Use of a subcutaneous ureteral bypass device for treatment of benign ureteral obstruction in cats: 174 ureters in 134 cats (2009–2015)

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OBJECTIVE

To determine outcomes of subcutaneous ureteral bypass (SUB) device placement for treatment of benign ureteral obstruction in cats.

DESIGN

Retrospective case series.

ANIMALS

134 cats with SUB devices placed in 174 obstructed ureters during 144 hospitalizations.

PROCEDURES

Medical records of cats that underwent SUB device placement for treatment of benign ureteral obstruction between 2009 and 2015 were reviewed. The SUB device was placed by use of fluoroscopic and surgical methods. Signalment, history, diagnostic imaging results, postprocedural results, duration of hospitalization, complications, and short- and long-term outcomes were recorded.

RESULTS

Ureteral obstructions were caused by ureterolithiasis (114/174 [65.5%]), stricture (28/174 [16.1%]), both ureterolithiasis and stricture (29/174 [16.7%]), or pyonephrosis (1/174 [0.6%]); in 2 (1.1%) cats, the cause was not recorded. Fifty-two of the 134 (39%) cats had bilateral ureteral obstruction. At admission, 127 (95%) cats were azotemic. Median serum creatinine concentrations at admission and 3 months after SUB device placement were 6.6 and 2.6 mg/dL, respectively. Median renal pelvis diameters before and after the procedure were 9.2 and 1.5 mm, respectively. Postsurgical complications included device occlusion with blood clots (14/172 [8.1%]), device leakage (6/172 [3.5%]), and kinking of the device tubing (8/174 [4.6%]). Cats survived to hospital discharge after 135 of the 144 (94%) hospital admissions. The most common long-term complication was catheter mineralization (40/165 [24.2%]), which was documented a median of 463 days after device placement. A high postoperative serum ionized calcium concentration was significantly associated with SUB device occlusion.

CONCLUSIONS AND CLINICAL RELEVANCE

Results suggested that SUB device placement may be a viable option for treatment of cats with benign ureteral obstruction. (*J Am Vet Med Assoc* 2018;253:1309–1327)

Options for renal decompression in cats with benign ureteral obstructions include traditional ureteral surgery (eg, ureterotomy, ureteral reimplantation, ureteronephrectomy, and renal transplantation),[1–4] nephrostomy tube placement,[5] ureteral stent placement,[4,6–10] and placement of an SUB device.[3,6,7,9,11,12,a] However, traditional surgical methods have been associated with high complication and mortality rates and persistent ureteral obstruction,[2–4,11] and nephrostomy tube placement, although reportedly resulting in high success rates when appropriate devices and techniques are used, is considered only a short-term solution.[5]

Ureteral stenting is an effective treatment for benign ureteral obstruction in cats, especially when traditional surgery is contraindicated or considered too risky, and has been associated with low perioperative morbidity and mortality rates.[4,6–11] However, ureteral stent placement can be technically challenging in cats and has been associated with a high rate of long-term complications, such as dysuria, recurrent ureteral obstruction, and chronic UTIs.[4,6–8,10]

Placement of an SUB device, which consists of a locking-loop nephrostomy catheter and cystostomy

ABBREVIATIONS

CKD	Chronic kidney disease
IRIS	International Renal Interest Society
MST	Median survival time
PET	Polyethylene terephthalate
SUB	Subcutaneous ureteral bypass
UTI	Urinary tract infection

catheter connected to a subcutaneous shunting port, has been described[3,6,7,9,11,12,a] and appears to provide a viable alternative when surgical relief of benign ureteral obstructions or ureteral stent placement is not possible or contraindicated, or when the patient cannot withstand prolonged anesthesia.[a] However, outcomes of SUB device placement in a large group of cats with benign ureteral obstruction have not, to our knowledge, been reported.

The objectives of the study reported here were to describe methods for placement of an SUB device in cats, determine outcomes (including complications) of SUB device placement in a large group of cats with benign ureteral obstructions, and identify preoperative predictors of long-term outcomes in these cats. We hypothesized that placement of an SUB device would be safe and effective for treatment of benign ureteral obstructions of any cause in cats, would be associated with a low perioperative mortality rate, and would result in good to excellent short- and long-term outcomes. Additionally, we hypothesized that no preoperative predictors of long-term outcome would be identified.

Materials and Methods

Case selection criteria and medical records review

Medical records of all cats with benign ureteral obstructions that underwent SUB device placement by either of 2 authors (ACB or CWW) between March 2009 and June 2015 were retrospectively reviewed. For each patient, the diagnosis of ureteral obstruction had been made on the basis of abnormalities detected on at least 2 of the following 3 imaging modalities: abdominal ultrasonography (detection of renal pelvic dilatation with associated hydroureter caused by an obstructive ureteral lesion), abdominal radiography (observation of renal, ureteral, or bladder calculi), and antegrade ureteropyelography in conjunction with ureterography at the time of SUB device placement. Cats were included in the study only if the following information was available from the medical record: preoperative history, results of preoperative diagnostic imaging and serum biochemical analyses, details of the anesthetic and surgical procedures, and details of all intraoperative, perioperative, short-term, and long-term complications. Both short- and long-term clinical status and results of repeated serum biochemical analyses were recorded, including whether cats died and, if so, the cause of death. Cats that were still alive at the time of the study were included only if a minimum of 6 months of follow-up information after SUB device placement was available. Cats with malignant causes of obstruction were excluded from the study.

When possible, owners of cats included in the study were asked to complete a questionnaire soliciting information on whether various clinical signs (ie, dysuria, polyuria, urine odor, signs of painful urination, hematuria, poor appetite, weight loss, signs of SUB port discomfort, altered posture when urinating, altered activity level, vomiting, diarrhea, and constipation) were present at the time of follow-up. Owners were also asked to assign an overall quality-of-life score for their cats (scored on a scale from 1 to 10, where 1 = terrible, verging on the need for euthanasia; 5 = good days and bad days; and 10 = excellent with no complaints).

Cats included in the study were grouped according to the type of SUB device that was implanted. Cats in group 1 consisted of all cats in which any SUB device was implanted prior to the development and marketing of a commercial SUB device (ie, cats that underwent surgery between March 2009 and February 2011). Cats in group 2 consisted of cats in which a commercial SUB device[b] was implanted (ie, cats that underwent surgery between March 2011 and June 2015). In addition, in 2009, 2010, 2014, and 2015, the nephrostomy and cystostomy catheters that were used were made from polyurethane, and in 2011, 2012, and 2013, the nephrostomy catheters were made from polyurethane but the cystostomy catheters were made from silicone. Cats were also grouped on the basis of their IRIS stage at their 3-month follow-up examination after surgery (stage 1 = serum creatinine concentration within reference limits and low urine specific gravity; stage 2 = serum creatinine concentration between 1.6 and 2.8 mg/dL; stage 3 = serum creatinine concentration between 2.9 and 5.0 mg/dL; and stage 4 = serum creatinine concentration > 5.0 mg/dL).

Complications associated with placement of the SUB device were classified as intraoperative (from the time of anesthetic induction to < 8 hours after surgery), perioperative (from 8 hours to 7 days after surgery), short-term (from 8 to 30 days after surgery), or long-term (> 30 days after surgery). Specific complications that were recorded consisted of urine leakage from the device or urinary tract, kinking of the device tubing, blood clot development causing device occlusion, mineralization of the device causing occlusion, esophagostomy tube placement complications, development of fluid overload, dysuria, perioperative worsening of azotemia, development of a seroma or incisional infection, postoperative development of UTI, and death. For cats that died, the cause of death was classified as ureteral, definitely renal, likely renal, unlikely renal, definitely not renal, or unknown.

Preoperative evaluation

Before surgery, all patients underwent abdominal ultrasonography with, at a minimum, a focus on examination of the urinary tract; abdominal radiography; and, if a heart murmur or arrhythmia was present, thoracic radiography. If deemed appropriate, echocardiography was performed prior to anesthesia. In all cats, antegrade ureteropyelography was performed prior to SUB device placement during laparot-

omy with an 18- or 22-gauge over-the-needle catheter and a 50:50 mixture of sterile saline (0.9% NaCl) solution and iohexol.[c] Pyelocentesis was performed, and the urine sample was submitted for aerobic bacterial culture and antimicrobial susceptibility testing. Ureteropyelography was performed with fluoroscopic imaging.[d] Preoperative data collected for the present study consisted of location of the ureteral obstruction; whether a ureteral stricture was suspected on the basis of ureteropyelographic findings, ultrasonographic imaging, or surgical exploration; whether a circumcaval ureter was found during surgical exploration; number of ureteral calculi found radiographically, ultrasonographically, and at the time of surgery; whether nephroliths were present on radiographic and ultrasonographic images; diameter of ureteral calculi; diameter of the ureteral lumen; diameter of the renal pelvis in the transverse plane on ultrasonographic images; whether contralateral ureteral stones or nephroliths were present; and whether cystoliths were present on radiographic and ultrasonographic images.

Preoperative management

Patients were medically managed for a minimum of 24 hours prior to SUB device placement to allow for treatment of any UTI and possible spontaneous passage of calculi. When possible, any patient with a UTI received appropriate antimicrobial treatment for a minimum of 48 hours prior to SUB device placement, and antimicrobial treatment was continued for approximately 6 weeks after SUB device placement. The minimum 24-hour medical management period was eliminated if a patient had life-threatening hyperkalemia, fluid overload, or a urine output < 1 mL/kg/h (0.45 mL/lb/h) despite euhydration or overhydration.

Preoperative medical management consisted of various combinations of IV fluid therapy (to achieve euhydration), α-adrenoreceptor antagonist administration (prazosin, 0.25 mg, PO, q 12 h), and mannitol administration (0.25 to 0.5 g/kg [0.11 to 0.23 g/lb], IV, over 30 minutes, followed by 1 mg/kg/min, IV, as a constant rate infusion for 24 hours). Antimicrobials, histamine H_2 receptor antagonists, proton pump inhibitors, antiemetics, and phosphate binders were administered as necessary at dosages selected by the attending clinician. In addition, intermittent hemodialysis or preoperative nephrostomy tube placement was performed when necessary.

SUB device placement

Various modifications for SUB device placement were used throughout the study period, depending on available materials, patient characteristics (eg, ability to withstand prolonged anesthesia), and operator preference. In general, in group 1 patients, locking-loop nephrostomy and cystostomy catheters (5, 6, or 8F catheters with a 15-mm loop)[e] were placed from the lateral margin of the kidney at the greater curvature and the cranial aspect of the body of the urinary bladder and were connected to a subcutaneous port or to a T-piece connector[f] that was connected to the port **(Figure 1)**. When the catheters were directly connected to a subcutaneous port, nephropexy and cystopexy were performed with 3-0 polydioxanone after the catheters were tunneled subcutaneously along the body wall.

For group 2 patients, a commercially available kit[b] that included a locking-loop pigtail nephrostomy catheter (6 or 6.5F catheter with an 8-mm loop) and a multifenestrated straight cystostomy catheter (6.5 or 7F catheter) or a locking-loop cystostomy catheter (6.5F catheter with an 8-mm loop) was used for SUB device placement. The nephrostomy catheter was typically placed from the caudal pole of the kidney, and the cystostomy catheter was inserted at the apex of the urinary bladder. The nephrostomy and cystostomy catheters had a radiopaque marker just distal to the last fenestration to improve visibility of the fenestrations and increase ease and safety of placement. A nephropexy or cystopexy was not performed after placement; instead, a PET cuff was used to adhere the catheter to the renal capsule or serosal surface of the urinary bladder to avoid leakage. Rarely, if a patient was unstable under anesthesia, the nephrostomy and cystostomy tubes were internally attached with a male-to-male adapter[g] without tunneling the catheters subcutaneously to a shunting port. Additionally, if a port was used in a cat with bilateral ureteral obstruction and the cat was not stable under anesthesia, a 3-way port[h] was used to connect the 2 nephrostomy catheters to a single bladder catheter. In other situations, separate nephrostomy and cystostomy catheters on each side were each connected to an independent shunting port. The size of the shunting port (small vs large) was chosen on the basis of size of the patient and amount of subcutaneous fat to ensure the port could be easily palpated for flushing following placement (Figure 1).

In general, cats were positioned in dorsal recumbency for SUB device placement, and hair was clipped from the ventral aspect of the neck, thorax, and abdomen and from the vulva or prepuce. Cefazolin (22 mg/kg [10 mg/lb], IV, at induction and every 2 hours during the anesthetic period) was administered in cats that were not already receiving antimicrobials, and a triple-lumen jugular catheter (5.5F, 13-cm-long catheter)[i] was placed in the right jugular vein.

