Holmium:YAG Laser Lithotripsy for Urolithiasis in Horses

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**Background:** Laser lithotripsy has been used as an alternative to surgical removal of uroliths. Additionally, the ultrastructure and the differences in mineralogy and microstructure from 1 successful and 1 unsuccessful laser lithotripsy case are described.

**Objective:** To describe the procedure and efficacy of laser lithotripsy for removal of lower urinary tract uroliths in horses.

**Animals:** Six client-owned horses with 7 episodes of naturally occurring urocystoliths, urethroliths, or both.

**Methods:** Retrospective study of all horses treated between 2006 and 2008 by laser lithotripsy. All horses were sedated followed by laser lithotripsy. Quantitative urolith analysis was performed in all cases. Ultrastructure and microstructure analyses were performed on uroliths from 2 horses.

**Results:** Procedural success was achieved in 5 of 7 laser lithotripsy procedures. No complications occurred as a result of laser lithotripsy. One horse developed uroabdomen likely as a result of manual lithotripter disruption of the bladder after failure of laser lithotripsy. There were differences in microstructure between 1 urolith that was successfully fragmented by laser lithotripsy and 1 urolith that was resistant to laser fragmentation.

**Conclusions and Clinical Importance:** Laser lithotripsy is an effective procedure for removal of some urocystoliths, urethroliths, or both in horses.

**Key words:** Calcium carbonate; Cystoscopy; Minimally invasive surgery; Urinary.

The prevalence of urolithiasis in horses has been estimated at 0.11% over a 20-year period. The most common urolith and sabulous deposit mineral type is calcium carbonate. Options for resolution of lower urinary tract urocystoliths, urethroliths, or both include surgical or minimally invasive removal.

Disadvantages of some surgical methods used to remove lower urinary tract uroliths include general anesthesia and the possibility of complications such as peritonitis and perforation of the bladder, urethra, or rectum. Minimally invasive methods of lower urinary tract urolith removal in the horse have included using electrohydraulic and ballistic lithotripters under general anesthesia or pulsed dye and holmium:yttrium, aluminum, garnet (Ho:YAG) laser lithotripters under sedation with epidural anesthesia. The main advantage of laser lithotripsy is the ability to perform the procedure under sedation. Disadvantages of laser lithotripsy include the cost of the laser and endoscopic access to the bladder via perineal urethrotomy in males.

Laser lithotripsy is performed by endoscopically delivering the Ho:YAG beam with a wavelength of 2,100 nm to the surface of the urolith through a flexible optical fiber. Laser lithotripsy occurs through a photothermal effect. The efficacy of the Ho:YAG laser to fragment uroliths in horses is variable. Proposed reasons for failure of the Ho:YAG laser to effectively fragment equine uroliths have included differences in urolith porosity and calcium carbonate polymorphs present in the urolith, though these have not been substantiated.

The purpose of this study is to describe the efficacy and procedure of Ho:YAG laser lithotripsy of lower urinary tract uroliths in sedated horses without the use of perineal urethrotomy or epidural anesthesia. Additionally, quantitative mineral, microstructure, and ultrastructure analyses of uroliths from 1 successful case (urolith 1) and 1 unsuccessful case (urolith 2) of laser lithotripsy were performed to investigate possible reasons why some uroliths are resistant to complete fragmentation.

**Materials and Methods**

**Cases**

Cases consisted of client-owned horses presented to the Virginia-Maryland Regional College of Veterinary Medicine between May 2006 and November 2008 for management of lower urinary tract uroliths (urocystoliths, urethroliths) or for stranguria, hematuria, pollakiuria, or urinary obstruction that was found to be because of lower urinary tract urolithiasis.

