

Canine Silica Urolithiasis: Causes, Detection, Treatment and Prevention

Carl A. Osborne

Jody P. Lulich

Lisa K. Ulrich

*“There is a difference between unanswered questions
and unquestioned answers.”*

Carl A. Osborne

TERMINOLOGY

The name silicon (Si) is derived from the Latin word “silicis” meaning flint. Silicon is a naturally occurring nonmetallic element. When combined with oxygen, Si forms SiO_2 and is called silica or silicon dioxide. The term silicate is a noun used to designate a salt derived from silicic acid (as in aluminum silicate and magnesium trisilicate). The term silicon should not be confused with silicone. Silicone refers to any of a group of synthetic resins, oils, greases, plastics, etc. in which the carbon element has been replaced with silicon.

Inorganic Silica

Inorganic silica, whose basic formula is SiO_2 , occurs naturally in crystalline, microcrystalline, cryptocrystalline or amorphous forms. The designation SiO_2 as crystalline refers to the orientation of silicon molecules in a fixed, orderly and repetitive pattern resulting in a characteristic shape. Crystals reflect internal order. The term microcrystalline refers to the fact that the crys-

tals are so small that they can only be seen through a microscope. The term cryptocrystalline refers to the fact that the crystals are too small to be seen by light microscopy. The designation as amorphous (without shape) refers to the orientation of SiO_2 molecules in a random or non-periodic pattern. Amorphous minerals are also called mineraloids. Most silica-containing uroliths removed from dogs are composed of amorphous silica.

Inorganic crystalline silica is the basic component of sand, quartz and granite. Microcrystalline silica is found in quartz, chalcedony (agate, onyx, etc.) and chert (flint, jasper, etc.). Amorphous silica is found in glass, opal and diatomaceous earth.

Organic Silica

Although silicate and silica minerals constitute more than 90% of the earth’s crust, they occur in very low concentrations in most animals. The low quantities of silica in most animals may be attributable to the low solubility of silica in all but a very few naturally occurring waters. In contrast, plants often contain

higher quantities of silica. For example, grasses contain between 1 and 4% silica by dry weight. Plants notable for their high silica content include rice and scouring rushes (genus *Equisetum*), which contain up to 16% silica (Salisbury and Ross, 1985).

EPIDEMIOLOGY AND MINERAL COMPOSITION

Prevalence

Silica accounted for 0.4% of all canine uroliths submitted to the Minnesota Urolith Center from 1981 to 2007, (1,414 of 350,803 [Table 38-8]) and 0.33% of (134 of 40,612) uroliths submitted in 2007. Silica accounted for 0.34% of all upper tract uroliths analyzed at the Minnesota Urolith Center from 1981 to 2007 (19 of 5,591). Silica uroliths were more commonly removed from the lower urinary tract (99%) than the upper urinary tract (1%) (Table 38-9).

Age and Gender

In approximately 310,000 cases of urolithiasis evaluated at our center, only one case of silica urolithiasis was documented in dogs less than 12 months of age. The mean age of dogs at the time of urolith retrieval was 7.7 years (range eight months to 19 years). Males were affected (95%) more commonly than females (5%). However, female dogs may void small silica uroliths before they induce clinical signs, reducing the detection rate.

Breeds

From 2000 to 2006, 82 different breeds were affected including mixed breeds (19%), German shepherd dogs (13%), golden retrievers (6%), Shih Tzus (6%), black Labrador retrievers (6%), rottweilers (2%), miniature schnauzers (2%) and cocker spaniels (1%). A high prevalence of silica uroliths in German shepherd dogs, Yorkshire terriers, Shih Tzus, Lhasa apsos, golden retrievers, miniature schnauzers and old English sheepdogs has been recognized (Aldrich et al, 1997, Ling, 1995). Several of these breeds also appear to be at risk for calcium oxalate uroliths. This association, and the observation that silica uroliths often contain calcium oxalate, prompt questions about the possibility of epitaxy associated with silica and calcium oxalate urolithiasis.