An abdominal incision was made to expose the urinary bladder and the affected kidney. The entire urinary tract was visually explored to determine a cause of the ureteral obstruction, and perirenal fat was bluntly dissected off the caudal or caudolateral pole of the affected kidney, exposing a 1 × 1-cm to 2 × 2-cm region of the renal capsule. With the aid of fluoroscopy, the nephrostomy catheter was placed by use of the modified Seldinger technique. Briefly, an 18-gauge over-the-needle catheter[j] was inserted at the caudal pole of the kidney and used to puncture the

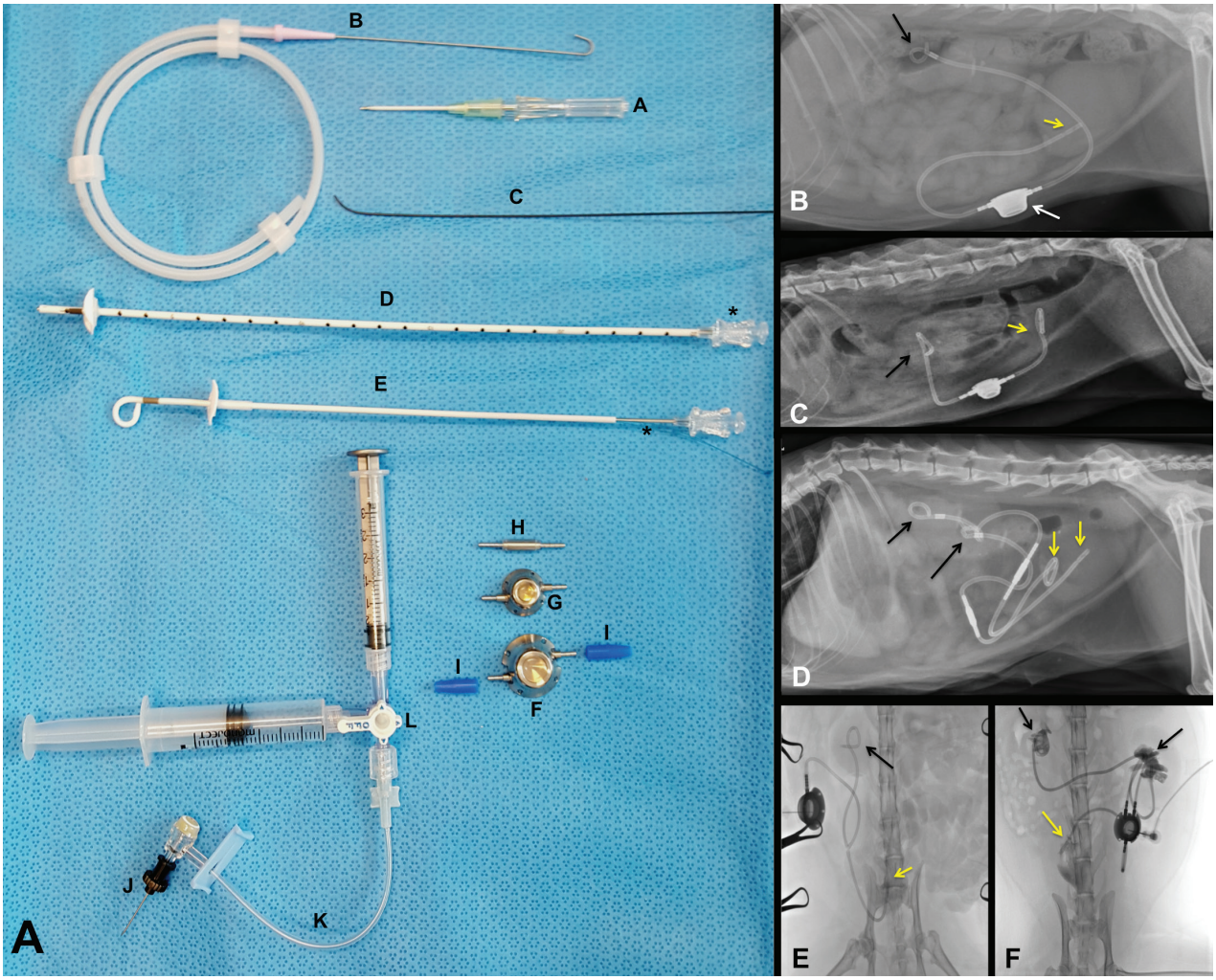

Figure 1—Photograph of the components used for placement of an SUB device in cats with benign ureteral obstruction (A) and lateral (B through D) and ventrodorsal (E and F) fluoroscopic images of various arrangements of SUB devices in cats (B through F). A—Components used for SUB device placement consisted of an 18-gauge over-the-needle catheter (A), 0.035-inch J-wire (B), 0.035-inch angle-tipped hydrophilic guidewire (C), straight cystostomy catheter (D) with 1-cm marks along the shaft and an inner hollow stylette (asterisk), locking-loop pigtail nephrostomy catheter (E) with a PET cuff and silicone sleeve and stiff hollow stylette (asterisk), large shunt port (F), small shunt port (G), male-to-male metallic adaptor for indwelling ureteral bypass (H), blue boots to go over the male adaptors on the ports (I), 22-gauge Huber point needle (J), T-port extension set (K), and 3-way stopcock (L). B—Lateral fluoroscopic image of the abdomen of a cat following placement of a commercial SUB device. Notice the large shunt port (white arrow), pigtail nephrostomy catheter (black arrow), and straight cystostomy catheter (yellow arrow). C—Lateral fluoroscopic image obtained following placement of a prototype SUB device. Notice the pigtail nephrostomy (black arrow) and cystostomy (yellow arrow) catheters. D—Lateral fluoroscopic image obtained following bilateral ureteral bypass. Notice that on each side, a male-to-male adapter has been used to connect a pigtail nephrostomy catheter (black arrows) to a pigtail or straight cystostomy catheter (yellow arrows). E—Ventrodorsal fluoroscopic image obtained following placement of a prototype SUB device. Notice that a 3-way T-connector has been used to connect the nephrostomy (black arrow) and cystostomy (yellow arrow) catheters to the subcutaneous shunt port. F—Ventrodorsal fluoroscopic image obtained following placement of a prototype SUB device. Notice that a 3-way shunt port has been used to connect bilateral nephrostomy tubes (black arrows) to a single cystostomy tube (yellow arrow).

renal pelvis. A urine sample was obtained for bacterial culture, and iohexol diluted with an equal volume of sterile saline solution was injected into the renal pelvis to perform antegrade pyeloureterography and document the location of ureteral obstruction. The volume injected was typically less than that removed during pyelocentesis. Under fluoroscopic guidance, a 0.035-inch angle-tipped hydrophilic guidewire[k] or 0.035-inch metallic J-wire[l] was then advanced through the 18-gauge catheter and coiled inside the renal pelvis, being careful to avoid perforation **(Figures 1–3)**. Once 1 to 2 loops were made within the renal pelvis, the 18-gauge catheter was removed over the wire while the wire was carefully secured within the renal pelvis. Next, under fluoroscopic guidance, the 6.5F locking-loop pigtail nephrostomy catheter was advanced over the guidewire into the renal pelvis, the guidewire was removed, and the locking

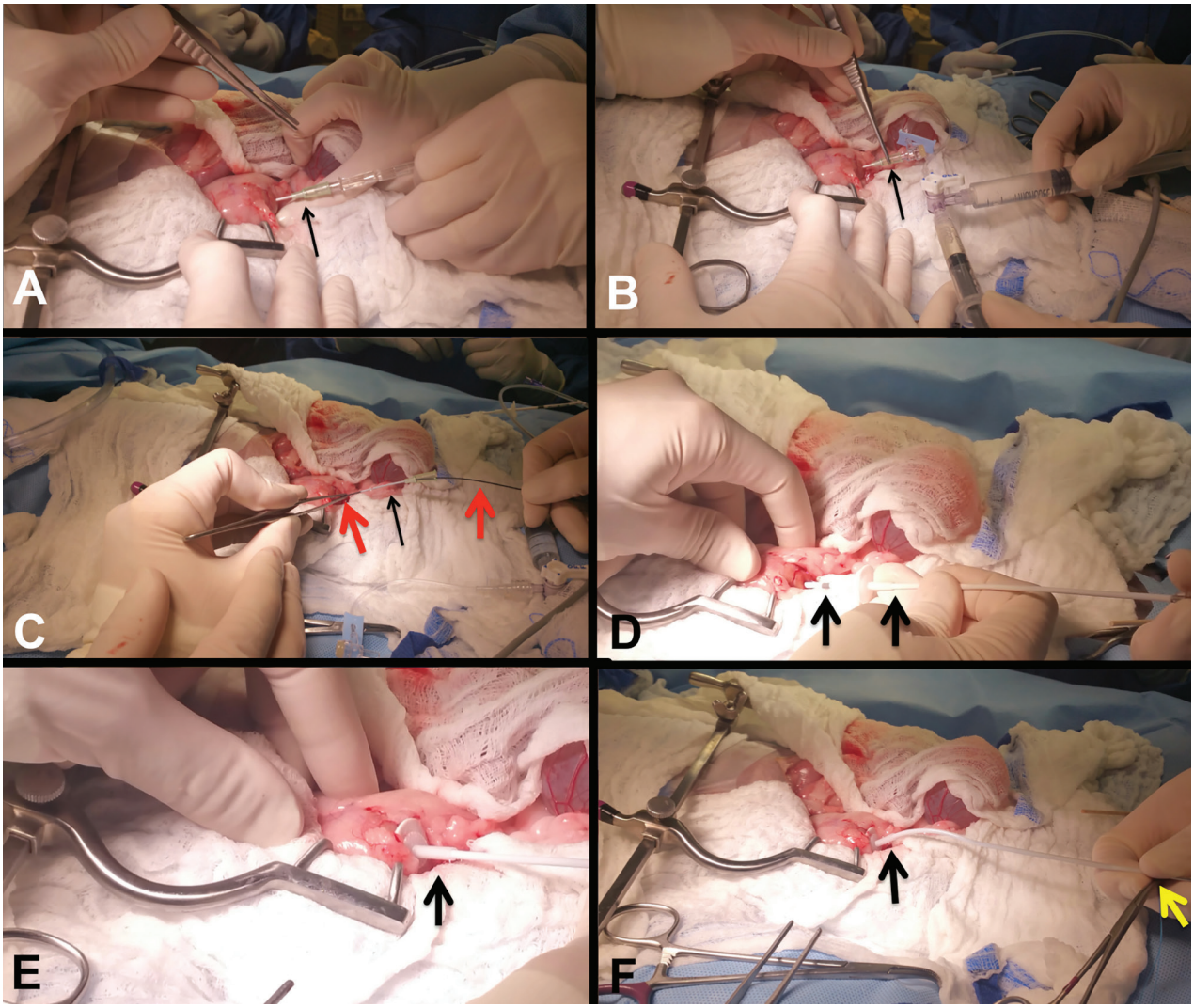

Figure 2—Intraoperative photographs obtained during placement of the nephrostomy catheter of an SUB device for treatment of right ureteral obstruction in a cat (in all images, cranial is to the left). A—An 18-gauge IV catheter (black arrow) inserted from the caudal pole of the kidney has been used to puncture the renal pelvis. B—A T-port and 3-way stopcock have been attached to the renal pelvis catheter to allow drainage of urine from the kidney and injection of iohexol for contrast pyelography. C—A 0.035-inch angle-tipped hydrophilic guidewire (red arrows) was advanced through the catheter (black arrow) and coiled inside the renal pelvis, and the catheter was removed. D—A locking-loop nephrostomy catheter (black arrows) was advanced over the guidewire and into the renal pelvis. E—With the nephrostomy catheter (black arrow) appropriately placed within the renal pelvis, the PET cuff and silicone sleeve were advanced to the level of the renal capsule and glued in place to prevent urine leakage. F—Following placement of the nephrostomy catheter (black arrow), the locking string at the end of the catheter was secured with a hemostat (yellow arrow).

string was pulled to lock the coil in place and prevent catheter dislodgement. A contrast study with fluoroscopic guidance was performed to confirm that the radiopaque marker was within the renal pelvis and to ensure appropriate draining and filling of the renal pelvis without any evidence of leaking. The PET cuff was then gently advanced over the nephrostomy catheter to the renal capsule, followed by the silicone sleeve, and sterile cyanoacrylate glue[m] was applied between the PET cuff and renal capsule to provide security and prevent leakage or dislodgement.