**Laser Lithotripsy**

Horses were placed in standing stocks and sedated (xylazine 0.9 mg/kg IV or detomidine 0.01–0.03 mg/kg IV with or without butorphanol 0.01–0.02 mg/kg IV). Repeated boluses of sedatives were given as needed to minimize horse movement. Lactated
Ringer’s solution was administered (4–5 mL/kg/h IV). The vulva or penis was aseptically prepared with soap and water. Urethrocystoscopy was performed using either a 1 or 2 mm flexible videendoscope and abnormalities documented. Maximum urethrolith diameter was estimated to be identical to the diameter of the urethra in all cases. The diameter of the urethra was estimated endoscopically relative to the size of the endoscope, which had a diameter of 8.9 mm and by how easily a 16 mm catheter passed through the urethra. The maximum urocystolith dimension was estimated by transrectal palpation, endoscopically compared with the known diameter of the endoscope or various endoscopic baskets, or directly with a ruler for uroliths removed in toto by a subsequent cystotomy.

All laser lithotripsy procedures were performed by the same person (DCG) with assistance from numerous individuals. Saline (0.9%) was infused continuously during lithotripsy through the working channel of the endoscope in male and female horses and through a transurethral catheter placed adjacent to the endoscope in females. Saline ingress and egress were performed as needed to maintain a clear view and to prevent excessive distention of the bladder. Once the urolith was identified, a 550 μm optical fiber was advanced directly through the working channel until approximately 1 cm of bare fiber was visible at the tip of the endoscope. A Ho:YAG laser with a maximum power of 20 W was used for lithotripsy. With the fiber in contact with the urolith, the laser was activated by a foot pedal. The fiber was moved across the surface of the urolith, repeatedly in the same location, in a manner such as to create a crater or line along which a fragment would break off the main urolith. Frequently, the fiber would drill into the urolith, at which point a portion of the urolith would fragment or if it failed to do so the fiber would become lodged in the urolith and have to be forcefully removed. Lithotripsy was repeated until all resulting fragments were smaller than the urethral diameter or until it became apparent that lithotripsy would not completely fragment the urolith. Small intact uroliths and large urolith fragments were periodically removed with various endoscopic baskets. Smaller fragments were removed by repeated ingress and egress of sterile saline through a sterilized 16 mm polyvinyl chloride tube placed transurethrally into the bladder. This procedure was repeated numerous times if needed on a daily basis, under sedation, until all endoscopically detectable urolith fragments had been removed. The pulse frequency and energy settings of the laser were recorded. The lithotripsy time was defined as the total time beginning with the 1st activation of the laser and ending with all efforts to remove uroliths and fragments on the day(s) of the lithotripsy procedure. The time spent removing urolith fragments on subsequent days after each lithotripsy procedure was not recorded. The technique, endoscopic findings, and adverse effects or complications were recorded for each horse. A successful laser lithotripsy was defined as fragmentation and removal of all endoscopically detectable uroliths and fragments.

Urolith Analysis

A fragment of urolith material from each case was submitted to the Minnesota Urolith Center for initial determination of mineral composition.

Subsequently, a representative intact urocystolith that had been removed via basket retrieval from a horse in which laser lithotripsy was successfully performed (urolith 1) and a large, solitary urocystolith that was refractory to lithotripsy and was removed via laparocystotomy (urolith 2) were submitted to the G.V. Ling Urinary Stone Analysis Laboratory for further analysis. The oil immersion method of optical crystallography was performed on samples from the surface, outer portion, and interior of each urolith and the chemical composition of each was determined by Fourier-transform infrared spectroscopy as described previously. Thin sections were also prepared using the standard petrographical method to observe the microstructure of the samples using a polarized light microscope. X-ray diffractometry (XRD) was implemented to determine, which polymorphs of calcium carbonate were present in the samples. Samples for XRD were taken from urolith 1 as a whole and from the surface, the outer layer, and the interior of urolith 2 as described previously except the CuKα radiation was generated at 45 kV and 40 mA and each sample was scanned from 20 to 60° with a 0.02° step scan counting 0.6 seconds for each step. The ultrastructure and the Ca and Mg content of the 2 uroliths were analyzed using an electron probe microanalyzer as described previously.

