Failure of holmium:yttrium-aluminum-garnet laser lithotripsy in two horses with calculi in the urinary bladder

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Laser lithotripsy appears to be a viable alternative to standard techniques for the treatment of urolithiasis in horses.

Holmium:yttrium-aluminum-garnet lasers fragment uroliths primarily through a photothermal mechanism, which is distinct from the photomechanical fragmentation process associated with pulsed dye lasers.

Lithotripsy with a holmium:yttrium-aluminum-garnet laser may require longer surgical times than lithotripsy with a pulsed dye laser and may be ineffective in horses with certain types of urinary calculi.

Failure of holmium:yttrium-aluminum-garnet laser lithotripsy was recommended. The gelding was discharged until use of a laser lithotriptor could be procured through a private contractor.

A 550-µm low-hydroxy quartz optical fiber in a polyethylene sheath was introduced into the urinary bladder through the biopsy channel of the endoscope, and the red helium-neon aiming beam of the laser was centered on the calculus. A Ho:YAG laser operating at 2.1 µm at an energy of 0.6 to 2 J/pulse, with variable pulse duration (250 to 600 µs), variable pulse rate, and maximum power of 32 W, was used to attempt lithotripsy. Targeting of the laser was difficult because of the limited mobility of the endoscope and the inversion of the endoscope as a result of retrograde insertion through the penis. Energy settings up to 2.4 J/pulse and a frequency of 10 Hz were used. Small amounts of powdered or flaked material were discharged from the surface of the urolith, but the calculus was not appreciably reduced in size. Approximately 2 hours were spent in attempts to fragment the calculus with this approach. The laser was activated for 20 minutes of this time, with the remaining time dedicated to fiber positioning, targeting, and lavage.

An indwelling catheter was placed in the left jugular vein. The horse was sedated with detomidine (8 µg/kg [3.6 µg/lb] of body weight, IV, q 35 min), butorphanol (8 µg/kg, IV, q 35 min), and acepromazine (0.02 mg/kg [0.01 mg/lb], IV, once) and restrained in stocks. A 20-gauge epidural catheter was placed, and xylazine hydrochloride (0.17 mg/kg [0.08 mg/lb]) and mepegivcaine (0.22 mg/kg [0.1 mg/lb]) were administered via the epidural catheter to induce perineal analgesia. A 2-m flexible videoendoscope that had been disinfected by immersion for 15 minutes in an activated dialdehyde solution and rinsed with sterile saline (0.9% NaCl) solution prior to use was passed retrograde into the bladder through the urethra. Urine was removed from the bladder with suction and submitted for urinalysis and bacterial culture. Physiologic saline solution was infused through the biopsy channel of the endoscope to lavage the bladder and facilitate examination of the calculus during lithotripsy.

An 8-year-old Hanoverian gelding (horse 1) was referred to the Veterinary Teaching Hospital at the Virginia-Maryland Regional College of Veterinary Medicine for evaluation of hematuria and stranguria following exercise. On physical examination, the horse appeared to be in good physical condition; rectal temperature, pulse rate, and respiratory rate were normal. Transrectal palpation and ultrasonography revealed a 6 × 8-cm ovoid cystic calculus. The horse was sedated with detomidine (6 mg, IV) and butorphanol (6 mg, IV) for cystoscopy, which revealed moderate hyperemia and ulceration of the bladder mucosa, along with a yellow plaque that adhered to the bladder mucosa. The cystic calculus was spiculated, greenish-yellow, and freely movable within the bladder lumen.

Because a pulsed dye laser has been used to fragment similar calculi in the bladder and urethra of other horses,1 laser lithotripsy was recommended. The gelding was discharged until use of a laser lithotriptor could be procured through a private contractor.

The horse was readmitted to the teaching hospital 12 days later for laser lithotripsy. On the basis of the laser contractor’s success with a holmium:yttrium-aluminum-garnet (Ho:YAG) laser lithotriptor2 for resolution of urolithiasis in humans and the lower cost of a Ho:YAG laser, compared with a pulsed dye laser, fragmentation of urolithiasis in humans and the lower cost of a laser lithotriptor was attempted. Results of a preoperative CBC and serum biochemical analyses were within reference limits.