In instances when the renal pelvis was < 5 to 7 mm in diameter and the proximal portion of the ureter was dilated, a 22-gauge IV catheter inserted from the caudolateral aspect of the kidney was used to inject contrast medium into the renal pelvis **(Figure 4)**. If the catheter was appropriately angled toward the ureter, a 0.018-inch angle-tipped hydrophilic guidewire was then advanced down the ureter and the 22-gauge catheter was removed over the wire. Next, an 18-gauge catheter without the inner cannula was advanced over the 0.018-inch wire and inserted into the proximal aspect of the ureter. Then, the 0.018-inch wire was removed and exchanged for a 0.035-inch hydrophilic guidewire. This was advanced into the proximal portion of the ureter, rather than coiled within the renal

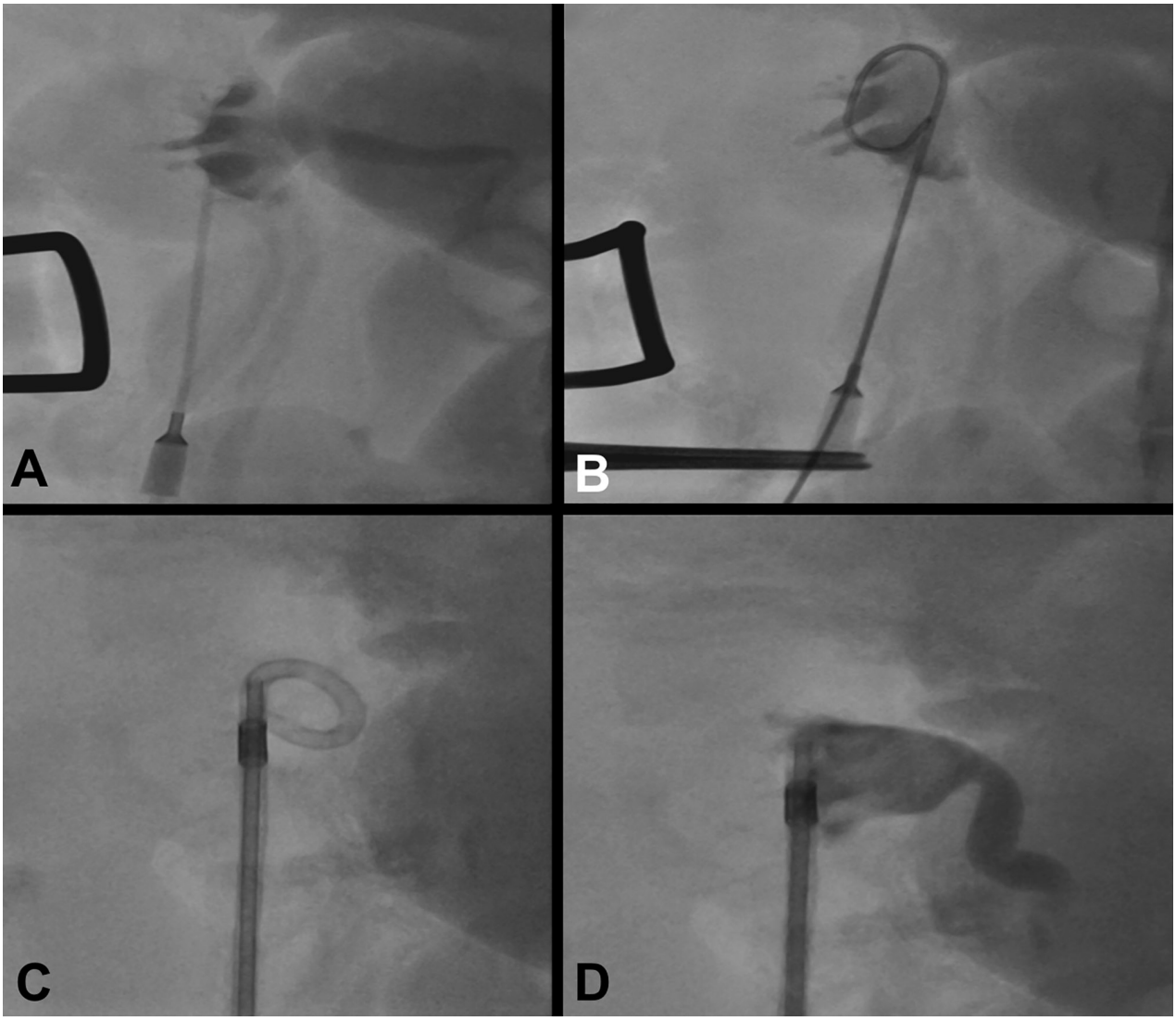

Figure 3—Ventrodorsal fluoroscopic images obtained during placement of the nephrostomy catheter of an SUB device for treatment of right ureteral obstruction in a cat. A—An 18-gauge IV catheter has been advanced into the renal pelvis from the caudal pole of the kidney. B—A guidewire has been introduced through the catheter and coiled inside the renal pelvis. C—A locking-loop nephrostomy catheter has been advanced over the guidewire and coiled within the renal pelvis. Notice that the radiopaque marker band indicating the position of the last fenestration is within the renal pelvis. D—Pyelographic image obtained to ensure proper nephrostomy tube placement and a lack of leakage.

pelvis, and the nephrostomy catheter was advanced over this wire into the ureter, with the locking string cut and removed to create a ureterostomy catheter.

For cystostomy tube placement, a purse-string suture of 3-0 poliglecaprone 25 was placed at the apex of the urinary bladder **(Figure 5)**. A stab incision was made in the center of the purse-string suture with a No. 11 scalpel blade, and the cystostomy catheter was advanced into the urinary bladder. The purse-string suture was secured around the cystostomy catheter, and the PET cuff was glued to the serosal surface of the bladder with sterile cyanoacrylate glue and sutured to the bladder wall with 3-0 poliglecaprone 25. The catheter was then leak tested with sterile saline solution. A locking-loop pigtail or straight catheter was chosen on the basis of the size of the cat, with a locking-loop catheter typically used in smaller cats to avoid contact with the bladder trigone, which could theoretically cause dysuria.

Skin and subcutaneous tissues lateral to the ventral abdominal incision were dissected off the ventral aspect of the fascia of the rectus abdominus muscle **(Figure 6)**, and the nephrostomy and cystostomy catheters were passed through the body wall. Care was taken to ensure there was enough space for the shunting port and a 1- to 2-cm segment of each catheter without creating excessive dead space. With locking-loop catheters, the catheter and locking string were pulled through the body wall in unison, and a blue boot was placed

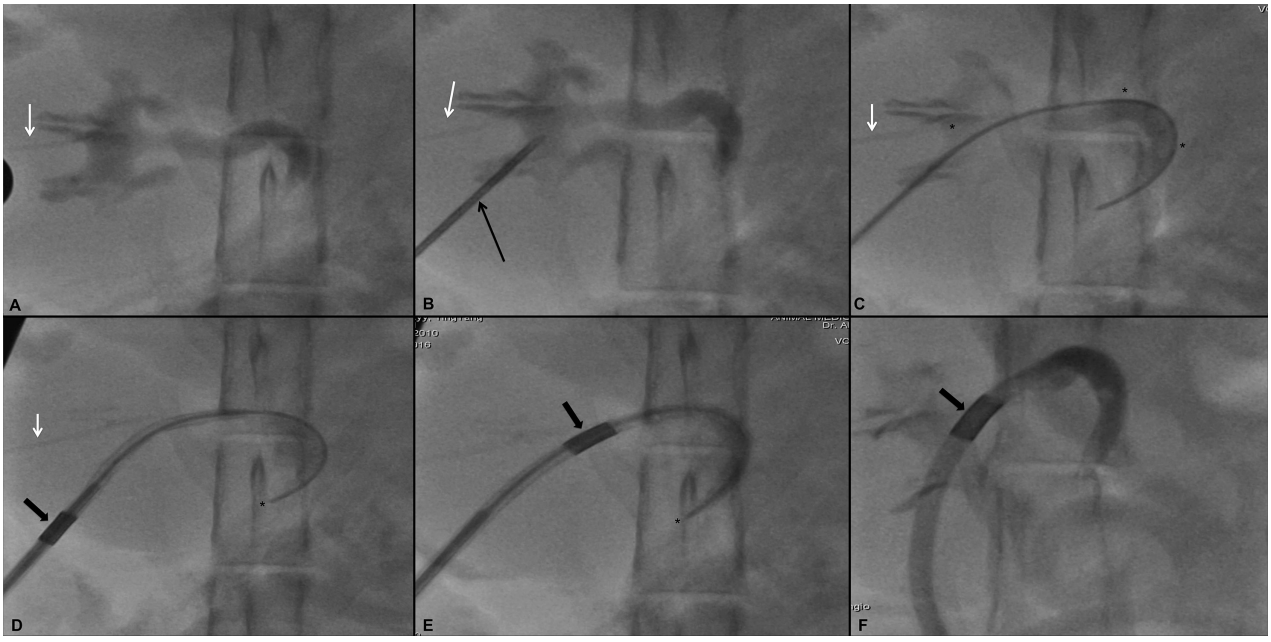

Figure 4—Ventrodorsal fluoroscopic images obtained during nephrostomy catheter placement in a cat with a small, minimally dilated renal pelvis. A—A 22-gauge IV catheter (white arrow) inserted in the renal pelvis from the lateral aspect of the kidney has been used to perform contrast pyelography. B—An 18-gauge IV catheter (black arrow) has been advanced into the renal pelvis at an angle to the first catheter (white arrow). C—A 0.035-inch angle-tipped hydrophilic guidewire has been advanced through the 18-gauge IV catheter and into the renal pelvis and ureter (asterisks). Notice that the 22-gauge IV catheter (white arrow) is still in place. D and E—A locking-loop nephrostomy catheter with the locking string cut has been advanced over the guidewire into the renal pelvis and ureter (asterisk). Notice that the radiopaque marker band (black arrow), which indicates the position of the last fenestration in the nephrostomy catheter, is within the renal pelvis. F—With the nephrostomy catheter in its final position, the radiopaque marker band (black arrow) is within the renal pelvis.

over the catheter to avoid losing the lock on the coils of the catheters. The locking string was then secured to the first barb of the shunting port to wedge the string and lock it in place, then the string was cut flush with the catheter, and the catheter was advanced onto the port, making sure no string was visible between the port and catheter that could have been a site for leakage.

Once the catheters were attached to the shunting port, the system was leak tested by digitally holding off the catheters on each side of the port during port infusion with sterile saline solution and a Huber point needle. Then the port was sutured to the ventral aspect of the rectus sheath with 3-0 polypropylene (Figure 6). The system was drained, and a mixture of iohexol and sterile saline solution was injected and observed by means of a digital subtraction radiography technique to test for patency and to ensure that the nephrostomy and cystostomy catheters were flowing and draining properly without kinks or leaks. A local splash block of bupivacaine (0.6 mg/kg [0.27 mg/lb]) was placed around the port, and the subcutaneous pocket and abdominal cavity were closed in a routine manner. Fluoroscopy was then performed to confirm that no kinks were present in the device at the completion of the procedure **(Figure 7)**. Finally, an esophagostomy tube[n] was placed in the left lateral aspect of the neck.

Postoperative management

Patients were monitored for hydration status by means of serial measurements of body weight, urine output, serum concentrations of electrolytes and other biochemical analytes, blood gas partial pressures, plasma total solids concentration, and PCV. If antimicrobial treatment had not been initiated prior to surgery, marbofloxacin (2.75 to 5.5 mg/kg/d [1.25 to 2.5 mg/lb/d], PO) was administered for 2 weeks to decrease biofilm formation on the device.[13] If results of bacterial culture were positive, antimicrobials selected on the basis of results of susceptibility testing were administered for 6 weeks. Postoperative analgesia was provided in accordance with clinician preference. Serum biochemical analyses (ie, BUN, creatinine, phosphorus, potassium, sodium, total calcium, and ionized calcium concentrations) were performed and plasma total solids concentration and PCV were measured every 24 hours until hospital discharge. Prior to hospital discharge, the SUB device was flushed under ultrasound guidance to ensure that there were no occlusions.