Analysis of uroliths 1 and 2 revealed differences in porosity and presence of surface laminations. To evaluate if the presence of surface laminations were dependent upon stone size, the cross-sectional texture of 134 equine calcium carbonate uroliths, which were analyzed at UC Davis Urolith Laboratory between 1981 and 2008, were classified as having surface laminations present or not. The average size of uroliths was calculated as an arithmetic average of diameter measured in 3 directions perpendicular to each other (x, y, and z).

Results

Laser lithotripsy was successfully performed in 4 horses with 5 instances of urolithiasis and was unsuccessful in 2 horses. These successful cases of urolithiasis included a solitary 6 cm urocystolith in a 25-year-old half Arab mare and a solitary 3 cm urocystolith in a 6-year-old American Paint gelding. A successful outcome was achieved in a 26-year-old Arab gelding obstructed with a urethrolith approximately 2 cm in size; the horse also had a fine layer of small urocystoliths, which did not require lithotripsy. Lithotripsy was successful at 12 and 14 years of age in an American Paint gelding with an approximately 2 cm urethrolith. In one of these episodes, there were 30–50 concurrent small urocystoliths, 2 of which were moved into the proximal urethra via an endoscopic basket, lasered, and fragments removed. The remainder of the urocystoliths were removed by lavage and stone baskets, and 1 of these urocystoliths (urolith 1) was submitted for further analyses described above. Endoscopically, uroliths from cases that were successfully treated appeared similar to urolith 1 with speculated elongated projections with deep interprojection spaces (Fig 1A). Only 1 of these 5 cases had a urine culture performed and the result was negative.

All cases of successful lithotripsy received flunixin meglumine (1.1 mg/kg IV or PO q24h–12h) and/or phenylbutazone (1.8–3 mg/kg PO q24h–12h) for 4–14 days and oral trimethoprim sulfamethoxazole (25–44 mg/kg PO q12h) for 7–14 days. In 3 cases trimethoprim sulfamethoxazole was administered before lithotripsy and in 2 cases it was preceded by 3 days of administration of ceftriaxone (2.2 mg/kg IV q12h).

Horses in which laser lithotripsy failed to effectively, completely fragment the uroliths included a mixed-breed gelding with a 9 cm urocystolith and an American Paint mare with a 10 cm urocystolith. After 73 minutes of laser lithotripsy in the gelding only very small drill holes the size of the laser fiber had been made in approximately 20% of the surface of the urolith with few fragments dislodged from the urolith so the procedure was terminated. The gelding underwent a successful left inguinal laparocystotomy under general anesthesia. The
anesthetic period was 155 minutes and the gelding recovered uneventfully. It received penicillin (17,000–20,000 IU/kg IM or IV q12h), gentamicin (6.6 mg/kg IV q24h), and flunixin meglumine (1.1 mg/kg IV or PO q12h) for 48 hours surrounding lithotripsy and for 96 hours surrounding the laparocystotomy. A bladder swab culture taken intraoperatively was negative. After 30 minutes of laser lithotripsy in the American Paint mare only drill holes the size of the laser fiber had been made in the surface of the urolith without dislodging any fragments. The procedure was terminated because of inefficient fragmentation. Subsequently, a manual lithotrite was used to disrupt the urocystolith whereas the urolith was held steady via rectal palpation. Several fragments were removed digitally by transurethral palpation before this too was terminated. The mare was scheduled for laparocystotomy the next day, however, within hours of termination of the lithotripsy procedures she became febrile, tachycardic, tachypneic, with a dull mentation. Abdominocentesis was performed and revealed a septic neutrophilic exudate. An abdominal exploratory was performed. The peritoneal cavity contained free fluid, urolith fragments, and a 2-cm rent in the dorsal aspect of the body of the bladder. The horse was euthanized. The mare received trimethoprim sulfamethoxazole (30 mg/kg PO q12h) and flunixin meglumine (1.1 mg/kg IV or PO q12h) for 2 days starting the day of lithotripsy. A necropsy was performed, and the bladder was thickened and erythematous with multiple mucosal ulcers and hemorrhagic cystitis. An Enterococcus species was isolated by bacterial urine culture. This urocystolith (uroolith 2) was submitted for further analyses. Endoscopically the majority of the surface of urolith 2 was smooth (Fig 1B). The surface appearance of the urocystolith from the other failed lithotripsy case was similar to that of urolith 1, although the projections were shorter and the interprojection spaces more shallow than urolith 1.

