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**Urolithiasis**

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**Abstract:** This article reviews the diagnosis, treatment, and prognosis of urolithiasis in horses. The etiology of urolith formation is unknown, but with the use of rectal palpation, ultrasonography, and videoendoscopy, the diagnosis can easily be made. New technologic advancements, such as laser and shock-wave therapies, are less invasive and can be used to reduce patient morbidity and improve surgical outcomes. However, the traditional surgical techniques, such as laparocystotomy and perineal urethrotomy in males and urethral sphincterotomy and manual extraction in females, are still the preferred treatments for successfully resolving urolithiasis in horses. The overall prognosis for horses with urolithiasis is good to fair.

Urolithiasis is an uncommon disease process in horses. At Purdue University’s Large Animal Hospital, only nine cases of equine urolithiasis were seen over a period of 10 years. Interestingly, urolithiasis is not more common in horses than other species despite the alkalinity of equine urine and the high amount of calcium excreted in equine urine. It would be expected that this would create an opportune environment for calculus formation. However, equine kidneys contain glands in the renal pelvis that produce large amounts of mucus that likely serve to protect against crystal formation. Equine urine also contains other components, such as pyrophosphate, citrate, magnesium, and glycosaminoglycans, that may inhibit urolith formation. Although cases of urolith formation in the kidneys, ureters, and urethra have been reported, the most common site for urolith formation in horses is the bladder. No obvious age, breed, or sex predisposition for urolithiasis has been observed in horses. However, urolithiasis more often becomes a clinical problem in males because their urethral anatomy predisposes them to obstructive urolithiasis. The male urethra is long and less distensible than the female urethra. Therefore, the male urethra impedes passage of calculi, but the short, distensible urethra of mares permits easier passage of small calculi; thus the incidence of urethral obstruction in males is higher than in mares.

**Etiology**

The etiology of uroliths in horses is not completely understood. It is known that two steps must occur for a urolith to form: nucleation and crystal formation. Nucleation occurs when a nidus and the correct environment exist simultaneously. The best environment for nidus formation is urine stasis and subsequent supersaturation of urine. Urine stasis increases the probability of contact between crystalloid material in the urine and the nidus, facilitating urolith formation. The nidus can consist of desquamated epithelial cells, leukocytes, necrotic debris, mucoproteins, and hyperhydrated calcium salts that precipitate to allow nucleation. Therefore, care must be taken during catheterization and endoscopy of the urinary tract to lessen trauma to the urethral and urinary bladder epithelium. Allowing a patient that is receiving...
NSAIDs to become dehydrated can precipitate nidus formation due to subsequent sloughing of cells from the renal papilla. Intravesical foreign bodies and luminal penetration by absorbable or nonabsorbable sutures can also serve as a nidus for urolith formation in horses. Spontaneous nucleation alone does not cause calculus formation; for calculus formation to occur, urine stasis must also be present to increase the chance of contact between precipitating crystalloid material and the uroepithelium or damaged uroepithelial surfaces. Other contributing factors that facilitate urolith formation in horses include excretion of large amounts of calcium, increased uric acid concentration, increased oxalates, and inhibition of substances that inhibit crystal formation (i.e., pyrophosphate, citrate, magnesium, glycosaminoglycans, glycoproteins). Once a urolith forms, it enlarges by accumulating pre-existing microscopic spherules on its surface.

Two main types of uroliths have been described in horses. Type I uroliths are the most common and the easiest to break down for removal. These uroliths are yellow green, have a spiculated surface, and are normally composed of a variety of hydrated calcium carbonate salts (Figure 1). Type II uroliths are less common. They are white, have a smooth surface, and are harder than type I uroliths. Type II uroliths are mainly composed of calcium carbonate salts but also contain magnesium and phosphorus. In an evaluation of the mineral composition of 32 equine uroliths by Osborne et al, 88% were completely composed of calcium carbonate, 6% were composed of mainly calcium carbonate salts, and 1% was composed of calcium oxalate monohydrate.

**Diagnosis**

Urolithiasis is diagnosed based on history, clinical signs, and physical examination findings. A variety of clinical signs can be seen, depending on the specific location of the urolith and the degree of urinary tract obstruction. The primary presenting clinical signs of urolithiasis in horses with cystic and urethral calculi include hematuria, tenesmus, pollakiuria, incontinence, stranguria, and dysuria. Horses with calculi of the kidneys and ureters often present with weight loss and signs of abdominal pain. In chronic cases of urolithiasis, urine scalding of the hindlimbs and perineum may be seen.

