Published in final edited form as:

Vet Surg. 2020 July ; 49(5): 1043–1051. doi:10.1111/vsu.13443.

Use of a bipolar sealing device to seal partial cystectomy with and without augmentation with a single-layer simple continuous suture pattern in an ex vivo canine model

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Abstract

Objective: To evaluate the ability of a bipolar sealing device (BSD) to seal canine bladder tissue, and to determine the influence of suture augmentation on resistance to leakage of sealed partial cystectomies.

Study design: Ex vivo, simple randomized study.

Sample population: Urinary bladders harvested from canine cadavers (n = 23).

Methods: Partial cystectomy of the cranial third of each bladder was performed using a BSD. This seal was augmented with a simple continuous pattern of 4-0 polydioxanone in half of the specimens. A pressure transducer inserted through the ureter measured intraluminal pressure at initial leakage and catastrophic failure as dyed saline was infused via a catheter inserted through the urethra. Initial leakage pressure and pressure at catastrophic failure were compared between sutured and non-sutured sealed partial cystectomies.

Results: Sutured sealed cystectomies were able to sustain lower initial leakage pressures (8.6 vs. 17.7 mmHg; $P = 0.0365$) but greater pressures at catastrophic failure (34.3 vs. 21.8 mmHg; $P = 0.007$). Catastrophic failure occurred along the seam of all non-sutured sealed cystectomies, and at the suture holes in 10 of the 12 sutured bladders.

Conclusions: Partial cystectomies were effectively sealed with a BSD in this canine cadaveric bladder model. Augmentation with a simple continuous suture pattern increased the pressure at which catastrophic leakage occurred but lowered initial leak pressure.

Clinical Significance: This study provides evidence supporting the evaluation of BSD use for partial cystectomy in live animals.

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The authors have no conflict of interest to declare.

Introduction:

Urinary bladder cancer comprises approximately 2% of all cancers reported in the dog, with transitional cell carcinoma (TCC) identified as the most prevalent type.¹⁻⁴ Partial cystectomy has been advocated for non-trigonal TCC as a component of multimodal therapy.⁵ In addition to potentially mitigating the clinical signs associated with the mass, full thickness excision of non-trigonal bladder TCC has been identified as a positive prognostic factor for progression-free interval and survival time.⁵ Specifically, a retrospective study of dogs undergoing partial cystectomy for TCC found an overall progression free interval and median survival time of 235 and 348 days, respectively.⁵ Furthermore, dogs in this study receiving piroxicam following partial cystectomy demonstrated a prolonged median survival time of 772 days.⁵

Seeding of TCC cells and subsequent development of distant TCC following fine needle aspirate and surgical biopsy or excision of bladder TCC has been documented in dogs.⁵⁻⁷ Given that TCC cells are found not only in affected bladder tissue but also in the urine of dogs with TCC, seeding neoplastic cells to distant sites remains a risk of partial cystectomy in dogs with non-trigonal TCC.^{7,8} Therefore, alternative methods of reducing TCC cell seeding during partial cystectomy may hold clinical value.

Electrothermal bipolar sealing devices (BSD) are widely used in veterinary and human surgery to seal tissue and achieve hemostasis.⁹⁻¹¹ The BSD uses pressure and energy to create a permanent seal by melting collagen and elastin within vessel walls.¹² Use of a BSD has also been described for sealing porcine and human bladder tissue to facilitate laparoscopic nephroureterectomy including a peri-ureteral cuff of bladder tissue in patients with upper urinary TCC.^{13,14} In this porcine model and subsequent human patients, histopathology confirmed that the BSD sealed and ablated urothelial tissue through clamping and subsequent activation of the BSD.¹³ The BSD's ability to simultaneously seal and divide tissue could facilitate excision of the bladder apex while maintaining a sealed bladder lumen, thus limiting exposure of the surgical field to neoplastic cells within the urine and the affected bladder wall.