For successful lithotripsy cases the pulse frequency setting for the laser ranged from 8 to 10 Hz and the energy setting from 0.8 to 2.5 J. The lithotripsy time ranged from 101 to 150 minutes. Lithotripsy was performed on a single day in 4 cases and on 2 separate days in 1 case because of time constraints of the operating veterinarian. All uroliths and fragments were removed in 1 case after bladder lavage on 2 consecutive days after lithotripsy, 1 case on a single day after lithotripsy, and in 3 cases all uroliths and fragments were removed on the day of lithotripsy. For unsuccessful cases the pulse frequency setting for the laser ranged from 8 to 10 Hz and the energy setting from 1.4 to 2.5 J. Lithotripsy time ranged from 30 to 73 minutes. All cases, both lithotripsy and laparocystotomy, were discharged 3 days after their definitive treatment.

The only complications that could be attributed to laser lithotripsy were small mucosal laser burns to the uroepithelium in 2 horses and breakage of the tip of a laser fiber in the bladder of 1 horse. The laser burns seemed superficial and were not associated with any distinct postprocedural clinical signs. The broken fiber tip was easily recovered with an endoscopic forcep.

The mineral composition of all uroliths was calcium carbonate. Two specimens, urolith 1 and urolith 2 (Fig 1A and B), were analyzed for the mineralogy, microstructure, ultrastructure, and the calcium and magnesium content. Grossly, urolith 1 was spherical with a diameter of approximately 15 mm with spiculated elongated projections with interprojection spaces visible at the surface. Urolith 2 was oval with a length of 100 mm and height of 75 mm. The depth of urolith 2 could not be accurately determined because a portion of urolith 2 had been removed with a manual lithotrite. The majority of the surface area of urolith 2 was smooth textured with the poles of the oval appearing more similar in texture to urolith 1. Initial observation by the oil immersion method of optical microscopy and subsequent IR spectroscopy showed that both specimens were composed of 100% calcium carbonate. Urolith 1 contained calcite as a major component, whereas a small amount of aragonite and vaterite were also detected (Fig 2). These 3 minerals are polymorphs, which have different crystallographic...
structures for the same chemical composition. Calcite was also a major mineral component of the 3 portions of urolith 2. The outer portions and interior contained vaterite as well, whereas this mineral was not detected in the surface sample. The content of vaterite present in the inner and outer portion of urolith 2 was higher than that of urolith 1 although the vaterite in both was a minor component.

Urolith 1 consisted of elongated coral-like projections arising from a central core (2–4 mm in diameter). Because of this morphology, this specimen as a whole contained a large volume of interprojection spaces as compared with the volume of the carbonate projections and core (Fig 3A and B). Needle-like aragonite crystals were observed on the surface of the projections. In contrast to urolith 1, urolith 2 had thick bands, 2–3 mm thick, which were relatively parallel to the surface of the specimen (Fig 3D and E). However, below those bands, internal elongated projections with large interprojection pore spaces were observed, which were similar to those observed on the surface of urolith 1. In addition, many spherules were observed in the interior portion of urolith 2, which are composed primarily of vaterite.