Diagnostic procedures such as rectal palpation of the urinary tract, ultrasonography, and cystoscopy can help determine the site, size, and number of calculi. The diagnosis of cystic calculi can be confirmed during rectal palpation by direct palpation of the urolith. However, it is imperative to examine the entire urinary tract when urolithiasis is diagnosed. In a report by Laverty et al, 9% of the observed group had calculi in more than one location.
Ultrasonography may help evaluate concurrent nephrolithiasis. Endoscopy is indicated to confirm urethral and cystic calculi (Figure 2). Other laboratory tests that are frequently conducted when urolithiasis is diagnosed include complete white blood cell count to identify infectious processes, serum biochemistry to identify azotemia, and urinalysis to determine urine pH and the presence of crystals and bacteria. If bacteria are identified, a bacterial culture is also indicated.

Treatment
Conservative and surgical treatments of urolithiasis have been described in the literature. Surgical intervention is frequently required to resolve clinical signs of urolithiasis. Previously described surgical techniques include laparocystotomy, perineal urethrotomy, urethral sphincterotomy and manual extraction, laparoscopic cystotomy, and pararectal cystotomy (Gökel’s technique). Recent technological innovations such as laser lithotripsy and shock-wave therapy have been used to disrupt calculi. Selection of the appropriate surgical technique depends on the site and size of the calculus, the sex of the animal, the availability of surgical facilities and instrumentation, the anesthetic risk, and economic constraints. Because cystic calculi are the most common and treatment differs greatly between the sexes, this article discusses the surgical management of cystic calculi in female and male horses separately.

Surgical Treatment of Urolithiasis in Mares
The mare urethra is wide and is easily distended using manual manipulation. Therefore, uroliths can be extracted manually in some instances. Following intravenous sedation and epidural anesthesia, the urethra is gently dilated with a well-lubricated, gloved hand. The calculus is manipulated into the trigone of the bladder, usually by manual transrectal positioning. Once the calculus is forced into the trigone, a few fingers are inserted into the urethra; with the use of manual dilation, the calculus is extracted from the bladder. This technique is particularly useful in mares with calculi less than 10 cm in diameter. If this technique is unsuccessful, the calculus can be fragmented with a lithotrite (Figure 3), divided with a mallet and osteotome, or physically disrupted with laser or shock-wave lithotripsy. The fragments are then manually removed or flushed from the bladder. The instillation of sterile lubricating jelly can help minimize trauma to the urinary bladder and urethral mucosa by lessening the adherence of calculi fragments to the urethral and urinary bladder epithelium. When using this method, urethral sphincterotomy may help access and remove larger stones. In addition, newer techniques have been developed to break calculi into smaller fragments. These techniques involve the holmium:yttrium–aluminum–garnet (holmium:YAG) laser, the pulsed dye laser, and electrohydraulic and ballistic shock-wave lithotripsy. Laparocystotomy is typically not used because the anatomic features of the mare’s urethra make standing surgical procedures technically more feasible.

Surgical Treatment of Urolithiasis in Male Horses
Many surgical techniques have been described for treating cystic calculi in male horses. Recumbent techniques with the horse under general
anesthesia as well as standing procedures have been described. The recumbent techniques include laparocystotomy and laparoscopic cystotomy. The standing techniques include perineal urethrotomy and pararectal urethrotomy (Gökel’s technique). Either laser lithotripsy or shock-wave therapy can be used to facilitate removal of larger calculi.

Compared with standing surgical removal, surgical removal with the patient under general anesthesia allows more control and access by the surgeon, who can ensure that all uroliths and fragments are removed. However, standing surgical techniques require fewer personnel and less equipment and do not carry the risks associated with general anesthesia and recovery. In addition, standing surgery is more economical for clients with financial restraints. However, large uroliths may not be removable with standing procedures without the help of additional techniques, such as laser lithotripsy or shock-wave therapy to fragment the urolith. If all uroliths are not removed, remaining fragments can act as a new nidus for stone formation and can result in subsequent obstruction of the urinary tract in male horses.