MINERAL COMPOSITION AND ARCHITECTURE

Of 1,414 canine silica uroliths, 982 were composed entirely (100%) of amorphous silica, and 432 were composed of at least 70% of this mineral. Silica uroliths may contain varying quantities of other minerals, especially calcium oxalate. Ammonium urate and calcium phosphate are encountered less frequently in association with silica.

Most canine silica uroliths have a jackstone configuration (Osborne et al, 1981). The name jackstone was selected because their shape is similar to the small, six-pronged metal pieces used in the children's games of "jacks." Protrusions from different uroliths vary in number (usually from 15 to 30), length (from a few mm to more than one cm) and diam-

eter. Some protrusions are long and slender, whereas others are blunt, imparting a mammillary appearance to the urolith. Protrusions from individual uroliths are usually but not invariably similar in length and diameter. These features of silica uroliths often impart a distinctive appearance, which can often be identified by radiography. Cross sections of canine silica jackstones reveal that they are distinctly laminated; however, these laminations cannot be detected by radiography. In most dogs, silica jackstones occurred in multiples with some patients having more than 30. However, a few dogs had solitary uroliths. Silica uroliths ranged in diameter from less than 1 mm to more than 3 cm. Not all uroliths composed primarily of silica had a jackstone configuration. However, all silica uroliths formed by dogs had some form of surface protrusions at more or less regular intervals, imparting a regularly uneven surface contour to the uroliths. Some silica jackstones were coated with layers of struvite, which altered their characteristic shape. In some instances, struvite completely surrounded silica jackstones.

Calcium oxalate monohydrate, calcium oxalate dihydrate and ammonium urate uroliths may also have a jackstone-like appearance as detected by survey and contrast radiography. However, the macroscopic appearance of non-silica jackstones is typically different than that of silica jackstones.

ETIOPATHOGENESIS AND RISK FACTORS

Overview

Naturally occurring silica jackstones were first reported in dogs living in the United States in the mid-1970s (Osborne et al, 1986). An extensive review of the literature revealed a conspicuous absence of this type of canine urolith before that time. In the mid-1970s, silica uroliths were reported to occur only in dogs from the United States and Canada. However, in 1985, canine silica jackstones were recognized in Japan and shortly thereafter in Europe. Calcium magnesium aluminum silicate uroliths without a jackstone configuration were identified in dogs native to Kenya in 1977 (Brodey et al, 1977).

Relationship of Silica Uroliths to Food Hypothesis

Several observations prompt the hypothesis that development of canine silica uroliths may be related to hyperexcretion of silica in urine following consumption of an absorbable form of silica in various foods. It is noteworthy that silicic acid is readily absorbed across the intestinal wall (Ammerman et al, 1980; Sutor et al, 1970; White and Porter, 1969). The fact that ingested silica is rapidly cleared by the kidneys from plasma of dogs and other animals following absorption into the body also supports the "dietary risk factor" hypothesis (Benke and Osborn, 1979; King et al, 1933).

Possible Dietary Sources of Silica or Silicate

Silicate minerals occur in very low concentrations in most animals. Therefore, ingredients in pet foods derived from animal

sources are an unlikely source of this mineral. In contrast, plants contain larger quantities of silica. As mentioned above, grasses contain between 1 and 4% silica by dry weight and rice and scouring rushes (horsetails, genus *Equisetum*) contain up to 16% silica (Salisbury and Ross, 1985).

One plausible explanation as to why canine silica uroliths began to be recognized in the mid-1970s is that at that approximate time, the pet food industry initiated use of an increased quantity of plant-derived ingredients in moist and especially dry dog foods. Silicon is taken up by the roots of plants and deposited in their cell walls as silica, soluble silicates and organic combinations. Although unlikely, another factor could have been the addition of fillers, which contain relatively large quantities of silica (e.g., rice or soybean hulls), to some pet foods designed for reduction in obesity (Underwood, 1977).