Baseline intraluminal pressures in normal canine bladders reportedly range from 0 to 5.6 mmHg, and up to 11 mmHg following elective abdominal surgery; these pressures may be further reduced by placement of an indwelling urinary catheter.^{15,16} Importantly, while mean threshold bladder pressures in normal awake beagles range from 10.9 to 12.3 mmHg, mean peak bladder pressure during micturition may reach as high as 106 $\pm$ 23 mmHg.¹⁷ Thus, any method of canine bladder closure should theoretically be able to withstand pressures equivalent to the peak pressures measured in normal, awake dogs.

The use of a BSD on canine bladder tissue has not been previously reported. The objectives of this study were to evaluate the ability of a BSD to effectively seal canine bladder tissue, and to evaluate whether reinforcing the cystectomy site with a continuous suture pattern affects the intraluminal pressure at which leakage from the cystectomy site is observed. We hypothesized that the BSD would effectively appose and seal canine bladder wall, and that sealed cystectomy sites would fail at lower pressure when not reinforced with suture. The

results herein provide initial insight into the potential use of this novel partial cystectomy technique in dogs.

Materials and Methods:

Specimen collection:

Lower urinary tracts including the bladder, proximal urethra, and distal ureters were harvested via laparotomy at our institution from 23 dogs euthanized at a local shelter for reasons unrelated to this study. In compliance with our institution's Institutional Animal Care and Use Committee (IACUC), no IACUC approval was required for cadaver specimen collection and testing. All specimens were collected and tested within 4 hours of euthanasia; urinary tracts with gross abnormalities were excluded. Subjective qualitative assessment of the degree of empty bladder wall thickness was recorded by a single observer using a scale of 1 (thin) to 3 (thick). All bladders were manually expressed through the urethral opening until the bladders were subjectively empty and no additional urine could be drained from the urethral opening. Specimens were harvested, maintained, and tested at room temperature (approximately 21° C) and wrapped in 0.9% saline-soaked gauze to minimize tissue desiccation.

Cystectomy:

Bladders were randomly assigned using a random number generator (Microsoft Excel, Microsoft Office 11, Microsoft, Redmond, WA) to receive sealed partial cystectomy only (11 dogs) or sealed partial cystectomy augmented with a simple continuous pattern (12 dogs). A 10-mm electrothermal BSD (LigaSure Atlas Tissue Fusion Open Instrument, Medtronic Inc., Minneapolis, MN) was used to perform a partial cystectomy at the junction between the cranial third and caudal two thirds of the empty bladder. Specifically, with the BSD set at power level 3, the jaws of the BSD were placed across apposing bladder walls using manual manipulation such that tissue was not positioned in the junction of the jaws to avoid failure to seal at this site. Following a single activation cycle and division, the jaws were opened and advanced such that the jaws then encompassed approximately 80% unsealed tissue and 20% previously sealed tissue, at which point the BSD was activated again. If a gap in the sealed cystectomy site was noted after the initial BSD firing, the BSD was repositioned caudal to the gap (toward to the trigone) and reapplied to create a new seal adjacent and immediately caudal to the gap site using the same technique described above. The BSD was cleaned following each use as previously described.¹⁸ For bladders assigned to the sutured group, a simple continuous pattern using 4-0 polydioxanone on a ½-circle RB-1 taper needle (PDS*II, Ethicon, Inc., Somerville, NJ) was placed along the cystectomy site with bites taken 3-4 mm apart and 3-4 mm from the sealed edge of the cystectomy (Figure 1). To begin the simple continuous augmentation, a square knot with 4 throws was placed approximately 3 mm lateral to the start of the cystectomy site; the pattern was completed approximately 3 mm lateral to the end of the cystectomy site by placing a square knot comprised of 5 throws. All partial cystectomies and suture augmentation were performed by a single board-certified surgeon familiar with the use of the BSD (VFS).