**Recumbent Surgical Techniques**

**Laparocystotomy** has been recommended as the preferred treatment for cystic calculi in male horses. Described approaches include paramedian, ventral midline, and parainguinal laparocystotomy.\(^{9,12,17-19}\) The parainguinal approach has some advantages over the other approaches. The parainguinal approach avoids the major pudendal and superficial epigastric blood vessels and minimizes dead space created by reflection of the prepuce, which is encountered in the other approaches. In general, horses are positioned in dorsal recumbency under general anesthesia. An incision is made in the abdominal wall as described elsewhere or according to the surgeon’s preference. Once the abdominal cavity is entered, the bladder is palpated. The urinary bladder is often located just over the pelvic brim. Typically, the bladder is thickened secondary to the chronicity of the cystic calculus. The bladder is exteriorized by grasping the calculi and slowly pulling the bladder to the level of the abdominal incision. Exteriorization of the bladder can be greatly aided by preoperative administration of diuretics such as furosemide (1.1 mg/kg IV) and dimethyl sulfoxide 90% (500 mL per 5 L of balanced polyionic fluid to make a 10% solution) as well as crystalloid intravenous fluids (a 10-L bolus before surgery). Preoperative administration of intravenous fluids and diuretics should distend the urinary bladder, making exteriorization of the bladder easier during surgery.

Once the bladder is exteriorized, stay sutures made of absorbable material are placed into the bladder. One surgeon has also recommended placement of a laparotomy sponge around the bladder neck to maintain bladder retraction following cystotomy.\(^{12}\) A cystotomy incision is made on the ventral aspect of the bladder, just large enough to facilitate easy removal of the calculus. It is important to remove all calculi to lessen the chance of recurrence. After calculi removal, the bladder is lavaged and the mucosa evaluated. The cystotomy and abdominal wall are closed routinely as described elsewhere.

Complications of laparocystotomy include septic peritonitis, bladder leakage resulting in uroperitoneum, and abdominal incision infection and dehiscence.\(^{1,9,14,19}\) Fortunately, complications are unusual if proper surgical and aseptic principles are employed. The benefits of laparocystotomy include complete visualization of the bladder and calculi, removal of all calculi, and reduced trauma to the urethra and bladder. This method does not require specialized equipment beyond readily available surgical instrumentation.

**Laparoscopic or laparoscopic-assisted surgery** has been performed by some surgeons within the past 10 years to treat urolithiasis. The positioning of the laparoscopic portals and the surgical techniques have been described elsewhere.\(^{16-21}\)

Laparoscopic removal of cystic calculi is performed with the horse under general anesthesia and positioned in dorsal recumbency in Trendelenburg’s position.

Laparoscopic-assisted urolith removal involves a combination of laparoscopic visu-
eralization and parainguinal laparocystotomy. A portal is created at the umbilicus for the laparoscope, and an instrument portal is created 2 to 3 cm medial to the external inguinal ring. The cranial aspect of the bladder is grasped with laparoscopic grasping forceps and elevated to the ventral abdominal wall in the parainguinal region. The instrument portal is then longitudinally extended to facilitate exteriorization of the apex of the bladder, open cystotomy, and extraction of the urolith. After cystotomy closure, the bladder is repositioned and the incisions are closed. 21

Closed laparoscopic urolith removal involves a similar initial approach for the laparoscopic and instrument portals; however, the cystotomy, urolith removal, and cystotomy closure are performed completely within the abdominal cavity using intracorporeal techniques. 19 Once removed from the bladder, the uroliths are placed in a specialized sterile plastic bag. The bladder is then lavaged and closed using intracorporeal suture techniques. After cystotomy closure, one of the laparoscopic portals is enlarged to facilitate removal of the plastic bag containing the calculi.

The primary advantages of laparoscopic techniques are that they negate the need for large abdominal incisions and minimize the postoperative recovery time. Laparoscopic techniques also allow enhanced visualization of the bladder and tension-free bladder closure. Disadvantages of laparoscopic removal of cystic calculi include prolonged surgical times and the need for specialized surgical instrumentation and advanced surgical training in laparoscopic techniques. An additional complication associated with the ventral laparoscopic technique is iatrogenic damage to the caudal epigastric artery and vein during portal placement. 20

