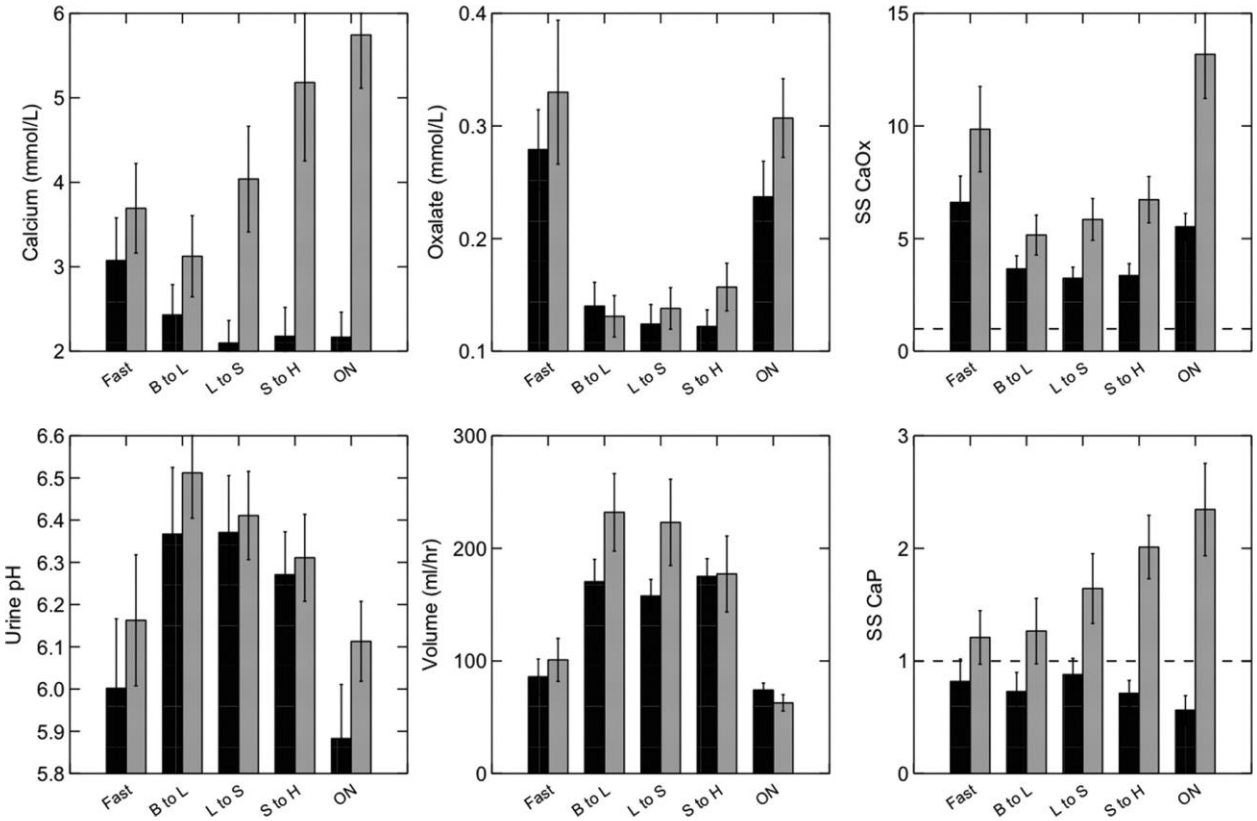

Figure 3.

Urinary collections of individuals who formed stones (gray bars) and individuals who did not form stones (black bars), measuring calcium-phosphate (CaP) and calcium-oxalate (CaOx) supersaturation (SS), through one day and one night. Participants had identical intakes and were evaluated using 15 urine samples, which were collected during fasting (Fast), breakfast to lunch (B to L), lunch to supper (L to S), supper to home (S to H), and overnight (ON) periods. Urinary oxalate (top middle panel), urinary pH (bottom left panel), and urinary volume (bottom middle panel) were not statistically different between the stone formers and non-stone formers. Urinary calcium was statistically higher in stone formers during the L to S, S to H, and ON periods (top left panel). CaP SS was statistically higher in the L to S, S to H, and ON periods than that of the non-stone formers (bottom right panel) and the non-stone formers did reach an average CaP SS > 1 (horizontal dashed line). CaOx SS was higher in stone formers through the L to S, S to H, and ON periods (top right panel), and together individuals who formed stones and individuals who did not form stones were able to achieve an average CaOx SS > 1. The increases in CaOx SS and CaP SS in stone formers is believed to be caused by the increased amounts of urine calcium in stone formers. Adapted from reference 4.