Pressure Testing:

The right ureter of each specimen was ligated using 3-0 polyglactin 910 (VICRYL™, Ethicon, Inc., Somerville, NJ) in an encircling ligature at the insertion on the trigone. An 8-F Foley catheter was inserted through the urethra into the bladder and secured with an encircling suture using 2-0 polydioxanone (PDS®II, Ethicon, Inc.) around the proximal urethra. The catheter was inserted such that approximately 1cm of the catheter tip was located within the neck of the bladder; this prevented the tip of the catheter from being placed near the cystectomy site. A 3-F latex catheter with the distal centimeter removed was inserted into the bladder through the left ureter and secured with an encircling ligature around the insertion of the left ureter on the trigone. A pressure transducer (BSL Pressure Transducer, Biopac Systems, Inc., Goleta, CA) was connected to the latex catheter.

A 5 L bag of 0.9% NaCl (Vetivex® Veterinary Fluids, Dechra Veterinary Products, Overland Park, KS) infused with 20 mL methylene blue (Methylene Blue 1% w/v, Biopharm, Inc., Hatfield, AR) was connected to the urethral Foley catheter; the dyed solution was infused into the bladder at a rate of 999 mL/hr using a syringe pump (ACCLAIM Encore™ Infusion System, Abbott Laboratories, Lake Bluff, IL).¹⁹ During infusion, intraluminal bladder pressure tracings were recorded using software (BSL Introductory System, BIOPAC Systems, Inc.) and saline infusion continued until catastrophic failure was reached. Initial leak pressure and pressure at catastrophic failure were recorded. Initial leak pressure was defined as the pressure at which blue dyed saline leakage was first visually observed from the cystectomy site. Catastrophic failure was defined as either a sustained (> 2 s) decrease in intraluminal pressure or the point at which intraluminal pressure plateaued for a minimum of 10 seconds during saline infusion. Location of failure was observed as either leakage through the suture holes or through a discrete opening of the sealed cystectomy site.

Immediately following each procedure, samples of the sealed partial cystectomy were obtained and fixed in 10% neutral buffered formalin. Two representative samples were obtained from each specimen: one from a portion of the sealed partial cystectomy site from which no leakage was observed, and a second from an area of the cystectomy site from which leakage was observed. A subset of paired samples from two specimens in the non-sutured group were routinely sectioned, embedded in paraffin, and processed for hematoxylin and eosin staining. Images were acquired using an Olympus DP26 camera (Olympus Corporation, Tokyo, Japan) and analyzed using cellSens Entry software (Olympus Corporation). The length of the crush region and the length of the histologically affected adjacent bladder were measured. Image acquisition and histologic evaluation were performed by a board-certified veterinary pathologist (J.A.L.).

Statistical analysis was performed using commercially available software (Prism 8, GraphPad Software, San Diego, CA). A prospective power analysis was performed using previously published data.^{13,20} Dog and bladder characteristics including sex, body weight, and bladder thickness were compared between groups using Fisher's exact test, Welch's t test, and Chi-square test, respectively. Initial leak pressures and pressure at catastrophic failure were tested for normality using the Kolmogorov-Smirnov test and compared between the sutured and non-sutured sealed partial cystectomies using a Welch's t test. A two-tailed *P*-value of < 0.05 was considered statistically significant.

Results:

Twenty-three canine cadavers were included in the study; 11 bladders received a sealed partial cystectomy alone (non-sutured group), and 12 received a sealed partial cystectomy augmented with simple continuous pattern (sutured group). Ten intact males, 8 neutered males, 4 spayed females, and 1 intact female were included. Median estimated body weight was 20 kg (range: 10 – 35 kg) and median bladder thickness score was 1 (range: 1 – 3). There was no significant difference in sex ($P > 0.999$), body weight ($P = 0.325$), or bladder thickness ($P > 0.999$) between the sutured and non-sutured groups.