Standing Surgical Techniques
Perineal urethrotomy can be performed in a standing male horse under epidural anesthesia. 1,15,22 Small calculi (<5 cm in diameter) and fragments of calculi can be removed from the bladder by lavage or with sponge forceps, canine whelping forceps, or lithotrites, all of which are inserted through the perineal urethral incision. Larger calculi (>10 cm in diameter) require crushing with lithotrites or with a mallet and osteotome. Likewise, techniques such as laser lithotripsy or shock-wave therapy can be used to fragment the calculi. 1,23–27 Perioperative endoscopic visualization is required to ensure complete removal of calculi. Small fragments should not be left within the bladder because they can result in urethral obstruction following healing of the urethrostomy incision or serve as a nidus for future urolith formation. 6 These small fragments can be removed through lavage of the bladder with fluids. Iatrogenic trauma to the urethra and bladder mucosa is not unusual when this technique is used. The perineal urethrostomy incision is left open to heal by second intention. Urethral trauma during this procedure may result in postoperative urethra stricture or fistula formation. Fortunately, stricture of the urethra in equine patients is unusual following perineal urethrostomy. A greater incidence for calculi recurrence has been reported secondary to debris remaining in the bladder following surgical removal because of poor visualization and chronic cystitis. 1,14

Pararectal cystotomy (Gökel’s technique) has been described as an alternative to perineal urethrostomy in horses with cystic calculi. However, this procedure is not widely used because of complications such as an increased risk of entrance into the abdominal cavity and damage to the genitourinary tract, poor visualization of the bladder, and the need for deep dissection. 1,12,13 Pararectal cystotomy is performed following standing chemical restraint and epidural anesthesia. An incision is made between the rectum and the semimembranosus muscle, and blunt dissection is used to expose the neck of the urinary bladder. The bladder is retracted to the level of the incision, the bladder neck is incised dorsolaterally, and the uroliths are removed with assistance per rectum. The wound is packed with gauze, and all incisions are allowed to heal by second intention. In one case report, this method was used successfully when other methods were not practical. However, the horse did develop unilateral orchitis secondary to the surgical procedure. 15

Critical Point
Selection of the appropriate surgical technique depends on the site and size of the calculus, the patient’s sex, the availability of surgical facilities and instrumentation, the anesthetic risk, and economic constraints.
Additional Treatment Options for Urolithiasis

**Laser lithotripsy** has been described for fragmentation of uroliths in male and female horses. Lithotripsy is usually performed in combination with perineal urethrostomy in males and via direct insertion into the urethra in females. Two surgical lasers have been used: the holmium:YAG laser and the pulsed dye laser.

**Holmium:YAG lasers** use a photothermal mode of action, which requires the calculus to be surrounded by water to absorb laser energy. This photothermal effect allows precise placement of the energy on a region of the calculus for fragmentation. The photothermal effect does not appear to predispose horses to a greater risk for soft tissue damage. In addition to being used to fragment a calculus, this laser has been successfully used to make grooves in uroliths to place a lithotrite before removal. Successful use of the holmium:YAG laser to fragment small, less dense uroliths has been reported. However, failure of the holmium:YAG laser to fragment very large, dense uroliths for removal has also been reported.

**Pulsed dye lasers** use a mechanical photoacoustic effect to fragment uroliths. They form a cavitation bubble, which is created by heated water around the calculus. When the bubble collapses, it emits an acoustic shock wave, resulting in fragmentation of the urolith. The pulsed dye laser has been associated with minimal trauma to the soft tissue and has been used successfully in treating not only cystic calculi but also urethral calculi in horses.

With both lasers, an endoscope is used to directly visualize the whole procedure and to prevent soft tissue damage. The pulsed dye and holmium:YAG lasers are delivered to the calculus transendoscopically. Disadvantages associated with these lasers are the costs of use or purchase and prolonged operative times. The use of lasers can be expensive, ranging from $550 (for holmium:YAG lasers) to $1500 (for pulsed dye lasers) to rent them per treatment. The cost of purchasing a laser could range from $20,000 to $100,000. According to the literature, the mean operative time for laser lithotripsy is approximately 2 hours; the time for actual use ranges from 12 to 30 minutes.

**Shock-wave lithotripsy** has also been used for urolith removal. Shock-wave lithotripsy is used in combination with an endoscope and either perineal urethrotomy in males or urethral sphincterotomy in females. Electrohydraulic and ballistic shock-wave lithotripsy have been described for fragmentation of urinary calculi.