Corn gluten feed, a by-product of the wet milling and distilling process designed to separate shelled corn into various components, was another suspected source of silica in some pet foods. Corn gluten feed remains after extraction of starch, gluten and germ from shelled corn. The term gluten, meaning “glue” in Latin refers to the sticky characteristic of substances derived from corn, wheat and other grains. Corn gluten feed contains about 40% protein and is contained in some low quality pet foods. We emphasize that corn gluten feed is not the same as corn gluten meal. Corn gluten meal is contained in many higher quality manufactured foods designed for dogs because it is readily digestible and a relatively inexpensive form of protein (approximately 60%), vitamins, minerals and energy. Corn gluten meal is an unlikely source of the silica in uroliths.

Contamination of various types of plants with soil during harvesting is also conceivable. Another possibility that may apply to some dogs is consumption of soil secondary to diet-associated pica.

Caution: studies performed in rats indicate that the type of silica compound ingested influences its absorption from the gastrointestinal tract (Yoko and Saboro, 1979). In addition, other factors (e.g., pH) may be involved (Pyrah, 1979; Yoko and Saboro, 1979). Therefore, detection of a relatively large quantity of silica in food is not itself synonymous with intestinal absorption and urinary excretion of silica.

Dogs and People

Silica uroliths developed in male dogs fed experimental foods containing a high concentration of silicic acid and talc [$Mg_3SiO_{10}(OH)_2$] for several months (Ehrhart and McCullagh, 1973; McCullagh and Ehrhart, 1974). Replacement of dietary silicic acid with purified cellulose prevented further urolith development. In a pilot study, we detected multiple tiny silica uroliths in the urinary bladder of an adult male beagle dog after it was given magnesium trisilicate orally for approximately four months.

Silica uroliths have been reported in several people who consumed large quantities of antacids containing magnesium trisilicate to alleviate signs of peptic ulcers (Farrer and Rajfer, 1984; Forman et al, 1959; Herman and Goldberg, 1960; Levison et al 1982; Pyrah, 1979).

The high prevalence of silica urolithiasis in native Kenyan dogs has been hypothesized to be related to consumption of unprocessed Kenyan corn, a common ingredient in their diet garnered primarily by scavenging (Brodey et al, 1977). It is also conceivable that Kenyan dogs could have consumed silica contained in the soil as they scavenged for food.

Another potential source is micro-fine silica, which is used in small quantities as an anti-caking agent in the manufacture of many pet foods. Although a cause and effect relationship between micro-fine silica and silica urolithiasis is unlikely, until additional information becomes available, it seems logical to avoid giving foods containing this ingredient to dogs with recurrent silica urolithiasis.

Ruminants

The association of food and silica urolith formation in ruminants is relevant to consideration of diet-related risk factors in dogs. Silica uroliths are common in range cattle and sheep that consume forage grasses with a high concentration of silica (Bailey, 1970; Emerick and Embry, 1960; Emerick et al, 1959; Pyrah, 1979; White and Porter, 1969). In Canada, prairie grass (*Festuca scabrella*) has been found to contain 4 to 8% silica (Bailey, 1966). It is noteworthy, however, that attempts to induce silica uroliths in sheep with inorganic forms of silica (sodium silicate) have been unsuccessful (Beeson et al, 1943; Emerick et al, 1959).

Dietary risk factors for induced silica urolithiasis in sheep include low phosphorus concentrations, a high calcium-phosphorus ratio and factors contributing to alkalinization (Emerick et al, 1959).

Rats and Guinea Pigs

Silica uroliths have been experimentally induced in rats fed diets containing 2% tetraethylorthosilicate (Emerick, 1984; Emerick et al, 1963; Stewart et al, 1993). Siliceous deposits were detected in the renal tubules of guinea pigs given large oral doses of soluble silica (Coe et al, 1991).

Applications of Observations to Diet Hypothesis

Affected dogs that formed silica uroliths submitted to the Minnesota Urolith Center were consuming a large variety of commercially manufactured moist and dry foods in addition to homemade foods. A widespread change in the formulation of commercially manufactured dog food in the U.S. was probably associated with the onset of silica urolithiasis in the mid-1970s and early 1980s, but this assumption has not yet been confirmed.