Representative back-scattered electron (BSE) images of the 2 specimens are shown in Figure 3C and F. Both specimens had similar BSE patterns, ie, alternating bright and dark bands as well as spherules, many of which also consisted of concentric bright and dark bands. It was shown in a previous study that this is caused by the substitution of magnesium for calcium in the calcium carbonate crystal lattice. No significant difference in substitution pattern of the 2 uroliths was observed. When analyzing these 2 stones by quantitative point analysis, a linear trend with a negative slope suggested substitution of Ca by Mg. However, no significant difference in the substitution pattern of the 2 uroliths was observed.

Sixteen of 134 uroliths had surface laminations. The median size was 28 mm (range 4.3–94 mm). The surfaces of some uroliths were covered entirely with surface laminations whereas other uroliths had both areas with a smooth surface and laminations, similar to urolith 2, and areas with a porous surface made up of elongated projections similar to urolith 1. Uroliths whose surfaces were covered entirely with the laminations were smaller in size (<21 mm).

Discussion

This case series demonstrates laser lithotripsy can be an effective minimally invasive treatment for some calcium carbonate stones in horses. In the 1 case, which suffered a rupture of the dorsal aspect of the bladder, it is very unlikely that the rupture was because of laser lithotripsy. Because the horse was standing during laser lithotripsy its urolith was on the floor of the bladder, thus the laser fiber would never have approached the dorsal aspect. Endoscopic visualization of the laser fiber also prevented disruption of the bladder wall. No gross or histologic evidence of thermal necrosis was observed. The combined effects of bacterial urinary tract infection, uroepithelial trauma caused by the urolith, and impact of the manual lithotrite either directly or indirectly on the bladder are the most likely causes of the rupture. Bladder rupture is a recognized risk with manual lithotrites and the urolith was being held transrectally in the dorsal aspect of the bladder where the rupture occurred. In order to prevent laser damage to the uroepithelium we ensured that the tip of the laser fiber was endoscopically visible whenever the laser was activated and that it was withdrawn into the working channel of the endoscope whenever visualization was impaired. We did not experience any significant complications directly attributable to
laser lithotripsy and therefore conclude that laser lithotripsy combined with lavage and stone basket retrieval is a safe procedure.

We successfully removed all uroliths and fragments from 5 of 7 cases. All cases were performed under standing sedation without the need for urethrotomy in the geldings and without epidural anesthesia. Considering the risks associated with general anesthesia, the risks of manual lithotrites, and the pain and more importantly the potential complications of urethrotomy or cystotomy, we conclude that laser lithotripsy performed as described is an effective method for removing those urethroliths and urocystoliths, which substantially fragment within the 1st 30 minutes of lithotripsy. We suggest 30 minutes because the inefficiency of laser lithotripsy seemed apparent to us within this time period in failed cases, though we carried on in both cases to be sure we were correct. All uroliths fragmented to some degree with lithotripsy but in the failed cases this was limited to the area directly at the tip of the laser fiber. Uroliths in which only these small pieces can be dislodged or in which only holes can be made in the surface of the uroliths must be managed by other means. Although electrohydraulic and pulsed dye lithotripters seem very effective their availability is limited because the Ho:YAG has become the lithotripter of choice for intracorporeal lithotripsy in humans. It is important to note that we used a Ho:YAG laser with a maximum power of only 20 W. Models with maximum power of 100 W are available. These higher powers may indeed have more efficiently and effectively fragmented uroliths, perhaps even the 2 uroliths we failed to remove via lithotripsy.

Failure to completely and efficiently fragment uroliths with the Ho:YAG laser in a similar manner as occurred with 2 horses in this report has been documented previously. Contradicting this is another report of success in 6 horses, although a manual lithotrite was used in combination with the laser in 3 of 6 cases. Differences in urolith porosity, calcium carbonate polymorphs, and magnesium and strontium substitution within the calcium carbonate crystal lattice have been speculated causes for varied success. However, the results of the present case study have shown that differences in gross morphology and microstructure between the 2 specimens may relate to the susceptibility of fragmentation during laser treatment. Formation of elongated coral-like