**Electrohydraulic shock-wave lithotripsy** works by the generation of a spark across two electrodes. The formation and dispersion of the spark generate the shock waves that act on a large focus area in the urolith. Shearing forces generated by the absorption of the electrohydraulic shock waves disrupt the urolith's crystalline structure, causing urolith fragmentation.

The electrohydraulic lithotriptor must be kept in close contact with the urolith because if it contacts the epithelium, it can cause burns and eventual scar tissue formation. Rodger et al, MacHarg et al, and Eustace and Hunt all had success in using electrohydraulic lithotripsy to treat cystic calculi in a colt, a mare, and two geldings, respectively.

**Ballistic shock-wave lithotripsy** is less frequently described than electrohydraulic shockwave lithotripsy. The mechanism of action for the ballistic shock-wave lithotriptor is the acceleration of a long, thin lithoclast probe by a gas-driven lithoclast handle. The extension length of the lithoclast probe is limited to 2 mm, thereby preventing serious injury to the uroepithelium of the bladder wall as a result of its elasticity. The described procedure was actually performed successfully by Koenig et al with the use of perineal urethrotomy and with the patient in dorsal recumbency. However, they also theorize that this modality could also be used in a standing animal. The specialized equipment and training and the long operative time might prevent widespread use of shock-wave lithotripsy.

**Postoperative Care and Recurrence**

Postoperative management should include adequate water intake for proper hydration, antimicrobial therapy to control bacterial cystitis, and NSAID administration to reduce abdominal discomfort. When bacterial cystitis is present, antimicrobial selection should
be based on culture and sensitivity results. Antimicrobial choice and duration of administration should be based on the degree of cystitis and the amount of urine spillage in the abdomen during the procedure. Trimethoprim–sulfamethoxazole, ampicillin, penicillin, aminoglycosides, and ceftiofur are possible choices in the postoperative treatment of cystic calculi in horses. In horses without concurrent bacterial cystitis, duration of treatment is normally 48 to 72 hours after surgery. NSAIDs such as flunixin meglumine are recommended for pain management following surgery. In addition, the horse should be checked regularly for proper urination.

In a study by Laverty et al, 12 of 29 horses available for follow-up had clinical recurrence of urolithiasis. Postoperative acidification of urine is recommended by some authors to prevent recurrence of uroliths. Urine acidifiers decrease the urine pH enough that a urolith nidus cannot form. Calcium carbonate crystals, the main components of equine uroliths, form in an alkaline environment and dissolve in an acidic environment. It has been reported that calcium carbonate crystals are not found in urinary sediment at a pH lower than 6.0. Several urine acidifiers (e.g., ammonium chloride, ammonium sulfate, ascorbic acid) have reportedly been used in horses. Ammonium chloride does not consistently maintain a low urinary pH. Remillard et al found ammonium chloride to be unpalatable to horses and instead administered ammonium sulfate at a dosage of 175 mg/kg/PO bid to achieve a urinary pH of 5.0 for 7 months. Sertich et al used ascorbic acid as a urine acidifier at a dosage of 4000 mg PO q12h to reduce a stallion’s urine pH from 8.5 to 7.5. A dose of 1 kg/horse PO q24h of ascorbic acid has also been described to achieve more adequate acidification of urine.

A definitive timeline for the course of treatment with urinary acidifiers has not been tested or described. However, in a case report by Remillard et al, after a 7-month course of ammonium sulfate, a horse with a history of chronic, recurrent urolithiasis was successfully managed by diet alone for 2 years without recurrence of the condition. Urinary acidifiers were used intermittently in the cases that were reviewed for this article. Acidifier use varied by type, dose, and duration of treatment. However, no prospective research has been conducted to determine the efficacy of acidifiers or a standardized method of treatment. Lack of efficacy data, a standard method of use, and the success that we and others have had without using urine acidifiers suggest that caution should be exercised when using urine acidifiers. More research is needed to determine their value and develop definitive regimens for treating equine urolithiasis.

Dietary change in addition to the use of urinary acidifiers has also been described for reducing the recurrence of urolith formation. Horses absorb a large amount of calcium through their gastrointestinal tract and subsequently excrete large amounts through their kidneys. Reducing the amount of calcium in their diet might help prevent urolith formation. Another method of dietary management is to control the dietary cation–anion balance (DCAB) to influence systemic pH and mineral excretion. A DCAB of less than 100 mEq/kg of dry feed matter makes the rations acidogenic. This decreases venous and urine pH and enhances the excretion of minerals, especially calcium. Increasing the amount of grain in the diet or feeding lower-quality hay usually lowers the DCAB. However, this method needs to be investigated further to determine its efficacy in preventing urolith formation and its safety for an extended period of time.