We consider foods containing large quantities of plant-derived ingredients as risk factors for silica urolithiasis in susceptible dogs. Corn gluten feed, rice hulls and soybean hulls have also been incriminated as dietary risk factors (Osborne et al, 1986).

Concentrations of lithogenic substances in urine are dependent on urine volume. Because dry foods (~10 to 20% water) are often associated with production of more concentrated urine compared with canned formulated diets (~75 to 80% water),

Table 44-1. Key nutritional factors for foods for canine silica urolithiasis prevention.

Factors	Dietary recommendations
Water	Water intake should be encouraged to achieve a urine specific gravity <1.020 Moist food will increase water consumption and formation of less concentrated urine
Protein	Restrict high quality dietary protein to 10 to 18% dry matter
Silica	Avoid foods with corn gluten feed, rice hulls and soybean hulls listed on the ingredient panel of the product label
Urinary pH	Feed a food that maintains an alkaline urine (urinary pH = 7.1 to 7.7)

consumption of dry diets may also be considered as a risk factor for silica urolith formation.

BIOLOGIC BEHAVIOR

The time required for naturally occurring silica uroliths to develop in susceptible dogs is unknown. Silica uroliths were induced in dogs four months after consuming foods containing large quantities of silicic acid (McCullagh and Ehrhart, 1974). Silica uroliths have been produced in rats within eight weeks after consumption of tetraethylorthosilicate (Forman et al, 1959; Emerick, 1984; Emerick et al, 1963). Silicious uroliths have also been observed in calves by the time they were approximately four months old (Forman et al, 1959). Evaluation of case reports of people who developed silica uroliths while consuming silicate-containing antacids suggests that the uroliths developed over a period of years (Farrer and Rajfer, 1984; Levinson et al, 1982).

We have observed recurrence of silica uroliths in five dogs following surgical removal of silica uroliths from the lower urinary tract. Struvite urocystoliths developed in at least two dogs as a consequence of infection with urease-producing staphylococci following surgical removal of silica urocystoliths. Formation of struvite uroliths in this situation is not surprising because urease-producing staphylococci are lithogenic in dogs.

KEY NUTRITIONAL FACTORS

Because initiating and perpetuating causes of silica urolithiasis are unknown, only supportive and symptomatic measures designed to reduce the degree of supersaturation of urine with lithogenic substances can be recommended for prevention. These key nutritional factors are discussed below and summarized in Table 44-1.

Water

Concentrations of lithogenic substances in urine depend on urine volume. For dogs with recurrent silica urolithiasis, increasing the volume of urine produced by increasing water consumption will increase the volume of urine in which lithogenic substances are dissolved or suspended. Moist foods rather than dry

foods should be considered. Oral administration of sodium chloride has been a favored empirical method to induce diuresis in dogs with uroliths. However, the use of sodium chloride to promote diuresis in dogs that form silica uroliths cannot be routinely recommended without evidence of safety and efficacy because of the unpredictable but marked occurrence of calcium oxalate in silica uroliths and because orally administered sodium chloride is associated with hypercalciuria. Strive to promote formation of urine with a specific gravity value less than 1.020.

Protein

Moderate restriction of dietary protein (10 to 18% dry matter) has the advantage of contributing to obligatory polyuria by decreasing renal medullary urea concentration and is therefore, recommended.

Besides the amount of protein, the predominant protein source can be important. Some protein supplying ingredients for pet foods are higher in silica than others. Animal-derived protein ingredients are an unlikely source of silica. In contrast, some plant-derived protein sources contain larger quantities of silica. As mentioned above, corn gluten feed is an example. On the other hand, many higher quality commercial pet foods contain corn gluten meal because it is readily digestible and is a relatively inexpensive source of protein. Corn gluten meal is an unlikely source of the silica in uroliths. Check the ingredient label. Foods listing “corn gluten feed” as one of the first four non-water ingredients should be avoided.

Silica

Foods with large quantities of plant-derived ingredients are suspected to be risk factors for silica uroliths in susceptible dogs. Consumption of dry foods may also be considered a risk factor for silica urolith formation. Corn gluten feed, rice hulls and soybean hulls have been incriminated (Osborne et al, 1986). Although an unlikely source, ingestion of micro-fine silica used as a de-caking agent in the manufacture of some foods is a possibility. Avoid foods whose product label ingredient panel lists corn gluten feed, rice hulls or soybean hulls.