A single gap along the cystectomy site was noted after initial BSD application in 4 dogs in both groups (Figure 2). Gaps ranged from 3 to 10 mm in length and were sealed by reapplying the BSD immediately caudal to the site of the initial gap. Initial leakage occurred at the gap site in 4 of the 4 dogs with gap formation in the non-sutured group, and at the gap site in 1 of the 4 dogs with gap formation in the sutured group. The site of catastrophic failure was the same as the site of initial leakage in 8 of 11 dogs in the non-sutured group and in 11 of 12 dogs in the sutured group. The site of initial leakage and catastrophic failure occurred along the seam of the sealed partial cystectomy (between the apposed bladder walls at the site of BSD activation) in all of the non-sutured bladders (Figure 3). Initial leakage occurred at the suture holes in 11 of 12 dogs in the sutured group (Figure 4), and catastrophic failure occurred at the suture holes in 10 of 12 dogs in the sutured group. Leakage occurred at the seam in the remaining bladders in the sutured group. There was no difference in subjective bladder thickness scores among cystectomies with and without initial gap formation ($P = 0.0791$). Similarly, there was no difference in body weight of dogs from which specimens demonstrated gap versus no gap formation with initial bladder sealing ($P = 0.414$).

Distributions of initial (Figure 5) and catastrophic (Figure 6) leak pressures are shown for both groups. Mean (95% CI) initial leak pressure was higher for the non-sutured group (17.7 (10.3 – 25.0) mm Hg) than for the sutured group (8.6 (3.6 – 13.6) mm Hg; $P = 0.0365$). Mean (95% CI) pressure at catastrophic failure was lower for the non-sutured group (21.8 (14.9 – 28.6) mm Hg) than for the sutured group (34.3 (28.2 – 40.4) mmHg; $P = .007$). There was no difference in initial leak pressures ($P = 0.834$) and catastrophic failure pressures ($P = 0.934$) between cystectomies with a gap observed after initial sealing and cystectomies in which gap formation was not observed after initial sealing.

Histology performed on the cystectomy sites from two of the non-sutured specimens evaluated the effect of BSD activation on bladder tissue at areas of effective sealing (no leakage) and non-sealed (leak) sites (Figure 7). The crushed sites in all specimens were characterized by full thickness coagulation of the tissue which was similar between the effectively sealed and non-sealed sites. Crush regions from the sealed sites measured 2930 and 2408 μm in length and from the non-sealed sites measured 2443 and 3807 μm . Within the non-sealed regions, there was a gap formation between the coagulated edges of tissue. In all samples evaluated, distant from the crush site, the epithelium was absent and the lamina propria (including connective tissue and vessels) was hyalinized and appeared coagulated (Figures 7 and 8). The connective tissue within the muscularis propria appeared similarly

coagulated, but the smooth muscle bundles appeared spared. There was no observed difference in bladder wall thickness at the sealed and non-sealed sites.

Discussion:

This study is the first to evaluate the effects of BSD application on canine bladder tissue. We demonstrated that the BSD may seal canine bladder wall in an ex vivo model and may effectively be used for partial sealed cystectomy in dogs. Further study is indicated to determine whether this technique reduces risk of exposure to viable cancer cells in clinical cases of bladder tumor excision. Reinforcing the sealed cystectomy site with a simple continuous suture pattern lowers initial leakage pressure but reduces the risk of catastrophic failure of the cystectomy site.

Although the BSD was effective in sealing bladder tissue, gaps were observed after initial BSD application in 35% of bladders. Despite being re-sealed with a second application of the BSD, the gap site was the site of failure in 63% of bladders with a gap observed after initial sealing. Although no difference in initial leak and catastrophic failure pressures was found when comparing bladders with and without initial gap formation, it is possible that an association of initial gap formation and intraluminal pressure at the time of leakage may have been detected with a larger sample size.