**Conclusion**

Scientific and technologic advancements have opened new avenues for treating urolithiasis in horses. Currently, we believe that laparocystotomy, perhaps combined with laparoscopy, will remain the preferred treatment for urolithiasis in male horses. However, the increased use of lithotripsy with radial shock waves may result in outcomes similar to those associated with laparocystotomy. The use of laser lithotripsy is currently limited to referral centers, mainly because of the higher costs associated with purchasing or renting this equipment. In female horses, urolithiasis can generally be treated with new modalities of laser and shockwave therapy offer equine practitioners less traumatic and less invasive methods of treating urolithiasis, but they are not yet being used routinely.
managed with manual extraction or lithotripsy techniques performed via the urethra. New modalities of laser and shock-wave therapies offer equine practitioners less traumatic and less invasive methods of treating urolithiasis, but they are not yet being used routinely. These modalities need to be refined to reduce surgical time and offer a greater probability of success before they can be recommended as replacements for more conventional treatments. Postoperative management of horses with urolithiasis should include broad-spectrum antimicrobial therapy for at least 48 to 72 hours. In addition, NSAIDs should be used for postoperative pain management. Although it is important to ensure adequate water consumption, the use of postoperative urinary acidifiers is questionable because of the lack of evidence of their efficacy and the absence of a definitive treatment regimen.

References
1. Which conditions must be present for urolith formation to occur?
   a. presence of a nidus and urine acidity
   b. calcium carbonate crystals and increased urine volume
   c. urine stasis and material to act as a nidus
   d. urine alkalinity and high-fraction excretion of calcium

2. Uroliths clinically present most frequently in the
   a. penile urethra of stallions.
   b. ureters of geldings.
   c. kidneys of mares.
   d. bladder of male horses.

3. The holmium:YAG laser may fail to fragment cystic calculi when
   a. large, very dense calculi are present.
   b. smaller, denser calculi are present.
   c. the calculi are in the ureters.
   d. calculi are composed of calcium carbonate crystals.

4. A complication associated with laparoscopic cystotomy is
   a. poor anesthetic recovery associated with prolonged recumbency in Trendelenburg’s position.
   b. injury to the caudal epigastric artery vein.
   c. longer surgical times for instrument portal placement.
   d. the inability to adequately visualize the bladder.

5. Which of the following regarding electrohydraulic shock-wave lithotripsy should be avoided?
   a. use in the kidneys
   b. the pressure generated when the cavitation bubble collapses
   c. contact between the epithelium and electrode, which may cause burning and scarring
   d. use on a large, dense urolith

6. When urolithiasis is suspected in a horse, it is
   a. not important to check the whole urinary tract if the clinician has already palpated a calculus in the bladder.
   b. important to check the whole urinary tract because nephroliths are the most common calculi.
   c. not important to check the whole urinary tract in mares because of their lower incidence of urolithiasis.
   d. important to check the whole urinary tract because multiple calculi can be present in several locations.

7. Which statement regarding NSAID administration and patient hydration in horses with urolithiasis is correct?
   a. It is important to ensure adequate hydration in affected patients because cells that slough from the renal papilla can serve as a nidus for calculus formation.
   b. Patient hydration is not important when NSAIDs are administered.
   c. Only male horses need to be adequately hydrated because they cannot excrete calculi as easily as females.
   d. It is important to ensure adequate patient hydration because NSAIDs must be excreted through the urine to be effective.

8. The most common urolith found in horses is
   a. type I, which is smooth and white.
   b. type II, which is smooth and white.
   c. type I, which is yellow green and spiculated.
   d. type II, which is yellow green and spiculated.

9. The most commonly used method of urolith removal in mares is
   a. laparocystotomy.
   b. Gökel’s pararectal cystotomy.
   c. manual removal through the urethra with or without sphincterotomy.
   d. pararectal cystotomy.

10. In electrohydraulic shock-wave lithotripsy, calculus fragmentation is achieved through
    a. a photothermal mode of action.
    b. crystalline structure disruption by shearing forces that are created by shock waves.
    c. cavitation bubble formation, which emits an acoustic shock wave.
    d. a mechanical photoacoustic effect.