Urinary pH

Silica is less soluble in acidic than alkaline water, and currently available information suggests that silica is less soluble in acidic than alkaline biologic environments. It is noteworthy that the urinary pH of eight non-infected dogs with silica uroliths was acidic to neutral at the time of diagnosis (mean = 6.0; range = 5.0 to 7.0). Whether or not alkalinization of urine is beneficial in increasing the solubility of silica or silicates in urine is unknown. However, until more research evidence is available, we recommend that the urinary pH produced by a food or a food and urine alkalinizing agents be in the range of 7.1 to 7.7.

FEEDING PLAN

Effective dietary and medical protocols to induce dissolution of canine silica jackstones have not yet been developed. At this time, surgery is the only practical option to remove large silica

uroliths. Voiding urohydropropulsion may be used to remove small urocystoliths (Figure 38-5 and Table 38-7) (Lulich et al, 1993). Lithotripsy may be considered to remove urethroliths. Litholytic foods that do not contain large quantities of plant ingredients and that induce diuresis may prevent further growth of silica uroliths.

At this time, our recommendations include change of diet, augmentation of urine volume and consideration of altering urinary pH (Table 44-1) (Osborne et al, 1986; Osborne et al, 1999).

Assess and Select the Food

Although the role of food in the genesis of canine silica uroliths is still somewhat speculative, it seems reasonable to recommend that food(s) of affected patients be changed, especially if the problem is recurrent. Although empirical, this maneuver is unlikely to be harmful and may be helpful. Based on the assumption that the primary source of excessive silica in foods is vegetable in origin, selection of a food with reduced quantities of specific vegetable protein and other plant-based ingredients is recommended. Our empirical experience with this method of prevention has been favorable. Table 44-2 lists selected veterinary therapeutic foods that can be considered for prevention of silica urolithiasis and compares their key nutritional factor content to the recommended levels. Select the food that is most similar to the key nutritional factor profile. Because these foods are intended for long-term feeding, they should also be approved by the Association of American Feed Control Officials (AAFCO), or some other credible regulatory agency. Dogs consuming dry foods may be at greater risk for urolithiasis than dogs consuming moist foods. Dry foods are often associated with higher urine concentrations of urolith constituents (in the case of silica urolithiasis, more plant origin ingredients) and more concentrated urine. Therefore, when possible, moist foods should be selected.

Assess and Determine the Feeding Method

A few dogs with silica uroliths have a history of pica and coprophagia associated with consumption of dirt and/or compost in one form or another. The relationship of the onset of pica with the diet history should be investigated with the goal of correcting this problem.

Transitioning a patient from the current food to a new food selected for the prevention of silica urolithiasis should be done gradually over a period of a few days. Begin the transition by feeding 75% of the current food and 25% of the new food on Day 1. On Day 2, feed half of each food. On Day 3, feed 75% new food and 25% old food. By Day 4 or 5, feed only the new food.

Because moist foods tend to increase water intake and produce a less concentrated urine, recommend the client feed specific amounts (meal fed) two to three times per day rather than free-choice feeding. Moist foods can spoil if left at room temperature for several hours (Chapter 11). Opened containers of moist foods should be refrigerated and the feeding bowl should be kept clean.

Table 44-2. Levels of key nutritional factors in selected commercial foods used to minimize recurrence of silica uroliths in dogs compared to recommended levels.*

Dry food	Protein (%)	Urinary pH**
Recommended levels	10-18	7.1-7.7
Hill's Prescription Diet u/d Canine	11.2	7.70
Moist food		
Hill's Prescription Diet u/d Canine	13.3	7.40

*Manufacturer's published values; protein expressed as % dry matter; when possible recommend moist foods; where possible, check the ingredient panel of the product label and avoid foods that list corn gluten feed, rice hulls or soybean hulls.