Follow-up

Following hospital discharge of the cat, owners were advised to have a serum biochemical profile, CBC, urinalysis, urine bacterial culture, abdominal radiography, urinary tract ultrasonography, and flush-

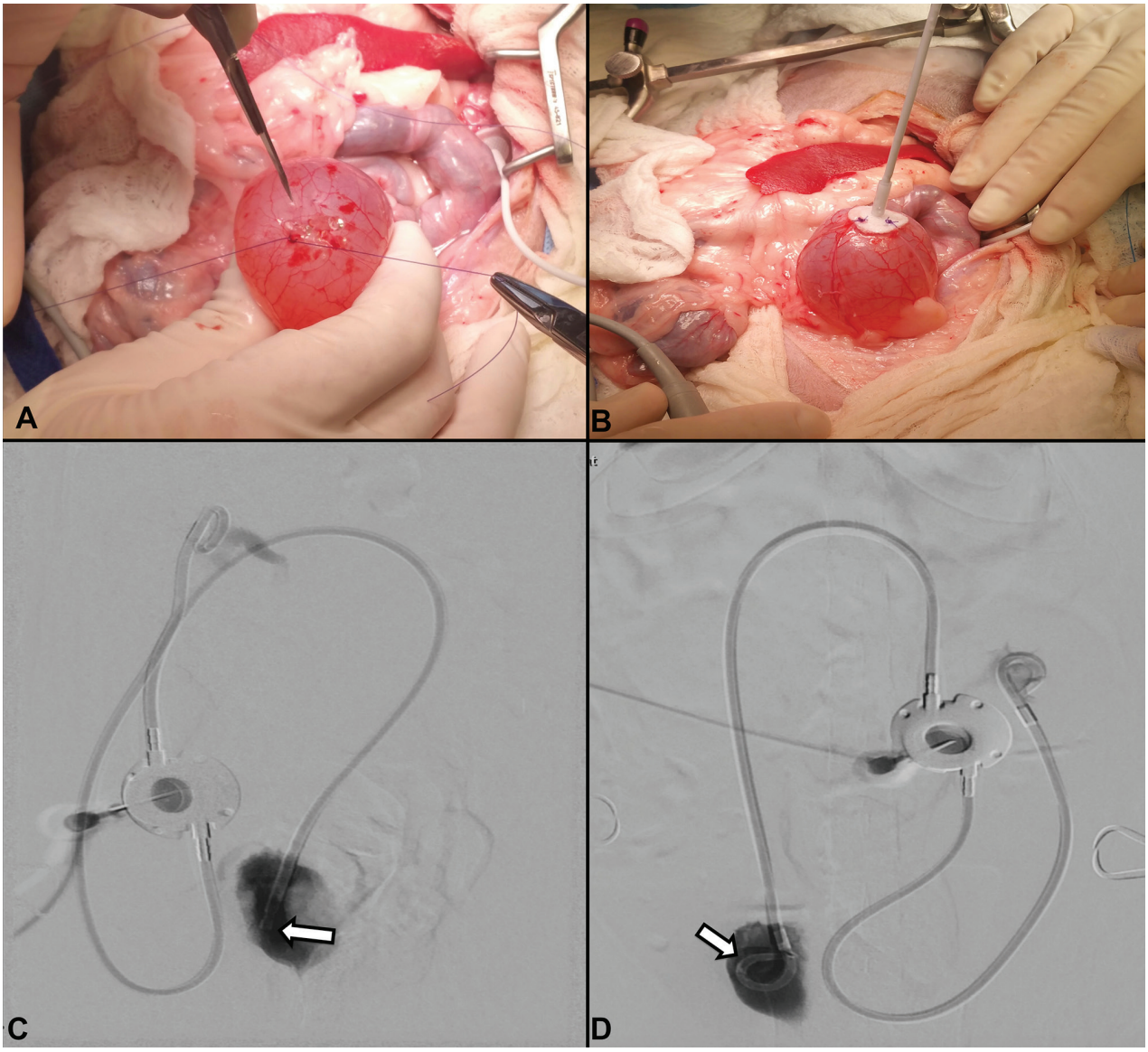

Figure 5—Intraoperative photographs obtained during cystostomy catheter placement (A and B) and ventrodorsal radiographic images obtained with a digital subtraction technique following placement of an SUB device (C and D) in a cat. A—A purse-string suture has been placed at the apex of the urinary bladder, and a No. 11 scalpel blade has been used to make a stab incision in the center of the suture. B—Once the cystostomy catheter was inserted, the purse-string suture was tightened and the PET cuff was glued and sutured to the apex of the urinary bladder. C and D—Ventrodorsal fluoroscopic images obtained during infusion of iohexol illustrating straight (C; arrow) and pigtail (D; arrow) cystostomy catheters.

ing of the SUB device performed and systolic blood pressure and body weight measured 1 to 2 weeks, 4 weeks, and 3, 6, 9, and 12 months after surgery, and then every 3 to 6 months thereafter. The SUB flushing procedure was typically performed without the need for sedation. Hair overlying the port was clipped, and the skin was aseptically prepared. With a noncoring Huber needle, a 2- to 3-mL urine sample was obtained from the system and submitted for urinalysis and bacterial culture. Then, with the aid of ultrasound guidance, 0.5 mL of saline solution was flushed into the device, and the renal pelvis was monitored for bubbles. The 0.5-mL volume that had been infused was then aspirated, and another flush was performed while ultrasonographically imaging the urinary bladder. Once bubbles were seen throughout the entire system, the Huber needle was gently removed.

If calcium oxalate stones were identified or suspected, owners were advised to administer potassium citrate (50 to 75 mg/kg [22.7 to 34.1 mg/lb], PO, q 12 h) and have urine pH and serum potassium concentration monitored. In addition, for patients that were persistently azotemic, owners were advised to feed a prescription renal diet, and for patients with a serum creatinine concentration < 2.0 mg/dL, owners were advised to feed a prescription neutralizing

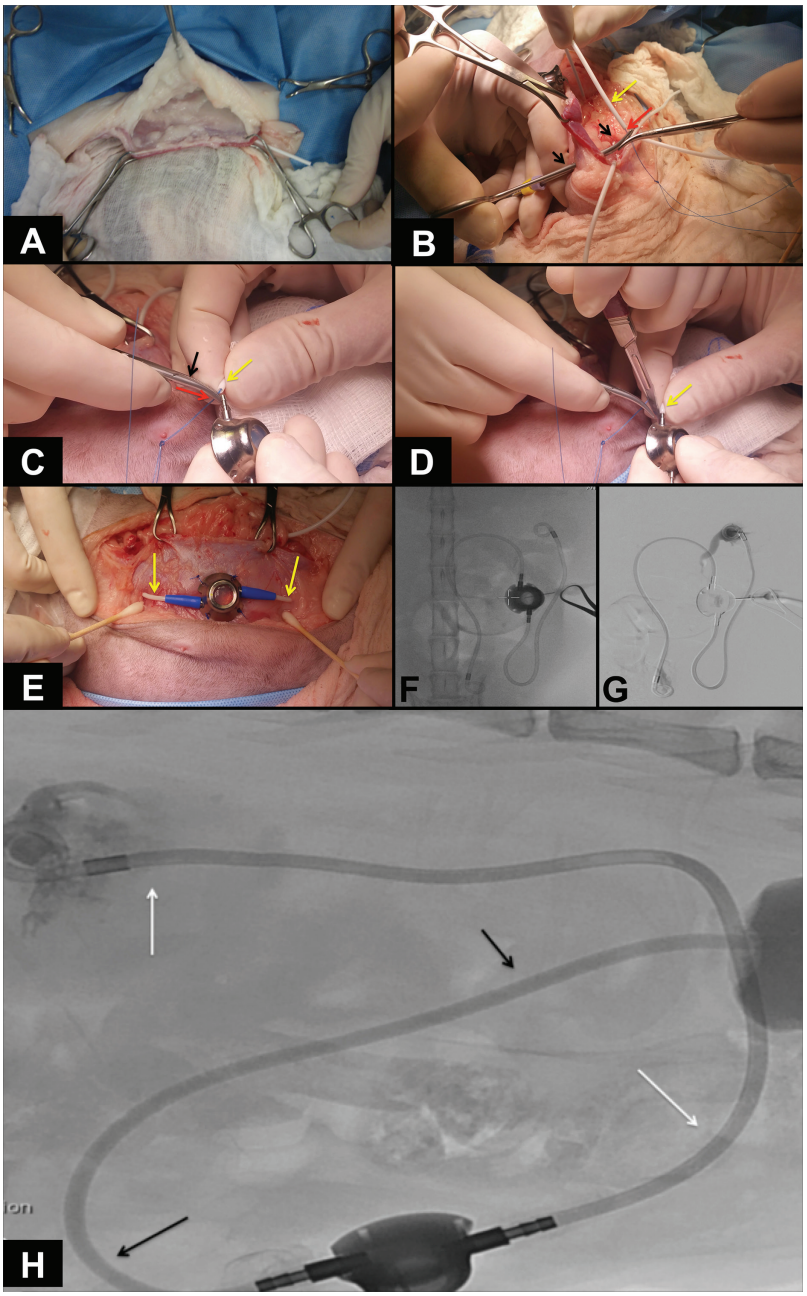

Figure 6—Intraoperative photographs and fluoroscopic images obtained during placement of the subcutaneous port of an SUB device in a cat. A—Subcutaneous fat has been dissected to expose the ventral aspect of the rectus abdominis muscle sheath. B—Hemostats (black arrows) were passed through the body wall to grab the locking string (red arrow) of the nephrostomy catheter (yellow arrow) and pull the catheter into the subcutaneous space without unlocking the loop. C—The nephrostomy catheter (yellow arrow) was attached to the shunt port with the locking string (red arrow) still held with the hemostat (black arrow). D—A No. 11 scalpel blade was then used to cut the locking string flush with the adaptor to prevent any wicking of urine and leakage at the catheter-port junction. E—The nephrostomy and cystostomy catheters (yellow arrows) were both connected to the shunt port with blue boots covering the junctions and the port was sutured to the rectus sheath. F—Ventrodorsal fluoroscopic image obtained following flushing of the SUB device with iohexol. G—Ventrodorsal fluoroscopic image obtained with a digital subtraction technique following flushing of the SUB device with iohexol. H—Lateral fluoroscopic image of the SUB device illustrating the shunt port, nephrostomy catheter (black arrows), and cystostomy catheter (white arrows).

stone diet. For patients with serum phosphorus concentration > 5 mg/dL, owners were advised to administer aluminum hydroxide (90 mg/kg/d [41 mg/lb/d], mixed with food). Patients with persistent ionized hypercalcemia were tested for hyperparathyroidism (which included measurements of serum parathyroid hormone, parathyroid hormone–related protein, ionized calcium, and vitamin D concentrations), and if idiopathic hypercalcemia was diagnosed, supplemental dietary fiber was recommended. If this did not resolve the ionized hypercalcemia within 4 weeks, then oral administration of alendronate (10 mg/wk) was initiated, and the dosage was titrated as needed.

Statistical analysis

Patient outcome was characterized as survival (yes vs no) to hospital discharge and survival (yes vs no) 1 month, 3 months, 6 months, and 1 year after hospital discharge and at the time of final follow-up. Multivariate analysis was performed to determine whether the following preoperative, intraoperative, or perioperative factors were associated with survival to hospital discharge, hospitalization time, or overall survival time: patient age and weight at the time of SUB device placement, history of oliguria or anuria, need for preoperative hemodialysis, history of weight loss, history of CKD, duration of ureteral obstruction (if known), history of dysuria, ultrasonographic size of the renal pelvis prior to device placement, preoperative results of serum biochemical analyses (SUN, creatinine, phosphorus, and potassium concentrations and PCV), preoperative UTI, IV administration of mesenchymal stem cells after surgery, need for a blood transfusion during hospitalization, procedure time, type of SUB device used (group 1 or 2), development of fluid overload, development of postobstructive diuresis, and hospitalization time.

Postoperative factors tested for an association with overall survival time consisted of IRIS stage 3 months after SUB device placement and development of complications (device leakage, blood clot occlusion, device mineralization, need for device exchange, postoperative dysuria, postoperative

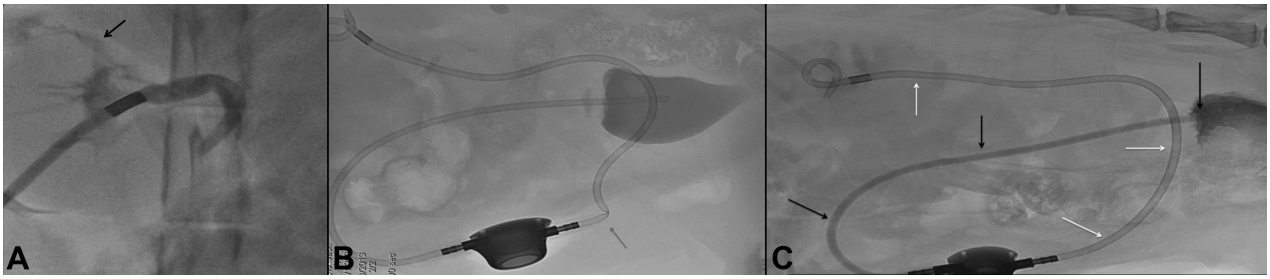

Figure 7—Fluoroscopic images illustrating various complications following SUB device placement in cats. A—Ventrodorsal fluoroscopic image showing iohexol leaking out of a renal calix and under the renal capsule (black arrow). B—Lateral fluoroscopic image showing kinking of the nephrostomy catheter (arrow) where it exits the abdominal cavity. C—Lateral fluoroscopic image obtained following flushing of the shunt port with iohexol. Contrast (black arrows) is seen within the cystostomy catheter, indicating that this catheter is patent, but is not seen within the renal pelvis or nephrostomy catheter, indicating blockage of the nephrostomy catheter (white arrows).

UTI, chronic UTI, postoperative hypercalcemia, and postoperative chronic hematuria).