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J/pulse at 10 Hz) was delivered to the calculus during the lithotripsy attempt. The procedure was terminated. A 30-F Foley catheter was advanced into the urinary bladder through the perineal urethrotomy site, and the urinary bladder was lavaged with 18 L of physiologic saline solution. One liter of saline solution containing 20 ml of dimethyl sulfoxide (DMSO) was infused into the bladder following lavage. Dimethyl sulfoxide (250 mg/kg [114 mg/lb]) mixed in 2 L of lactated Ringer’s solution was administered IV at the end of the procedure. The epidural catheter was sutured in place with 2-0 nylon and covered with a nylon patch. Administration of flunixin meglumine (1.1 mg/kg [0.5 mg/lb], IV, q 12 h) and trimethoprim-sulfamethoxazole (TMS: 25 mg/kg [11.4 mg/lb], PO, q 12 h) was initiated, and the gelding was returned to the box stall. The laser contractor was contacted to schedule the use of a pulsed dye laser lithotriptor.

Analysis of the preoperative endoscopic urinalysis sample revealed cloudy yellow urine with a specific gravity of 1.024 and a pH of 8.3. Protein and blood were detected in small amounts. Microscopic examination of the sediment revealed 8 to 10 RBC, 1 to 2 epithelial cells, and occasional WBC per high-powered field. Calcium carbonate crystals were visible in the sediment. Bacteriologic culture of the urine yielded Pseudomonas aeruginosa (> 100,000 colony forming units [CFU]/ml), which was resistant to TMS and susceptible to aminoglycosides, enrofloxacine, and ticarcillin. Quantitative analysis of urolith fragments revealed 100% calcium carbonate.

Administration of flunixin meglumine was continued for 1 day after surgery, after which time administration of phenylbutazone (2.2 mg/kg [1 mg/lb], PO, q 12 h) was initiated. Intravenous administration of gentamicin (6.6 mg/kg [3 mg/lb], q 24 h) was begun, and oral administration of TMS was discontinued on the second postoperative day on the basis of results of bacteriologic culture and in vitro susceptibility testing of the urine sample. The perineal urethrotomy site was cleaned daily with dilute povidone-iodine solution, and zinc oxide paste was applied to the site to decrease urine scald. Ingress-egress lavage of the bladder with 2 L of physiologic saline solution was performed daily for 4 days after pulsed dye laser lithotripsy revealed steady decreases in the degree of mucosal hyperemia and fibrin accumulation. Endoscopically guided ingress-egress lavage with 6 L of physiologic saline solution through a semirigid polypropylene urinary catheter resulted in removal of all visible fragments. The Foley catheter was removed. Cystoscopy performed daily for 4 days after pulsed dye laser lithotripsy revealed steady decreases in the degree of mucosal hyperemia and fibrin accumulation. One liter of physiologic saline solution containing 20 ml of DMSO was infused into the bladder following cystoscopy on each occasion.

Administration of gentamicin and phenylbutazone was continued until the horse was discharged. The epidural catheter was flushed daily with heparinized lactated Ringer’s solution (30 L total) infused into the urinary bladder. Administration of gentamicin and phenylbutazone with instructions for stall confinement and handwalking for 2 weeks and administration of enrofloxacine (2.5 mg/kg [1.1 mg/lb], PO, q 12 h) for 7 days. Daily cleaning of the perineal urethrotomy site and application of zinc oxide ventral to the site were recommended until the urethrotomy healed. Avoidance of alfalfa hay was recommended owing to its high calcium content, which may favor recurrence of urolithiasis. Administration of ascorbic acid (vitamin C, 4 g, PO, q 12 h) to acidify the urine was also suggested. The owners were instructed to return the gelding for follow-up cystoscopy in 2 to 3 weeks.