**Protocols for measuring urinary pH may vary.

Besides offering moist foods, there are several additional ways to facilitate increased water intake. These include: 1) Ensuring multiple water bowls are available in prominent locations in the dog's environment; this may mean providing several bowls outside in a large enclosure or a bowl on each level of the house. 2) Bowls should be clean and, if possible, kept full of fresh water. 3) Small amounts of flavoring substances (e.g., salt-free bouillon) can be added to water sources to increase consumption. 4) Ice cubes can be offered as treats or snacks. 5) If a dry food is selected, advise the client to add liberal quantities of water; however, as with moist foods left at room temperature for too long, be aware that there are also potential food safety issues that might arise from leaving moistened dry foods out for prolonged intervals (Chapter 11).

If the patient has a normal body condition score (BCS 2.5/5 to 3.5/5), the amount of the previous food being fed was probably appropriate. On an energy basis, a similar amount of the new food would be a good starting point.

Oral administration of sodium chloride has been a favored empirical method to induce diuresis in dogs with uroliths. However, the use of sodium chloride to promote diuresis in dogs that form silica uroliths cannot be routinely recommended without evidence of safety and efficacy because of the unpredictable but marked occurrence of calcium oxalate in silica uroliths and because orally administered sodium chloride is associated with hypercalciuria.

ADJUNCTIVE MEDICAL MANAGEMENT

Urine Alkalinizing Agents

Silica is apparently less soluble in acidic than alkaline water, and currently available information suggests that silica is less soluble in acidic than alkaline biologic environments. It is noteworthy that the urinary pH of eight non-infected dogs with silica uroliths was acidic to neutral at the time of diagnosis (mean = 6.0; range = 5.0 to 7.0). Whether or not alkalinization of urine is beneficial in increasing the solubility of silica or silicates in urine is unknown. Likewise, the effects of orally administered alkalinizing agents (e.g., sodium bicarbonate) on the absorbability of silica from the gastrointestinal tract have not been evaluated. Nonetheless, it seems prudent to recommend that efforts

Table 44-3. Summary of recommendations for prevention of canine silica uroliths.

1. Perform appropriate diagnostic studies including complete urinalysis, quantitative urine culture and diagnostic radiography. Determine precise location, size and number of uroliths.
2. If uroliths are available, determine their mineral composition. If unavailable, determine their composition by evaluation of appropriate clinical data.
3. Small urocystoliths may be removed by voiding urohydropropulsion (Figure 38-5 and Table 38-7). Consider surgical removal of larger uroliths causing clinical disease.
4. To prevent further growth of existing silica uroliths or to prevent recurrence of silica uroliths after surgical removal:
 - a. Avoid use of foods containing large quantities of plant proteins, and especially avoid those containing rice hulls, soybean hulls or corn gluten feed.
 - b. Enhance diuresis by adding moisture to the food.
 - c. Avoid efforts to deliberately acidify urine.
5. If necessary, eradicate or control urinary tract infections with appropriate antimicrobial agents.

to deliberately acidify the urine of dogs with recurrent silica uroliths be avoided. The observation that silica may occur in uroliths in association with calcium oxalate is additional support for the recommendation to avoid acidification of urine. Mild alkalinization (pH range 7.1 to 7.7) of the urine (but not of the digestive system) might be considered for dogs affected by silica uroliths that recur frequently. Prevention of systemic acidosis is recommended to minimize calcium oxalate urolith formation.

REASSESSMENT

Therapy should be initiated in a stepwise fashion (Table 44-3). The goal of therapy is to prevent silica urolith recurrence. Dietary management should minimize exposure to minerals predisposing to silica uroliths and result in formation of less concentrated urine; strive to promote formation of urine with a specific gravity less than 1.020. A urinalysis and lateral abdominal radiograph should be evaluated periodically. Initially, every three to four months seems reasonable. Depending on results, the interval may be increased or decreased. The goal is to detect recurrent urocystoliths when they are small enough to be removed by voiding urohydropropulsion (Lulich et al, 1993) or lithotripsy.

REFERENCES

The references for Chapter 44 can be found at www.markmorris.org.