Factors tested for an association with postoperative blood clot occlusion of the device or device mineralization consisted of preoperative evidence of bacteriuria or UTI, preoperative hypercalcemia, preoperative creatinine concentration, postoperative hypercalcemia, bladder catheter shape (straight or pigtail), nephrostomy tube location (ureter or pelvis), port size (small, large, or 3-way), catheter orientation to the port (cranial-to-cranial or cranial-to-caudal), presence of long-term hematuria, and etiology of the ureteral obstruction (dried solidified blood calculi, calcium-containing stones, or stricture).

Complications tested for an association with survival time consisted of device leakage, blood clot occlusion, occlusion from mineralization, need for device exchange, postoperative dysuria, postoperative UTI, chronic UTI, postoperative hypercalcemia, and postoperative chronic hematuria.

Risk factors examined for an association with the development of dysuria following SUB device placement consisted of preoperative UTI, postoperative UTI, dysuria prior to SUB device placement, sex, use of bilateral versus unilateral SUB devices, type of bladder catheter (straight or pigtail), presence of dried solidified blood calculi, gross hematuria after surgery, a history of cystic calculi, cystic calculi at the time of surgery, and cause of the ureteral obstruction (ureterolithiasis or ureteral stricture).

Risk factors examined for an association with the development of gross hematuria following SUB device placement consisted of presence of dried solidified blood calculi, location of the nephrostomy tube (renal pelvis or ureter), cause of ureteral obstruction (ureterolithiasis or ureteral stricture), use of bilateral versus unilateral SUB devices, and bladder catheter shape (straight or pigtail).

For categorical variables, frequency analysis was performed with the χ^2 or Fisher exact test with false-discovery rate adjustment, when appropriate. Continuous variables were summarized as mean and SD or median and range. Overall survival time (time until death due to any cause or loss to follow-up) was determined with the Kaplan-Meier product-limit method. Median survival times were reported with their corresponding 95% confidence intervals when available. In instances when death had not yet occurred, time to last follow-up was used to calculate survival time, and the case was censored. Survival times were compared between groups by use of the log-rank test. Cox proportional hazards models were used to examine the survival distribution. Mean differences over time within patient populations were evaluated with mixed-model repeated-measures ANOVA with subject assigned as a random effect and a compound symmetry covariance structure.

All statistical analyses were performed with standard software.[o] Values of $P < 0.05$ were considered significant.

Results

Cats

One hundred thirty-four cats met the criteria for inclusion in the study. Of these, 82 (61%) had unilateral ureteral obstruction and 52 (39%) had bilateral ureteral obstructions, for a total of 186 obstructed ureters. A SUB device was placed in 174 of the 186 obstructed ureters, with 94 of the 134 (70%) cats undergoing unilateral SUB device placement and 40 (30%) undergoing bilateral SUB device placement. The remaining 12 obstructed ureters that did not have a SUB placed were either not treated (n = 4) or had a ureteral stent placed (8). In 10 of the 40 cats that had SUB devices placed bilaterally, the device was placed during separate hospital admissions. Thus, there was a total of 144 hospitalizations for the 134 cats. No SUB device placement failures occurred.

History and clinical findings at hospital admission

Median age at the time of SUB device placement was 9 years (range, 0.22 to 18.8 years). Of the 134 cats, 74 (55%) were castrated males, 59 (44%) were spayed females, and 1 (0.7%) was a sexually intact male. There were 94 domestic shorthairs, 15 domestic longhairs, 6 Siamese, 3 Russian Blues, 3 Persians,

2 Ragdolls, 2 Burmese, and 1 each of the following: Norwegian Forest Cat, Scottish Fold, Somali, Japanese Bobtail, British Shorthair, Siberian, Maine Coon, Birman, and Himalayan. Median body weight was 4.1 kg (9.0 lb; range, 1.5 to 9.0 kg [3.3 to 19.8 lb]). Pertinent history included a previous episode of ipsilateral ureteral obstruction (25/174 [14%] ureters) treated by means of ureterotomy or reimplantation (n = 3 ureters), medical management (1), or ureteral stent placement (21). Twenty-seven of 120 (22.5%) cats had a history of azotemia and were suspected to have CKD on the basis of small kidney size, a history of polyuria and polydipsia, and a loss of corticomedullary definition in both kidneys, and 17 of 113 (15%) cats had previously undergone cystotomy for removal of cystic calculi.

Preoperative signs included poor appetite (96/125 [77%]); chronic weight loss (77/121 [64%]); vomiting (67/120 [56%]); polyuria, polydipsia, or both (33/106 [31%]); hematuria (28/111 [25%]); and dysuria (26/113 [23%], with only 1 having evidence of concurrent UTI or cystolithiasis). Oliguria or anuria was documented for 16 of 112 (14.3%) cats on the basis of a urine output < 1 mL/kg/h or a failure to observe urination within 24 hours and a small bladder detected ultrasonographically. Median documented duration of ureteral obstruction was 2 weeks (mean, 3.5 months; range 0 to 48 months). For 12 of 144 (8%) hospitalizations, intermittent hemodialysis was performed immediately prior to SUB device placement because of oliguria, hyperkalemia, or overhydration causing the cat to not be stable enough for anesthesia.

Physical examination revealed 1 large and 1 small kidney in 105 of 128 (82%) cats. Median body condition score (assessed on a scale of 1 to 9) was 4 (range, 2 to 9). A heart murmur was detected during 95 of 144 (66%) hospitalizations. Hydration status was reported for 127 cats, with 41 (32%) cats considered dehydrated, 79 (62%) considered appropriately hydrated, and 7 (6%) considered overhydrated.

Clinicopathologic findings

At the time of hospital admission, median PCV was 27% (range, 15% to 59%; reference range, 29% to 45%) and median plasma total solids concentration was 7.2 g/dL (range, 5 to 9.8 g/dL; reference range, 5.9 to 8.5 g/dL). Median BUN concentration was 82 mg/dL (range, 15 to 270 mg/dL; reference range, 15 to 34 mg/dL), median serum creatinine concentration was 6.6 mg/dL (range, 1.2 to 23.8 mg/dL; reference range, 0.8 to 1.9 mg/dL), median serum sodium concentration was 152 mEq/L (range, 140 to 160 mEq/L; reference range, 145 to 158 mEq/L), median serum potassium concentration was 4.4 mEq/L (range, 2.1 to 9.6 mEq/L; reference range, 3.4 to 5.6 mEq/L), median serum phosphorus concentration was 5.5 mg/dL (range, 2.3 to 22.8 mg/dL; reference range, 2.1 to 5.7 mg/dL), median serum total calcium concentration was 10 mg/dL (range, 7 to 12.4 mg/dL; reference range, 8.2 to 11.8 mg/dL), and median serum ionized calcium concentration was 1.13 mmol/L (range, 0.6 to 2.0 mmol/L; reference range, 1.0 to 1.33 mmol/L). Serum ionized calcium concentration was high preoperatively in 27 of 107 (25%) cats, and 128 of 134 cats (96%) during 135 of 144 (94%) hospitalizations had a high serum creatinine concentration at the time of hospitalization.

Median urine specific gravity at the time of hospital admission was 1.015 (range, 1.007 to 1.063; reference range, > 1.035), and median urine pH was 6.0 (range, 5 to 8; reference range, 6 to 7). On urine sediment evaluation, 32 of 56 (57%) cats had hematuria (ie, > 5 RBCs/hpf), 32 of 56 (57%) cats had pyuria (ie, > 2 WBCs/hpf), 32 of 56 (57%) cats had epithelial cells, 12 of 56 (21%) cats had crystalluria, 8 of 47 (17%) cats had bacteriuria, and 3 of 47 (6%) cats had casts. Thirty-two of 129 (25%) cats were determined to have bacteriuria on the basis of results of urine bacterial culture or microscopic examination of a urine sample from the urinary bladder or renal pelvis. Microorganisms were identified in 21 cats and consisted of *Escherichia coli* (n = 10), *Enterococcus* spp (8), and *Staphylococcus* spp (3).

Diagnostic imaging findings

Preoperative thoracic radiographs from 56 cats were available for review. Eight had evidence of cardiomegaly, 3 had a bronchial pattern, 2 had pleural effusion and prominent pulmonary vasculature, and 2 had a nodular pattern.

Echocardiography was performed prior to device placement in 47 cats. Abnormalities were documented in 22 cats and consisted of various combinations of hypertrophic cardiomyopathy (n = 6), left atrial enlargement (5), restrictive cardiomyopathy (5), right ventricular outflow tract obstruction (4), systolic anterior motion of the mitral valve (4), mitral and tricuspid valve regurgitation (2), aortic insufficiency (2), evidence of fluid overload without structural heart disease (1), hypertrophic obstructive cardiomyopathy (1), and unclassified cardiomyopathy (1).

Preoperative abdominal radiographs from 125 cats were available for review. Nephroliths were visualized in 120 of 158 (76%) kidneys in which the renal pelvis was visualized. Cystic calculi were visualized in 31 of 131 (24%) cats for which diagnostic images (radiographs, ultrasonographic images, or both) of the urinary bladder were available for review. Median number of calculi in the affected ureter, determined on the basis of radiographic and ultrasonographic findings, was 2 (range, 0 to > 50).

Information on ultrasonographic, radiographic, and surgical findings was available for 105 obstructed ureters. Of these, 4 (4%) did not have calculi evident on radiographs but did have calculi identified on ultrasonographic images and at surgery, 3 (3%) did not have calculi evident on ultrasonographic images but did have calculi identified on radiographic images and at surgery, 1 (1%) had calculi evident on radiographs but the calculi were not determined to be the cause of the ureteral obstruction at surgery, and 1 (1%) had no evidence of calculi on radiographic

or ultrasonographic images but had calculi identified at surgery. The latter cat had dried solidified blood stones retrieved during a cystotomy.

Abdominal ultrasonographic images from 133 cats were available for review, and a report of ultrasonographic findings was available for all 134 cats. Obstructed ureters were documented in 186 ureters in the 134 cats, with bilateral obstructions in 52 (39%) cats and unilateral obstructions in 82 (61%). Median diameter of the renal pelvis in obstructed kidneys, determined in the transverse plane, was 9.2 mm (mean, 10.6 mm; range, 2.0 to 35.5 mm; reference range, < 1 mm). Hydroureter was documented for 172 of 173 ureters, with a median ureteral diameter of 3.3 mm (mean, 3.5 mm; range, 0 to 10 mm; reference range, < 0.3 mm). The 1 cat without hydroureter had obstruction at the ureteropelvic junction. Location of the ureteral obstruction was reported for 152 ureters and was classified as at the ureteropelvic junction in 3 (2%), in the proximal portion of the ureter (< 4 cm from the ureteropelvic junction) in 112 (74%), in the mid-ureter (4 to 8 cm beyond the ureteropelvic junction) in 13 (9%), in the distal portion of the ureter in 14 (9%), and throughout all regions of the ureter because of multiple obstructions in 10 (6.6%).

For the 174 ureters for which an SUB device was placed, the cause of ureteral obstruction was suspected to be ureterolithiasis alone in 114 (66%) ureters, a ureteral stricture alone in 28 (16%), a combination of stricture and stone in 29 (17%), and a purulent ureteral plug in 1 (1%); a cause could not be identified for the remaining 2 ureters. Dried solidified blood stones were documented as the cause of ureteral obstruction for 8 (5%) ureters. Twenty-five of 170 (15%) ureters were classified as circumcaval at surgery, with the area of obstruction located in the proximal 1 to 3 cm of the ureter. Five of the 25 (20%) circumcaval ureters were left-sided, and 20 (80%) were right-sided.

Medical management

All cats received IV fluid therapy prior to SUB device placement. Median duration of preoperative IV fluid therapy was 1.5 days (mean, 2.5 days; range, 0.5 to 8 days). Additional preoperative management included administration of an α-adrenoceptor blocker (n = 32), osmotic diuretic therapy (15), and intermittent hemodialysis (12).

SUB device placement

An SUB device was successfully placed for all 174 ureters in which it was attempted. The initial prototype device was placed in 20 (11%) ureters, and the commercially available device was placed in 154 (89%). In all instances, a pigtail nephrostomy catheter was used, with the catheter coiled and locked in the renal pelvis (149/174 [86%]) or passed into the proximal portion of the ureter (25/174 [14%]). The type of cystostomy catheter was recorded for only 170 SUB devices. A straight cystostomy catheter was used in 129 of the 170 (76%) and a locking-loop pigtail catheter was used in 41 (24%) SUB devices. The connection between the nephrostomy and cystostomy tubes could be determined from the surgical report or postoperative images for 166 SUB devices and was a small shunting port in 48 (29%), a large shunting port in 108 (65%), a 3-way shunting port in 6 (4%), and an intra-abdominal male-to-male adaptor in 4 (2%). Falciform or omental fat was harvested at the end of the procedure for adjunctive IV autogenous mesenchymal stem cell therapy in 20 of the 134 (15%) cats and was administered approximately 2 days and again 1 to 3 months after surgery. A urinary catheter was placed for postoperative quantification of urine output in 31 of 134 (23%) cats.