Cystoscopy 3 weeks after pulsed dye laser lithotripsy revealed the continued presence of a small amount of fibrin plaque on the bladder mucosa, but mucosal hyperemia was not observed. The perineal urethrotomy site had healed without complications and with an acceptable cosmetic result. Urinalysis yielded a specific gravity of 1.026, a pH > 9.0, trace amounts of protein, and < 2 cells/high-powered field. Calcium carbonate crystals were evident in the sediment but were characterized as slightly amorphous. Bacteriologic culture of the urine yielded no growth of any clinically important organisms in 3 days. The gelding was discharged with instructions to continue administration of ascorbic acid and begin paddock turnout and light riding. Administration of phenylbutazone (2.2 mg/kg, PO, q 24 h) for 2 days was recommended.
mended to relieve any inflammation that may have resulted from cystoscopy. Another cystoscopic examination was recommended in 3 weeks.

Follow-up cystoscopy 3 weeks later revealed a grossly normal urinary bladder and urethral mucosa. A small amount of fibrin was observed within the urinary bladder but was not adherent to the mucosa. Urinalysis and bacterial culture were not performed. The horse was discharged with instructions for 2 days of stall rest and phenylbutazone (2.2 mg/kg, PO, q 24 h) treatment, followed by a return to normal exercise and turnout.

The horse was reevaluated 18 months after lithotripsy. During that time, the gelding had resumed normal activity, and neither hematuria nor stranguria had been observed since lithotripsy. The urethral and urinary bladder mucosa appeared grossly normal during cystoscopy, and there was no evidence of urolith recurrence.

A 25-year-old Quarter Horse mare (horse 2) was referred to the Veterinary Medical Teaching Hospital at the Oklahoma State University College of Veterinary Medicine for evaluation of pollakiuria and hematuria. Physical examination findings were unremarkable except for mild fever (38.4°C [101.2°F]), and results of a CBC and serum biochemical analyses were within reference ranges, with the exception of hyperbilirubinemia (4.9 mg/dl; reference range, 0.1 to 2.6 mg/dl). Urinalysis and bacterial culture of a urine sample were not performed because of financial restrictions. Transrectal palpation and cystoscopy confirmed that the horse had a cystolith similar in appearance to that described for horse 1.

The horse was sedated with xylazine (0.37 mg/kg [0.17 mg/lb], IV, q 20 min) and restrained in stocks. Lidocaine (0.25 mg/kg [0.11 mg/lb]) was administered into the epidural space to induce perineal analgesia and anesthesia. A videendoscope was inserted into the bladder via the urethra, and a 320-mm polyamide-coated low-hydroxy quartz optical fiber was introduced into the bladder via the biopsy channel of the videendoscope. Fragmentation of the cystolith was attempted with a Ho:YAG laser operating at 2.1 mm, 0.25 to 1.25 J/pulse, 500 ms pulse duration, variable pulse rate, and maximum recommended power setting of 10 W. Initial energy settings were 4 W of power and 15 Hz frequency. Power settings up to 12 W were used, and 2 fibers were melted and fragmented in areas where the fibers were bent into acute angles (>90°) during the procedure. Two hours (15 minutes laser time) elapsed without successful fragmentation of the urolith (Fig 1); therefore, the procedure was terminated. The urethra was manually dilated, and the urolith was removed. The urolith was ovoid and measured 3.7 cm in diameter and 6.4 cm in length. Analysis of the urolith revealed 100% calcium carbonate.

Flunixin meglumine (1.1 mg/kg, IV, q 12 h) was administered for 3 days, and TMS (11.9 mg/kg [5.4 mg/lb], PO, q 12 h) was administered for 14 days. The horse was discharged 2 days after surgery, and follow-up information obtained 30 days after surgery revealed no complications or recurrence of urolithiasis.