Reasons for gap development after initial sealing in some bladders could not be elucidated from this study and warrants further investigation prior to clinical use. Urine leakage was observed in 18% of bladders sealed in human patients undergoing laparoscopic nephroureterectomy with the LigaSure.¹³ In that study, all 4 patients with urine leakage had been previously stented or had bladder changes consistent with bladder outlet obstruction. Thus the authors in that study hypothesized that periureteral inflammation and mucosal edema may have prevented adequate tissue approximation with the LigaSure, or previous obstructive changes may have thinned the bladder wall and caused cellular changes that affected the ability to achieve a watertight seal with the LigaSure. In the current study, bladder thickness was not different among cystectomies with initial gap formation versus those without, although 3 of the 8 bladders with initial gap formation had bladder thickness scores of 2-3, whereas only 1 of 15 dogs without initial gap formation had a score >1. Furthermore, the bladder thickness score used in this study was subjective; with objective measurement of bladder wall thickness and a larger sample size, an association between thicker bladder wall and gap formation may have been detected and such information could be useful in guiding appropriate patient selection for sealed partial cystectomy.

During testing, a pathologist was consulted and several representative sections of the sealed cystectomy sites (with and without gap formation) were analyzed histopathologically to evaluate for variation that could contribute to or explain gap formation along the sealed cystectomy sites. No differences or variation in wall thickness or composition or in tissue alignment was found in the representative samples. Because the sealed partial cystectomy was performed on cadaveric tissue in this study, evaluation of necrosis, edema, and inflammation was not possible. Further study is indicated to assess potential bladder wall damage, specifically lateral thermal damage, associated with use of a BSD on bladder tissue

in live dogs. Based on these findings and the pathologist's recommendations, additional histopathological analysis of the cystectomy sites was not pursued. Subjectively, gap formation appeared to occur when sealed tissues were disengaged from the jaws of the BSD. Thus, fewer activations of the BSD may be associated with a reduced incidence of gap formation if opening of the jaws between firings contributes to gap formation. In order to maintain consistency, this study only investigated a single BSD configuration and did not measure the length of cystectomy or the number of BSD activations; further study is needed to evaluate whether gap formation is associated with the number of BSD activations or shape of BSD. Use of a BSD handpiece with a longer jaw may allow for fewer activations and decreased gap formation. Similarly, an anastomotic prototype using the same bipolar sealing technology utilized by the BSD in this study was evaluated for sealing intestinal tissue in order to improve feasibility of laparoscopic intestinal resection and anastomosis.²¹ Thus it may be possible to design a modified BSD for partial cystectomy that would eliminate the need for repeated activations and potentially decrease the incidence of gap formation.

Despite the presence of gaps observed along the initial sealed cystectomy site in 8 dogs, a watertight seal was achieved by reapplication of the BSD immediately caudal to the gap site. Initial and catastrophic leak pressures in this study were similar to those observed in previous studies evaluating sutures for cystotomy closure in dogs and BSD sealing of porcine bladders, suggesting that sealed cystectomy provides an equivalent and adequate bladder closure.²⁰ Furthermore, the pressure required for catastrophic failure of the sealed cystectomy in this study exceeded expected post-operative resting intraluminal bladder pressure.¹⁶ Interestingly, the initial leak and catastrophic leak pressures in both this study and a previous study evaluating cystotomy closure in dogs are lower than the peak pressures observed in normal, awake dogs during micturition.^{17,20} A possible explanation for this discrepancy is the use of a cadaveric model in this study; the lack of development of a rapid fibrin seal and the absence of viable mucosa may have contributed to lower leak pressures in this cadaveric model compared to live tissue. While it is possible that post-operative intraluminal bladder pressure may exceed the initial and catastrophic leak pressures observed in this study, particularly for the sutured group, the clinical significance of this finding remains unknown, particularly given that similar leakage may be expected through suture holes following cystotomy. Because the intraluminal bladder pressure at catastrophic failure was higher for the sutured group than the non-sutured group in this study, augmentation with a simple continuous pattern is recommended to reduce the likelihood of catastrophic leakage post-operatively. The clinical significance of leakage through suture holes in vivo is unknown; the risk of this initial leakage through suture holes may be reduced by placement of an indwelling urinary catheter post-operatively.