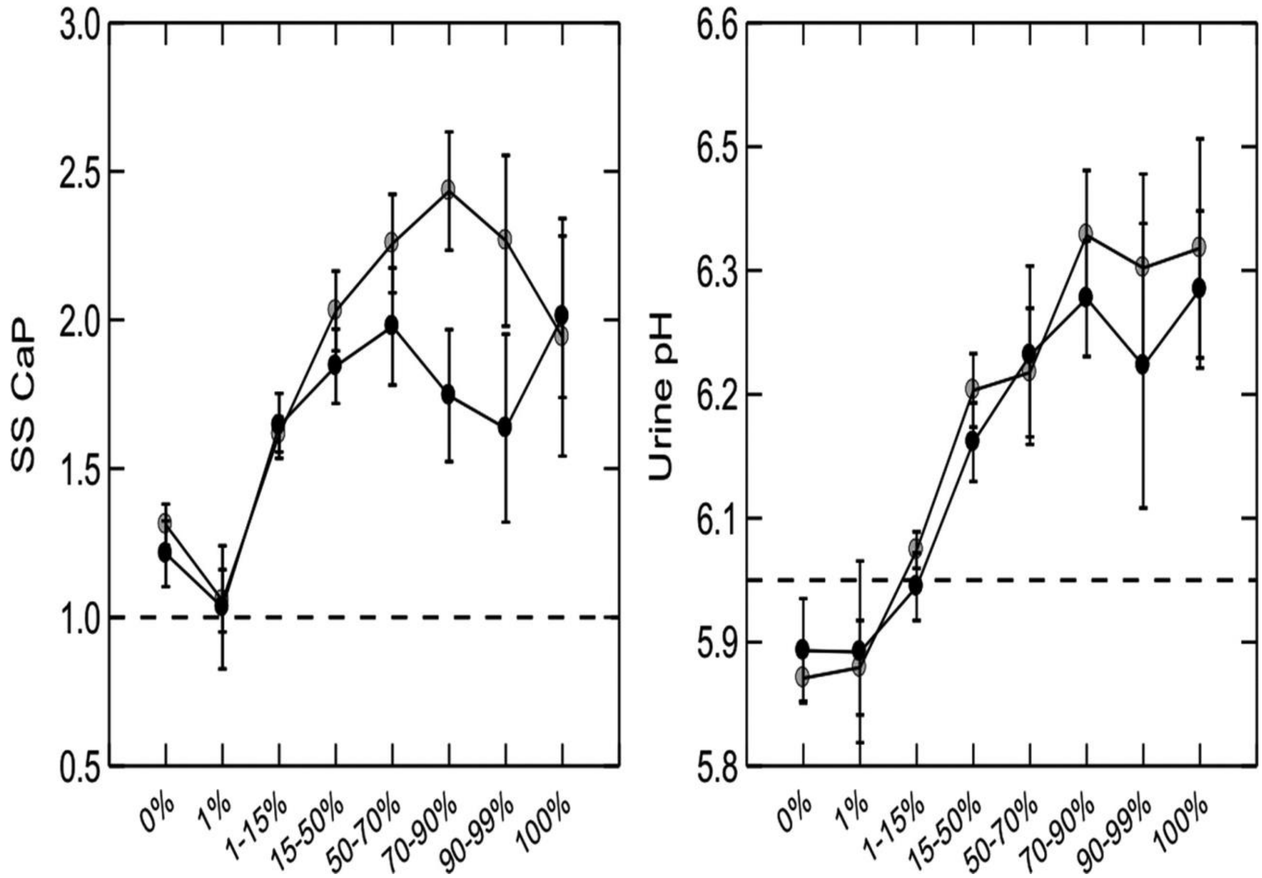

Figure 4.

Urinary calcium-phosphate (CaP) supersaturation (SS) and pH measurements in individuals who formed stones and individuals who have stones that are increasing in their composition of CaP. Stone formers were grouped by the percentage of CaP that made up their examined stones (x-axis). CaP SS (left panel, y-axis) and urinary pH (right panel, y-axis) steadily increased alongside each other as the CaP composition of stones increased, indicating a relationship between CaP SS, percent of CaP in stones, and urinary pH. Men (black circles) and women (gray circles) displayed similar behavior. Adapted from reference 4.