Pulsed dye laser lithotriptors have been used to fragment urethral and cystic calculi in 2 geldings. Pulsed dye lasers operate at a wavelength of 504 nm, with a pulse duration of 1 μs. Uroliths are fragmented by a mechanical photoacoustic effect. Laser energy produces microscopic vaporization of urolith material, and plasma, consisting of a rapidly expanding cloud of electrons and ions, is generated. This plasma absorbs additional laser energy, generating a symmetrically-expanding spherical cavitation bubble. Collapse of the cavitation bubble creates an acoustic shockwave emission that exceeds the tensile threshold of the urolith, resulting in urolith fragmentation.

Pulsed dye lasers use lower energy to fragment uroliths than do ultrasonic and electrohydraulic lithotriptors. In addition, the optical beam of pulsed dye lasers diverges, so that energy levels decrease with increased distance from the tip of the fiber. Therefore, use of pulsed dye lasers is associated with a low risk of soft tissue damage, and these lasers can be used safely throughout the urogenital tract. The flexible optical fiber is readily passed through the biopsy channel of an endoscope.

The primary disadvantages of pulsed dye lithotripsy include the expense associated with use of the lithotriptor (approx $1,500/use) and the potential delay in treatment while arrangements to use the equipment are made. Energy from pulsed dye lasers is not readily absorbed by water but is actively absorbed by pigments; therefore, the laser has been reported to be ineffective for lithotripsy of nonpigmented uroliths, such as cystine and calcium oxalate monohydrate uroliths. Additionally, clinical application of pulsed dye lasers is limited to lithotripsy, as soft tissue procedures cannot be performed with these lasers. Because of these limitations of pulsed dye lasers, there is a trend in human urology toward the use of more versatile Ho:YAG lasers.

Since its introduction in the early 1990s, the Ho:YAG laser has proven to be very versatile. Initially marketed for use in arthroscopic procedures and for discectomy, the Ho:YAG laser has been used for many applications in general and laparoscopic surgery, neurosurgery, angioplasty, orthopedic surgery, nasal
and sinus surgery, ophthalmologic surgery, and dentistry. Success rates approaching 90 to 100% have been reported for treatment of ureteral calculi with Ho:YAG lasers in humans, and these lasers have proven similarly effective for treatment of renal and bladder calculi. The ability to pass the transmitting fibers through flexible endoscopes greatly expands the versatility of Ho:YAG lasers.

Currently available medical lasers range in wavelength from 504 nm (pulsed dye laser) to 10,600 nm (carbon dioxide laser). The wavelength of the Ho:YAG laser is 2,124 nm, near the infrared portion of the electromagnetic spectrum, and a red helium-neon aiming beam is used for laser targeting. Unlike pulsed dye laser energy, energy from Ho:YAG lasers is strongly absorbed by water, and Ho:YAG lasers induce urolith fragmentation by photothermal and photoacoustic mechanisms. Direct contact of the fiber with the urolith is required for effective use in liquid media.

During lithotripsy with a Ho:YAG laser, a cavitation bubble is formed by the vaporization of water molecules; however, the bubble is pear-shaped and undergoes asymmetric expansion and collapse, resulting in weak acoustic emission and shockwave generation. However, the irregular shape of the cavitation bubble creates a vapor channel that effectively conducts laser energy to the urolith, a phenomenon known as the Moses effect. The surface of the urolith is ablated by direct laser irradiation and a rapid increase in surface temperature. Because of the long pulse duration, vaporization of water molecules is continuous, and expansion of interstitial water and vapor results in ejection of fragments from the parent urolith. The fiber tip must be perpendicular (0° incident angle) to the calculus surface to produce its effect.

The chemical composition of the parent urolith is apparently unchanged during Ho:YAG laser lithotripsy. However, chemical analysis of fragments ejected from the parent urolith may reveal thermal breakdown products. In addition, Ho:YAG laser lithotripsy of uric acid uroliths liberates cyanide into the surrounding fluid, raising health and safety concerns. On the other hand, it has been speculated that the laser’s photothermal effect may be bactericidal, which may be advantageous for the treatment of infected struvite uroliths.