Overall median procedure time was 70 minutes (mean, 73 minutes; range, 25 to 160 minutes). Median procedure time for unilateral device placement (65 minutes) was significantly ($P < 0.001$) shorter than median procedure time for bilateral placement (95 minutes).

A blood transfusion was performed in 25 of 134 (18.7%) cats preoperatively and in 19 (14%) postoperatively. Three cats received blood transfusions both before and after surgery.

Postoperative data

Median BUN and serum creatinine concentrations 24 hours after SUB device placement were 62.5 mg/dL (mean, 71.7 mg/dL; range, 15 to 180 mg/dL) and 3.2 mg/dL (mean, 4.3 mg/dL; range, 0.8 to 15 mg/dL), respectively. Median serum creatinine concentration, PCV, and plasma total solids concentration recorded prior to hospital discharge were 2.7 mg/dL (range, 0.8 to 11.2 mg/dL), 23% (range, 13% to 38%), and 6 g/dL (range, 4.4 to 7.8 g/dL), respectively. Postobstructive diuresis was documented in 21 of 92 (23%) cats in which urine output was estimated or quantified. Median hospitalization time was 4 days (mean, 4.6 days; range, 1 to 11 days). For 9 of the 144 (6%) hospitalizations, the cat was euthanized (n = 8) or died (1) prior to hospital discharge because of persistent kidney disease (4), pancreatitis (2), hemorrhage following esophagostomy tube placement (1), neurologic disease progression (1), and cardiopulmonary arrest of unknown cause (1).

Complications

Intraoperative complications—Information on intraoperative complications (ie, complications occurring from the time of anesthetic induction to < 8 hours after surgery) was available for all 174 device placements during 144 hospitalizations for the 134 cats. One or more intraoperative complications were documented during 12 of the 174 (7%) device placements, including a leak at the catheter-port junction (4/174 [2%]) requiring reattachment of the catheter, a blood clot within the device (4/174 [2%]) requiring thorough flushing of the catheter to remove the clot, kinking of a catheter (3/174 [2%]) requiring repositioning of the catheter in the abdomen prior to closure, renal bleeding during nephrostomy tube placement (1/174 [1%]) that was self-limiting, and

self-limiting subcapsular bleeding (1/174 [1%]). All complications could be rectified during the procedure or were self-limiting, and no cat died during device placement. Two cats had hemorrhage during esophagostomy tube placement. In one cat, the hemorrhage was of no consequence; the other cat was euthanized 6 hours after surgery because of failure to recover from anesthesia and financial concerns. This cat was 3 months old with bilateral ureteral obstructions. One cat died approximately 4 hours after anesthetic recovery; no complications were identified during surgery, and the only abnormality seen during a postmortem examination was pancreatitis.

Perioperative complications—Information on perioperative complications (ie, complications occurring from 8 hours to 7 days after surgery) was available for 172 device placements during 142 hospitalizations for 132 cats. Documented complications included a blood clot in the SUB device system identified ultrasonographically (9/172 [5%] devices), a leak in the SUB device system identified during flushing of the device with contrast medium (6/172 [3%] devices), echocardiographic or radiographic evidence of fluid overload (6/141 [4%] hospitalizations), a corneal ulcer (5/141 [3.5%] hospitalizations), dysuria (4/141 [3%] hospitalizations), urethral obstruction (3/141 [2%] hospitalizations), postoperative seizures (3/141 [2%] hospitalizations), worsening azotemia (2/141 [1.4%] hospitalizations), kinking of the device (1/172 [1%] devices) determined on radiographic evaluation, and severe bruising of the ventral body wall without device leakage (1/141 [1%] hospitalizations). Surgical revision was needed during 10 of the 141 (7%) hospitalizations because of leakage at the catheter-port junction requiring reattachment of the catheter (n = 3), blood clot occlusion of the catheter requiring catheter exchange (4), or urethral obstruction resulting from passage of a ureterolith and subsequent cystostomy (2) or perineal urethrostomy (1).

Short-term complications—Information on short-term complications (ie, complications occurring from 8 to 30 days after surgery) was available for 165 SUB devices placed during 135 hospitalizations in 125 cats. Four of 165 (2%) devices had evidence of a blood clot blocking one of the catheters, and 1 of 165 (1%) had a stone blocking the system. A seroma was documented following 1 of 135 (1%) hospitalizations, and urethral obstruction caused by passage of a ureterolith was also documented following 1 of 135 (1%) hospitalizations during this period.

Long-term complications—Information on long-term complications (ie, complications occurring > 30 days after surgery) was available for 159 SUB devices placed during 130 hospitalizations in 121 cats. Blockage as a result of mineralization was observed in 39 of the 159 (25%) devices, kinking was observed in 4 (3%), and a blood clot was identified in 1 (1%). Only 5 of the 39 (13%) devices with mineralization required exchange; ureteral patency was reestablished in the remaining instances. Urethral obstruction was documented in 2 of the 121 (1.7%) cats.

All complications—Overall, a cystotomy was needed following 6 of 172 (3%) SUB device placements because of cystic or urethral stones. Occlusion because of blood clots was identified in 14 of 172 (8%) devices, and occlusion because of mineralization was documented in 40 of 165 (24%) devices in the short or long term. Median time to blockage with a blood clot was 3.5 days (range, 1 to 41 days). Median time to blockage because of mineralization was 463 days (range, 17 to 1,530 days). Mineralization occurred 17 days after surgery in an 11-week-old kitten that had bilateral ureteral obstructions treated during separate episodes 17 days apart. Location of the occlusion was determined for 53 of 54 devices that had blood clot or mineralization occlusions, with the cystostomy catheter alone blocked in 22 of the 53 (42%), both the nephrostomy and cystostomy catheters blocked in 21 (40%), the nephrostomy catheter alone blocked in 9 (17%), and the 3-way port alone blocked in 1 (2%). Three of the six 3-way ports used to connect bilateral nephrostomy catheters to a single cystostomy catheter developed mineralization resulting in bilateral renal obstruction.

Five of 41 (12%) pigtail cystostomy catheters were blocked with stones and 3 (7%) were blocked with blood clots. Twenty-three of 128 (18%) straight cystotomy catheters were blocked with stones and 8 (6%) were blocked with blood clots. Cystostomy catheter shape was not significantly (P = 0.228) associated with whether an occlusion developed.

For 9 of the 14 occlusions caused by a blood clot in the perioperative, short-term, or long-term period, a catheter exchange was required. For the other 5, patency was restored with serial flushing (n = 4) or the infusion of tissue plasminogen activator (1). For 21 of the 40 occlusions caused by mineralization, catheter exchange was required. For 1, patency could be restored with serial flushing. For the remaining 19, additional treatment was not required because the ureter was assumed to be patent owing to a lack of renal pelvic or ureteral dilation during ultrasonographic examination and stable serum creatinine concentration.

Follow-up information

Median serum creatinine concentrations at the time of hospital discharge; 1 week, 3 months, 6 months, 1 year, 2 years, 3 years, and 4 years after surgery; and at the time of final follow-up were 2.7 mg/dL (range, 0.8 to 11.2 mg/dL), 3.2 mg/dL (range, 1 to 17 mg/dL), 2.6 mg/dL (range, 1.2 to 7 mg/dL), 3.1 mg/dL (range, 1.2 to 8.1 mg/dL), 2.5 mg/dL (range, 1.3 to 9.6 mg/dL), 2.6 mg/dL (range, 1.3 to 10.2 mg/dL), 2.55 mg/dL (range, 1.2 to 5.4 mg/dL), 4.2 mg/dL (range, 2.1 to 4.3 mg/dL), and 3 mg/dL (range, 1.0 to 17 mg/dL), respectively. In 5 of 141 (3.5%) hospitalizations, serum creatinine concentration increased after SUB device and prior to hospital discharge.

Median renal pelvis diameter measured ultrasonographically in the transverse plane at the time of final follow-up was 1.5 mm (range, 0 to 22 mm; n = 159 kidneys). Preoperative renal pelvis diameter was signifi-

cantly ($P < 0.001$) correlated with renal pelvis diameter at the time of final follow-up. However, preoperative renal pelvis diameter was not significantly associated with survival to hospital discharge ($P = 0.07$), serum creatinine concentration 3 months after surgery ($P = 0.857$), failure of the serum creatinine concentration to decrease after surgery ($P = 0.7$), IRIS stage 3 months after surgery ($P = 0.12$), or overall survival time ($P = 0.858$). Median survival time was not significantly associated with renal pelvis diameter after surgery ($P = 0.419$) or with failure of the serum creatinine concentration to decrease immediately after surgery ($P = 0.892$). However, MST was significantly ($P < 0.001$) associated with IRIS stage 3 months after surgery.

Darbepoetin was given to 18 of 128 (14%) cats at some time after surgery, and its administration was significantly ($P < 0.001$) associated with survival time, with an MST of 485 days if it was given and an MST of > 1,072 days if it was not given. Ionized hypercalcemia was documented in 15 of 71 (21%) cats at some time after surgery and was classified in all instances as idiopathic hypercalcemia on the basis of serum parathyroid hormone, parathyroid hormone–related protein, ionized calcium, and vitamin D concentrations. The presence of ionized hypercalcemia was significantly ($P = 0.039$) associated with device mineralization after surgery.

A positive urine bacterial culture result was documented for 29 of 122 (24%) cats at some time after SUB device placement. Infections were successfully cleared with a single episode of appropriate antimicrobial treatment in 18 of 23 (78%) cats in which treatment was attempted. In 6 cats, antimicrobial treatment was not attempted because an *Enterococcus* sp was isolated and clinical signs associated with the bacteriuria were not reported. Chronic bacteriuria was documented for 16 of 122 (13%) cats, with 10 of 122 (8%) cats having clinical signs suggestive of UTI. Organisms isolated at any time after surgery consisted of *Enterococcus* spp (n = 14), *Escherichia coli* (11), *Staphylococcus* spp (5), and other (2).

Cats with a positive urine bacterial culture result or bacteriuria at the time of SUB device placement were significantly more likely to have bacteriuria at some time after surgery ($P = 0.006$) and to have chronic bacteriuria ($P = 0.006$), with or without clinical signs of UTI. Placement of a urethral catheter after surgery was significantly ($P = 0.036$) associated with development of bacteriuria after surgery.

Results of analysis of bladder stones removed during SUB device placement were available for 21 cats. Stones were identified as calcium oxalate monohydrate (n = 16), dried solidified blood calculi (2), calcium oxalate with calcium phosphate (2), and urate (1).

Eleven of 132 (8%) cats reportedly had some degree of dysuria after SUB device placement, including 8 with dysuria unassociated with a UTI, concurrent ureteral stent, or recurrent bladder stones. Fourteen of 115 (12%) cats reportedly had gross hematuria after SUB device placement despite negative urine bacterial culture results and a lack of dysuria.

Outcome

Overall MST was 827 days (range, 0.25 to 2,397 days). The median follow-up time after SUB placement was 1,072 days (range, 0.25 to 2,397 days). No cat died during surgery or because of persistent ureteral obstruction immediately after surgery. Only 3 cats were lost to follow-up (45, 365, and 940 days after surgery). Sixty-nine of the 134 (51%) cats died, with death occurring between 0.25 days and 6.75 years after surgery. Thirty-seven of the 134 (27.6%) died of a suspected renal cause of death, and 4 (3%) died of suspected ureteral reobstruction associated with SUB device mineralization. In 8 cats, the cause of death was unknown; the remaining 20 cats died of causes unrelated to chronic renal disease. Six cats died of neoplasia (lymphoma [n = 3] or pancreatic [1], biliary [1], or transitional cell [1] carcinoma), 3 died of neurologic disease, 2 died of heart disease, 2 died of ureteral obstruction involving the contralateral kidney, and 1 each died of the following: pancreatitis, renal transplantation complications, aortic thromboembolism, severe osteoarthritis, arterial bleeding during placement of an esophageal feeding tube, severe postanesthetic bradycardia, and feline infectious peritonitis.

Survival rate following SUB device placement was 93.8% (135/144) at hospital discharge, 90% (129/144) 1 month after hospital discharge, 83% (120/144) 3 months after hospital discharge, 80% (115/144) 6 months after hospital discharge, and 74% (106/144) 1 year after hospital discharge.

Risk factor analysis

The only factors significantly associated with survival to hospital discharge were a history of oliguria or anuria ($P = 0.013$) and development of fluid overload ($P = 0.006$). Factors found to be associated with hospitalization time were preoperative BUN concentration ($P = 0.03$), preoperative creatinine concentration ($P = 0.02$), preoperative bacteriuria or a positive urine bacterial culture result ($P = 0.025$; median hospitalization time, 5.6 days vs 4.4 days), duration of ureteral obstruction ($P = 0.044$), the need for a blood transfusion preoperatively ($P = 0.054$; median hospitalization time, 5.3 days vs 4.3 days), and development of fluid overload ($P = 0.024$; median hospitalization time, 6.25 days vs 4 days).