Fig 3. Thin section photomicrographs (A, B, D, and E; all taken with crossed polarizers) and backscattered electron images by electron microanalysis (C and F) of the 2 specimens. (A, B) Urolith 1. The specimen has a large volume of interprojection surface spaces when compared to urolith volume. Note that projections in (A) were cut relatively along their growth direction, whereas those in (B) were cut relatively perpendicular to their growth direction. Needle-like crystals grown on projection surfaces.
projections with interprojection spaces in urolith 1 resulted in a skeletal morphology with a high porosity as a whole. The thickness of the elongated projections was approximately 1 mm, which is close to the size of the laser fiber, 0.55 mm. In addition, some of the projections were thinner at the base perhaps allowing for easier fragmentation by the laser beam. Although urolith 2 had a similar internal microstructure, the surface portion of urolith 2 was covered with thick bands of laminations. Many of those bands consisted of tightly aligned fibrous crystals of calcite. These bands may be structurally more stable and may have prevented effective fragmentation of the surface and thus the urolith as a whole. The dimensions of the uroliths in the 2 failed cases were far greater than urolith 1 raising the question of whether only large calculi form surface laminations. Examination of 134 equine calcium carbonate uroliths revealed a wide range of sizes for uroliths with surface laminations; therefore, calculus size does not determine the presence of surface laminations. Some individual uroliths had portions of the surface, which were smooth with laminations and portions that were porous with projections. Therefore, we speculate that a smooth or minimally spiculated surface appearance of a urolith viewed via endoscopy, but not the size of a urolith, may predict the presence of laminations and relative resistance of the urolith to laser lithotripsy. The endoscopic appearance of all uroliths in successful cases were similar to urolith 1. Although urolith 2 appeared to have a smooth surface, the appearance of the urolith from the other failed lithotripsy case did not appear endoscopically substantially different from those in the successful cases; however, it had somewhat shorter coral-like projections and more shallow interprojection spaces. Because cross-sectional texture and microstructure studies were not performed in this latter failed case, it is unknown how similar it was to urolith 1 or 2. The fact that thorough structural and chemical studies were performed on only 2 uroliths in which lithotripsy was attempted, due in part to the large amount of time and costs required, is a limitation. It is unknown if the conclusions made regarding these 2 uroliths can be applied to subsequent cases. Further investigation could include in vitro laser lithotripsy on a large number of uroliths of known texture and composition.

It still remains unclear whether or not the difference in mineralogy (ie, calcite, vaterite, and aragonite) affects the susceptibility to fragmentation. Physical properties such as density and hardness differ among the 3 polymorphs, which could affect the susceptibility to fragmentation. However, the major mineral constituent of both of the analyzed uroliths was calcite, as shown by XRD; therefore, the possible effect of the differences in physical characteristics of the minor polymorphs of calcium carbonate, vaterite and aragonite, on the urolith fragmentation would be minimal. Both specimens had similar BSE patterns, and it was shown in a previous study that this is caused by the substitution of magnesium for calcium in the calcium carbonate crystal lattice.2 Similar ultrastructure, and Ca-Mg substitution patterns of the 2 uroliths suggest that those are not major factors controlling the susceptibility to laser fragmentation.

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Footnotes

a One and 2 m Flexible Gastroscope, Olympus Surgical and Industrial America Inc, Orangeburg, NY
b 550μm SlimLine holmium laser fiber, Lumenis Inc, Santa Clara, CA
c VersaPulse PowerSuite 20W, Lumenis Inc
d Product Number 00711141, US Endoscopy, Mentor, OH
e Product 3210, Telemed Systems Inc, Hudson, MA
f Stomach Tube Canine Medium KI-300, Kalayjian Industries Inc, Signal Hill, CA
g Universal polarizing microscope, Carl Zeiss Inc, Thornwood, NY
h Olympus Polarizing Microscope, BH2 UMA, Olympus America, Carter Valley, PA
i XDS 2000 X-ray diffractometer, Middleton, WI
j SX100 microprobe analyzer, CAMECA, Courbevoie, France

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References