The Ho:YAG laser is a solid-state laser and requires less maintenance time and expense than do pulsed dye lasers. In addition, Ho:YAG lasers can be used to treat urinary tract tumors, strictures, benign prostatic hyperplasia, and soft tissue obstructions. The laser can be used for precise cutting, like a carbon dioxide laser, and hemostasis is good or excellent. However, the soft tissue ablative and photoacoustic effects may increase the risk of iatrogenic damage to surrounding soft tissues.

Holmium:yttrium-aluminum-garnet laser lithotripsy has proven effective for all human urolith compositions. However, Ho:YAG lasers are less efficient when used on calcium oxalate monohydrate uroliths than when used on calcium hydrogen phosphate dihydrate, cystine, magnesium ammonium phosphate hexohydrate, or uric acid uroliths. To the authors’ knowledge, the laser’s efficiency when used on calcium carbonate uroliths has not been determined, possibly because this type of urolith is rare in humans.

A Ho:YAG laser has been used for lithotripsy of cystic calculi in 5 horses and a urethral calculus in another horse. Cystic calculi ranged from 9 to 15 cm (mean, 11 cm) in diameter, and mean total surgery time was 3 hours and 33 minutes (mean laser time, 36 minutes), although for 3 of these calculi, the laser was used simply to create a groove to facilitate application of a lithotrite. In contrast, cystic calculi in the 2 horses described in the present report were 6 and 5.7 cm in diameter. It is possible that, with additional laser time, these 2 uroliths would have been fragmented; however, this likely would have resulted in unacceptably prolonged surgical times. Manual removal of the urolith from horse 2 was accomplished in a fraction of the time spent during the unsuccessful Ho:YAG lithotripsy attempt. In this horse, laser lithotripsy was not necessary but was attempted to determine its efficacy in horses. In horse 1, use of the pulsed dye laser resulted in complete urolith fragmentation in 40 minutes total surgery time.

Both of the calculi removed from the 2 horses in the present report, along with 3 of the uroliths removed from horses described in the previous report in which Ho:YAG laser lithotripsy was successful, were calcium carbonate. However, calcium carbonate is a polymorphic crystal and can occur in several ionic forms in urinary calculi. Calcite, a hexagonal crystal, is the most chemically stable and common form of calcium carbonate in equine uroliths. Vaterite, another hexagonal crystal, and aragonite, an orthorhombic crystal, are other forms of calcium carbonate identified in equine uroliths. It is possible that the crystalline lattice structure may alter urolith response to the photothermal and photoacoustic effects of Ho:YAG lasers, resulting in variations in response to lithotripsy. The substitution of magnesium or strontium for calcium in portions of the calcium carbonate crystal may also affect a urolith’s fragility and porosity.

In addition, several variations in the gross textural architecture of the laminations and the cementing substance have been identified, and these variations may play a role in determining the susceptibility of individual calculi to destruction with a lithotritor.

A primary disadvantage of Ho:YAG lasers, as seen in the 2 horses described in the present report, is a decreased capability for fragmentation, compared with pulsed dye laser lithotritors. A Ho:YAG laser exerts its fragmentation effects by drilling through the urolith instead of pulverizing it. As a result, lithotripsy with a Ho:YAG laser may require increased patience and surgical time. Although general anesthesia is not necessary for the lithotripsy of cystic and urethral calculi in horses, repeated sedation may be necessary to prevent excessive patient movement.
Increasing the energy density when using a Ho:YAG laser for lithotripsy has been shown to increase crater and fragment size and decrease duration of the procedure; however, increased pulse energy and total energy may increase the risk of optical fiber damage (as observed in horse 2), collateral tissue damage, and stone retropulsion. Recommended optimal power settings for lithotripsy in humans are pulse energies ≤1 J at pulse frequency rates up to 10 Hz. Total energies delivered during lithotripsy in the 2 horses described in the present report were 27,780 and 16,875 J, which exceeded energies used previously for lithotripsy in horses.

References