Factors that were significantly associated with overall survival time were a history of CKD ($P = 0.006$; MST > 1,007 days without CKD vs 815 days with CKD), a history of weight loss ($P = 0.004$; MST > 826 days without a history of weight loss vs 711 days with a history of weight loss), and development of fluid overload ($P < 0.001$; MST = 1,072 days for cats without fluid overload vs 81 days for cats with preoperative fluid overload, 255 days for cats with preoperative and postoperative fluid overload, and 74 days for cats with postoperative fluid overload). Hospitalization time was not significantly ($P = 0.369$) associated with overall survival time.

Development of postobstructive diuresis was significantly ($P < 0.001$) associated with preoperative serum creatinine concentration (median creatinine, 9.45 vs 4.9 mg/dL) but was not significantly associated with postoperative variables such as hospitalization time, survival to hospital discharge, overall survival time, serum creatinine concentration 3 months after device placement, or IRIS stage 3 months after device placement. The lowest postoperative in-hospital serum creatinine concentration was significantly ($P < 0.001$) associated with serum creatinine concentration 3 months after device placement.

Postoperative factors significantly associated with overall survival time consisted of IRIS stage 3 months after device placement ($P < 0.001$) and serum creatinine concentration 3 months after device placement ($P < 0.001$). For every 1-mg/dL increase in serum creatinine concentration 3 months after device placement, the risk of patient death increased by 26% (hazard ratio, 1.26; 95% confidence interval, 1.18 to 1.35; $P < 0.001$). Median survival times were 2,251, 2,397, 608, and 67 days for cats classified as IRIS stages 1, 2, 3, and 4, respectively, 3 months after surgery **(Figure 8)**. Neither the preoperative serum creatinine concentration ($P = 0.311$) nor the preoperative IRIS stage ($P = 0.153$) was significantly associated with overall survival time.

Preoperative evidence of UTI or bacteriuria was not significantly associated with blood clot occlusion of the device ($P = 0.39$) or device mineralization ($P = 0.31$). A positive preoperative urine bacterial culture result was significantly associated with a positive postoperative urine bacterial culture result ($P = 0.008$) and with development of chronic UTI ($P = 0.004$). Use of an indwelling urethral catheter after SUB device placement was significantly associated with having a positive postoperative urine bacterial culture result ($P = 0.036$), but not with development of chronic UTI ($P = 0.095$).

The only factors significantly associated with postoperative device occlusion from mineralization were postoperative ionized hypercalcemia ($P = 0.039$) and port size (small, large, or 3-way; $P < 0.001$). When occlusion location was classified as nephrostomy catheter, cystostomy catheter, or both catheters, there was a significant ($P = 0.044$) difference in prevalence of occlusion among locations, with the cystostomy catheter having the highest prevalence of occlusion. Prevalence of postoperative device occlusion from mineralization was 18% (5/28) for ureters for which bypass was needed because of ureteral stricture alone, 24% (27/114) for ureters for which bypass was needed because of stones alone, and 34% (10/29) for ureters for which bypass was needed because of both ureterolithiasis and stricture; these percentages were not significantly ($P = 0.486$) different from each other.

Prevalence of occlusion when cystostomy catheters were made from silicone (17/97 [17.5%]) was significantly ($P = 0.03$) higher than prevalence when cystostomy catheters were made from polyurethane (6/77 [7.8%]).

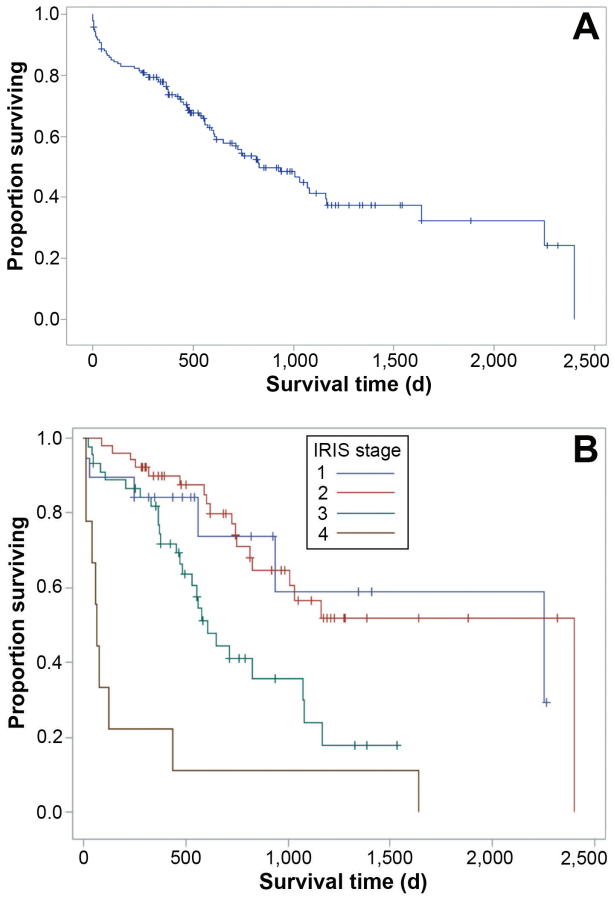

Figure 8—Kaplan-Meier survival curves for cats that underwent SUB device placement for treatment of benign ureteral obstruction (A; 174 devices were placed during 144 hospitalization episodes in 134 cats; information was available for 142 hospitalizations) and for cats grouped on the basis of IRIS stage 3 months after device placement (B; information was available for 124 hospitalizations). Vertical tick marks represent censored observations.

Factors significantly associated with postoperative blood clot occlusion of the device were catheter orientation to the port ($P = 0.029$) and preoperative serum creatinine concentration ($P = 0.024$). The only factor significantly ($P = 0.046$) associated with dysuria following SUB device placement was dysuria prior to SUB device placement. The only factor significantly ($P = 0.004$) associated with postoperative gross hematuria was the presence of dried solidified blood calculi. Postoperative complications significantly associated with overall survival time were chronic gross hematuria ($P = 0.02$; MST not met for cats with gross hematuria vs 935 days for cats without gross hematuria) and occlusion from mineralization ($P = 0.015$; MST = 827 days for cats without occlusion and > 1,165 days for cats with occlusion).

A quality-of-life score assigned by the owner at the time of last follow-up was available for 49 cats; median quality-of-life score for these cats was 9.0 on a scale from

1 to 10. The quality-of-life score was not significantly associated with postoperative dysuria ($P = 0.89$), chronic gross hematuria ($P = 0.49$), occlusion from mineralization ($P = 0.44$), or chronic UTI ($P = 0.12$).

Discussion

Results of the present study suggested that SUB device placement may be a viable option for treatment of cats with benign ureteral obstruction. For all cats, the device was successfully placed, resulting in immediate renal decompression, regardless of the underlying cause of ureteral obstruction (ie, ureterolithiasis, ureteral stricture, ureterolithiasis and ureteral stricture, or a mucopurulent plug), location of the ureteral obstruction, and presence of nephroliths. Notably, many of the cats in the present study had ureteral obstructions that traditionally would not have been considered amenable to surgical repair. Thus, it was not possible to compare our results with results of previous studies[1–4,14] that only included cats with ureteral obstruction amenable to traditional procedures such as ureterotomy or ureteral reimplantation.

Major complications associated with SUB device placement in the cats of the present study were device occlusion because of blood clots (14/172 [8%] ureters), which was identified a median of 3.5 days after surgery and required catheter exchange in 9 of 14 instances, and device occlusion because of mineralization (40/165 [24%] ureters), which was identified a median time of 463 days after surgery and required catheter exchange in 21 of 40 instances. Minor complications reported for cats in the present study were chronic UTI (10/121 [8%] cats) and dysuria unassociated with a UTI (8/132 [6%] cats). Interestingly only 10 of the 16 cats with chronic bacteriuria in the present study had clinical signs suggestive of a UTI. In other studies,[8,14] infection rates following ureteral stenting in cats were reportedly 13% and 26%. In the present study, minor pollakiuria or dysuria was not considered to adversely affect quality of life when client questionnaires were evaluated. Additionally, in the present study, dysuria was reported for 26 of 113 (23%) cats prior to SUB device placement, but only one of these cats had evidence of concurrent UTI or cystolithiasis, suggesting that lower urinary tract disease or ureteral colic could have been the cause of dysuria in some cats following SUB device placement. The only factor significantly ($P = 0.046$) associated with dysuria following SUB device placement was the presence of dysuria before SUB device placement. The lower rates of dysuria in the present study, compared with rates reported following ureteral stenting, were likely a result of location of the SUB device. In cats, the ureteral openings are located in the proximal portion of the urethra. Thus, a ureteral stent protrudes into the lumen of the proximal portion of the urethra, which could be irritating. In contrast, the cystostomy catheter for an SUB device is placed at the apex of the urinary bladder.

Chronic hematuria occurred after SUB device placement in 14 of 115 (12%) cats in the present study, which was similar to the rate of hematuria reported for cats after ureteral stenting (18%).[8] In cats, hematuria is typically not associated with UTI, dysuria, or anemia, and many of the cats in the present study with chronic hematuria had a history of dried solidified blood calculi, which are thought to be associated with idiopathic renal hematuria and may explain the blood found in the urine before and after surgery, particularly when ureteral patency was reestablished.

Kyles et al[1] found in cats treated for ureteral calculi that the most common preoperative factors associated with outcome were the need for preoperative hemodialysis, the use of a nephrostomy tube, and the presence of concurrent ipsilateral nephrolithiasis. In the present study, these variables were not significantly associated with overall survival time after device placement, although no cat received an externalized nephrostomy tube immediately before SUB device placement.

Interestingly, a substantial percentage of cats in the present study (25/174 [14%] ureters) had a history of a previous episode of ipsilateral ureteral obstruction that had been successfully treated by means of ureteral stenting, traditional ureteral surgery, or medical management. In 2 previous studies[1,3] involving use of traditional ureteral surgery for the treatment of ureterolithiasis, 40% to 50% of cats were found to have reobstruction within 1 year, and 86% of cats with reobstruction had evidence of nephrolithiasis on initial diagnostic imaging. Nephroliths were visualized in 120 of 158 (76%) kidneys in the present study, which could raise concerns about possible reobstruction with traditional treatment methods.

In the present study, serum creatinine concentration 3 months after device placement and IRIS stage 3 months after device placement were the only postoperative factors significantly associated with overall survival time, which was similar to results of other studies.[8,9] Cats that were IRIS stage 1 three months after device placement had an MST of 2,251 days, and cats that were IRIS stage 2 had an MST of 2,397 days. However, most of these cats were still alive at the time of last follow-up, so ultimate survival time may have been longer.

Enterococcus spp were isolated from 14 of the 16 cats with chronic bacteriuria after SUB device placement in the present study, but 6 of these 14 cats were not treated because of a lack of clinical signs of bacteriuria and because infection with *Enterococcus* spp rarely results in progression of renal disease in people.[15] Our findings suggested that cats with UTIs prior to renal decompression were more likely to have a UTI after device placement. However, use of an indwelling urethral catheter after SUB device placement was also associated with having a positive postoperative urine bacterial culture result and, thus, should be avoided when possible.

Interestingly, preoperative renal pelvis diameter was not significantly associated with survival to hospital discharge or overall survival time in the present

study. However, this was not unexpected because, in the authors' experience, severe ureteral obstruction may be associated with minimal dilation of the renal pelvis. For cats in the present study, preoperative diameter of the renal pelvis in obstructed kidneys ranged from 2.0 to 35.5 mm. The cat in which renal pelvis diameter was 2.0 mm had a 3-mm-long proximal portion of the ureter that abruptly tapered to a large ureteral stone. This cat had a serum creatinine concentration of 13.1 mg/dL at the time of surgery and a concentration of 2.4 mg/dL at the time of hospital discharge 4 days after SUB device placement. Our findings indicated that in cats with benign ureteral obstruction, severity of renal pelvis dilation was not predictive of severity of postrenal azotemia and was not associated with short- or long-term outcome, similar to the findings of Horowitz et al.[9] In the present study, preoperative renal pelvis diameter was significantly associated with postoperative renal pelvic diameter, meaning that a very large renal pelvis typically got smaller after renal decompression but stayed larger than normal over the long term, likely because of more severe stretching of the tissues. However, postoperative renal pelvis diameter was not significantly associated with MST in the present study.

For 57 of the 174 (33%) obstructed ureters in the present study, the cause of the obstruction was a ureteral stricture (alone or in combination with a stone). These ureteral strictures were most commonly associated with either a previous ureteral surgery or the presence of a circumcaval ureter. Typically, most circumcaval ureters are right-sided and cause obstruction of the proximal 1 to 3 cm of the ureter.[6–8] Thus, if no stone is seen in this location during ultrasonographic examination, ureteral stricture should be carefully considered. As previously reported,[6,7] strictures caused by a circumcaval ureter can be seen in approximately 15% to 17% of ureters with an obstruction. In the present study, 25 of 170 (15%) obstructed ureters were classified as circumcaval at surgery. In a study by Steinhaus et al,[7] 17% of all obstructed ureters were circumcaval, compared with 14% of unobstructed ureters examined at necropsy. In that same study,[7] 40% of cats with a circumcaval ureter had ureteral obstruction because of a stricture, whereas only 17% of cats without a circumcaval ureter had a stricture. A circumcaval ureter causes external compression of the ureteral lumen during development, narrowing the ureteral tube,[7] and predominantly affects the right ureter. In the study by Steinhaus et al,[7] 44% of cats in which a ureteral stricture was treated with a stent had reobstruction, compared with only 8% of cats in which the stricture was treated with SUB device placement. In the present study, postoperative device occlusion from mineralization was not significantly associated with underlying cause of ureteral obstruction (stricture alone vs stones alone vs both stones and stricture).

During SUB device placement in the present study, the nephrostomy catheter was coiled within the renal pelvis (149/174 [86%] ureters) or, if the renal pelvis was too small to safely accommodate the entire pigtail of the nephrostomy tube (approx 8 to 10 mm), advanced into the proximal portion of the ureter (25/174 [14%] ureters). Advancing the nephrostomy tube into the ureter was found to be effective, was not associated with a higher complication rate, and allowed device placement in cats with a smaller renal pelvis (2 to 5 mm in diameter) than previously recommended (10 to 15 mm in diameter).

Cats were discharged from the hospital in 135 of the 144 (94%) hospitalization episodes, with the most common causes of euthanasia or death prior to discharge being persistent azotemia (n = 4) and pancreatitis (2). In a previous study[8] of 69 cats that underwent ureteral stenting, pancreatitis was similarly a leading cause of perioperative death (3% of cats).

Procedure-related complications such as leakage and kinking of a catheter occurred most commonly early in the study period. Subjectively, leakage appeared to be more common when nephropexy and cystopexy were performed than when a PET cuff was used to prevent nephrostomy tube leakage. A common place to see leakage was at the junction of the port and catheter where the locking string was secured; however, being very strict about cutting the string so that it did not stick out of the catheter at the port-catheter junction appeared to alleviate this problem.

The most common long-term complication in the present study was blockage as a result of mineralization of the SUB device (40/165 [24%] devices), which was identified a median of 463 days after surgery. Factors associated with mineralization were use of a small port and the presence of postoperative ionized hypercalcemia. The cystostomy catheter had a higher prevalence of occlusion than the nephrostomy catheter or port, and silicone cystostomy catheters were more likely to be occluded than were the currently used polyurethane ones. In addition, since the conclusion of the present study, a new material, tetrasodium EDTA,[p] has been evaluated for infusion into the SUB device during routine SUB flushing. This material has been used to both prevent and treat biofilm-related infections as well as prevent and reverse mineralization of the SUB device. Anecdotally, since we have started routinely using this material for flushing of the SUB device, the rate of mineralization has been decreased, with a < 4.5% rate of mineralizations documented during 455 days of follow-up, compared with the 24% rate documented in the present study at a median of 463 days. Prospective evaluations are ongoing. In addition, 9 cats with partial SUB device occlusion as a result of mineralization have been evaluated in our practice, with tetrasodium EDTA used to flush the SUB device. In 8 of 9 instances, the SUB devices were fully patent after flushing, without the need for catheter exchange suggestive of demineralization of the device.

Despite the prevalence of device occlusion, catheter exchange was required for only 9 of 14 occlusions caused by a blood clot, and in the remainder, pa-

tency was restored with serial flushing of the system or infusion of tissue plasminogen activator. Similarly, only 21 of 40 occlusions caused by mineralization required catheter exchange. In 1 instance, patency was restored with serial flushing, and in the remaining 18, treatment was not required because the native ureter had regained patency. There is evidence that once a ureter is decompressed, as with a nephrostomy tube, then a ureteral stone is more likely to pass because of decreased luminal edema and hydrostatic pressure.[16] There is a risk that passage of ureteral stones may result in urethral obstruction, but this was uncommon in the present study.

Overall MST was 827 days for cats in the present study, and only 37 of the 134 (28%) cats died of suspected renal disease. This suggested that with appropriate treatment, cats with a benign ureteral obstruction could have a good to excellent prognosis after SUB device placement.

The present study had several limitations, most of which pertained to its retrospective nature. Because the authors were involved in the management of all cases included in the study, treatments, postoperative care, procedural decisions, and follow-up recommendations were generally consistent. Because of the inclusion of cats treated prior to development of the commercial SUB devices in which nephropexy and cystopexy, which are no longer recommended, were performed, the reported complication rate was higher than would have been the case if only those cats in which the commercial device was used had been included. We elected to include these earlier cases because they represented a part of the standard learning curve for any new procedure and wanted to ensure that all complications were reported. Since the development of the commercial device, which includes PET cuffs to prevent leakage and polyurethane catheters to decrease occlusion, and the improvement in operator experience, the success rate has subjectively improved.

Another limitation of the present study was that cause of death could not always be determined. Nevertheless, our findings suggested that with appropriate treatment, cats with benign ureteral obstruction have a good prognosis, with outcome dictated largely by severity of the underlying renal disease once renal decompression has been accomplished. Finally, although some cats in the present study were lost to follow-up, this is typical of retrospective studies, and the percentage lost to follow-up was lower than percentages typical for retrospective studies.

In summary, results of our study suggested that SUB device placement is a viable alternative in cats with benign ureteral obstruction regardless of the underlying cause or location of ureteral obstruction. There were few major short-term complications, and the most common long-term complication was device mineralization. Chronic infection was uncommon and was most often associated with subclinical bacteriuria. Still, the possibility of chronic infection should be discussed with the owner prior to consideration of SUB device placement. Overall, however, owners rated the quality of life of their cats quite high following SUB device placement.

Acknowledgments

At the time of the study, Drs. Berent and Weisse were consultants for Norfolk Vet Products, Skokie, Ill, the distributor of the SUB device that was used.

Footnotes

a. Berent A, Weisse C, Bagley D. Use of a subcutaneous ureteral bypass for the treatment of ureteral obstructions in dogs and cats (abstr). *J Vet Intern Med* 2011;25:1509.
b. SUB device, Norfolk Vet Products, Skokie, Ill.
c. Omnipaque, GE Healthcare, Princeton, NJ.
d. FluoroScan InSight 2, Hologic Inc, Bedford, Mass.
e. Locking-loop pigtail catheter (6F), Infiniti Medical LLC, Menlo Park, Calif.
f. T-piece connector, Norfolk Vet Products, Skokie, Ill.
g. Male-to-male metal adaptor, Norfolk Vet Products, Skokie, Ill.
h. Pants port, Norfolk Vet Products, Skokie, Ill.
i. Triple lumen catheter (5.5F × 13 cm), Arrow International Inc, Morrisville, NC.
j. Angiocath insyte-N peripheral venous catheter (18 gauge), BD Biosciences, Franklin Lakes, NJ.
k. Angle-tipped hydrophilic guidewire (0.035 inch), Infiniti Medical LLC, Menlo Park, Calif.
l. J-wire, Norfolk Vet Products, Skokie, Ill.
m. Gluture tissue adhesive, Abbott Animal Health/Zoetis, Florham Park, NJ.
n. Esophagostomy tube (14F), MILA International, Erlanger, Ky.
o. SAS version 9.4, SAS Institute Inc, Cary, NC.
p. t-EDTA (T-Flo-Loc), Norfolk Vet Products, Skokie, Ill.

References

1. Kyles AE, Hardie E, Wooden E, et al. Management and outcome of cats with ureteral calculi: 153 cases (1984–2002). *J Am Vet Med Assoc* 2005;226:937–944.
2. Roberts SF, Aronson L, Brown D. Postoperative mortality in cats after ureterolithotomy. *Vet Surg* 2011;40:438–443.
3. Livet V, Pillard P, Thollot-Goy I, et al. Placement of subcutaneous ureteral bypasses without fluoroscopic guidance in cats with ureteral obstruction: 19 cases (2014–2016). *J Feline Med Surg* 2017;19:1030–1039.
4. Culp WT, Palm C, Hsueh C, et al. Outcome in cats with benign ureteral obstructions treated by means of ureteral stenting versus ureterotomy. *J Am Vet Med Assoc* 2016;249:1292–1300.
5. Berent AC, Weiss CW, Todd KL, et al. Use of locking-loop pigtail nephrostomy catheters in dogs and cats: 20 cases (2004–2009). *J Am Vet Med Assoc* 2012;241:348–357.
6. Zaid MS, Berent A, Weisse C, et al. Feline ureteral strictures: 10 cases (2007–2009). *J Vet Intern Med* 2011;25:222–229.
7. Steinhaus J, Berent A, Weisse C, et al. Clinical presentation and outcome of cats with circumcaval ureters associated with a ureteral obstruction. *J Vet Intern Med* 2015;29:63–70.
8. Berent AC, Weisse C, Bagley D. Technical and clinical outcomes of ureteral stenting in cats with benign ureteral obstructions: 69 cases (2006–2010). *J Am Vet Med Assoc* 2014;244:559–576.
9. Horowitz C, Berent A, Weisse C, et al. Predictors of outcome for cats with ureteral obstructions after interventional management using ureteral stents or a subcutaneous ureteral bypass device. *J Feline Med Surg* 2013;15:1052–1062.
10. Kulendra NJ, Syme H, Benigni L, et al. Feline double pigtail ureteric stents for management of ureteric obstruction: short- and long-term follow-up of 26 cats. *J Feline Med Surg* 2014;16:985–991.
11. Berent AC. Ureteral obstructions in dogs and cats: a review of traditional and new interventional diagnostic and

therapeutic options. *J Vet Emerg Crit Care (San Antonio)* 2011;21:86–103.
12. Cray M, Berent A, Weisse C, et al. Treatment of pyonephrosis with a subcutaneous ureteral bypass device in four cats. *J Am Vet Med Assoc* 2018;252:744–753.
13. Reid G, Habash M, Vachon D, et al. Oral fluoroquinolone therapy results in drug adsorption on ureteral stents and prevention of biofilm formation. *Int J Antimicrob Agents* 2001;17:317–319.
14. Wormser C, Clarke DL, Aronson LR. Outcomes of ureteral surgery and ureteral stenting in cats: 117 cases (2006–2014). *J Am Vet Med Assoc* 2016;248:518–525.
15. Cai T, Mazzoli S, Lanzafame P, et al. Asymptomatic bacteriuria in clinical urological practice: preoperative control of bacteriuria and management of recurrent UTI. *Pathogens* 2016;5:E4.
16. Lennon GM. Double pigtail ureteric stent versus percutaneous nephrostomy: effects on stone transit and ureteric motility. *Eur Urol* 1997;31:24–29.

From this month's *AJVR*

Cell-mediated and humoral immune responses to bovine herpesvirus type 1 and bovine viral diarrhea virus in calves following administration of a killed-virus vaccine and bovine herpesvirus type 1 challenge

Travis R. Van Anne et al

OBJECTIVE
To evaluate cell-mediated and humoral immune responses of calves receiving 2 doses of a dual-adjuvanted vaccine containing inactivated bovine herpesvirus type 1 (BHV1) and bovine viral diarrhea virus types 1 (BVDV1) and 2 (BVDV2) before and after exposure to BHV1.

ANIMALS
24 Holstein steers negative for anti-BHV1 antibodies and proliferative cell-mediated immune responses against BHV1 and BVDV.

PROCEDURES
Calves were randomly assigned to 3 groups. The vaccinated group (n = 10) received 2 doses of vaccine on days 0 and 21. Control (n = 10) and seeder (4) groups remained unvaccinated. Calves were commingled during the study except for the 3-day period (days 53 to 55) when seeders were inoculated with BHV1 (1.04 X 10^7 $TCID_{50}$, IV) to serve as a source of virus for challenge (days 56 through 84). Rectal temperature and clinical illness scores were monitored, and blood and nasal specimens were obtained for determination of clinicopathologic and immunologic variables.

RESULTS
After BHV1 challenge, mean rectal temperature and clinical illness scores were lower for vaccinates than controls. In vaccinates, antibody titers against BHV1 and BVDV2, but not BVDV1, increased after challenge as did extracellular and intracellular interferon-γ expression, indicating a T helper 1 memory response. Additional results of cell marker expression were variable, with no significant increase or decrease associated with treatment.

CONCLUSIONS AND CLINICAL RELEVANCE
Calves administered 2 doses of a killed-virus vaccine developed cell-mediated and humoral immune responses to BHV1 and BVDV, which were protective against disease when those calves were subsequently exposed to BHV1. (*Am J Vet Res* 2018;79:1166–1178)

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