A potential advantage of the sealed cystectomy compared to open cystectomy may be the minimization of contamination of the surgical field with potentially tumor-laden urine during cystectomy. In a retrospective study reporting partial cystectomy for treatment of bladder TCC in dogs, abdominal wall seeding was observed in four cases (11%), with a median time of 150 days to occurrence of a body wall lesion following surgery.⁵ By preventing contact of tumor-laden urine with the peritoneal cavity and body wall, sealed partial cystectomy may reduce this risk.

A potential limitation of a sealed cystectomy for limiting the seeding of tumor cells into the surgical field is the formation of gaps along the cystectomy site in 35% of the 23 tested specimens in this study. Although these gaps were effectively re-sealed, the formation of gaps along the initial cystectomy site may negate the advantages of minimizing contamination of the surgical field with neoplastic cells. The relatively small size of the gaps may still minimize leakage of contaminated urine into the surgical field compared to the amount of leakage that occurs when performing a traditional cystectomy. Further study is needed to evaluate whether the incidence of gap formation along partial cystectomies performed with a BSD can be minimized to improve the clinical viability of this technique.

In addition to potentially limiting urine leakage and tumor cell seeding, use of the BSD may also destroy residual neoplastic urothelial cells at the cystectomy site.¹³ A previous study evaluating the effect of LigaSure activation on porcine and human bladder tissue found that LigaSure activation effectively ablated viable urothelial cells at the cystectomy site.¹³ Thus, use of the BSD may increase the likelihood of eliminating neoplastic cells at the cystectomy margin, potentially decreasing the risk of tumor recurrence at the cystectomy site.

Augmenting the sealed partial cystectomy site with a simple continuous pattern increased maximal leak pressure, suggesting that reinforcing the cystectomy site with suture may provide a clinical advantage. The holes created by the needle and suture, however, appear to lower the threshold for initial leakage. Although the volume of this initial leakage from the suture holes was small, it may still represent a risk for exposure of the surgical field to tumor cells in the urine. The length of the zone of lateral thermal effect was not assessed in this study, but a previous study evaluating the use of the 10mm LigaSure with porcine bladder found that the peripheral thermal effect zone (represented visually by a blanched area extending laterally from the application site) was 2 mm wide in both directions using the 10-mm LigaSure Atlas.¹³ It is possible that this zone of thermal effect may extend farther histopathologically and could increase the likelihood of leakage from needle holes created within or near this zone of thermal effect. Thus, placing reinforcing sutures farther from the thermal effect zone may reduce the likelihood of leakage at lower intraluminal pressures. Alternatively, an inverting suture pattern rather than a simple continuous pattern may provide improved protection against urine leakage from suture holes both by inverting the sealed cystectomy site and by taking bites further laterally from the thermal effect zone of the BSD. An inverting suture pattern was not evaluated in this study. While such a pattern may be beneficial in minimizing urine leakage, an inverting double-layer pattern was not shown to reduce the incidence of urine leakage in a previous study.²² In addition, an inverting pattern may also lead to a greater reduction in residual bladder volume compared to a simple continuous suture pattern. Thus, it may be prudent to consider the size of the patient's bladder and the percent of bladder resected when choosing the suture pattern used for augmentation of the sealed cystectomy site. It is also possible that leakage through suture holes may occur at lower pressures in cadaveric tissue compared to live bladder tissue in vivo due to post-mortem changes. Furthermore, the rate chosen for bladder infusion, while based on previous study, supersedes that encountered during bladder filling in the live dog.¹⁹ This supraphysiologic rate of bladder expansion may have affected the pressures at which initial and catastrophic leakage were observed.

Conversely, the ex vivo model utilized in this study did not account for bladder healing and maintenance of a watertight seal at the cystectomy site. Post-operative urinary leakage was not observed in 21 of 22 human patients undergoing nephroureterectomy using a BSD and maintained with indwelling Foley urinary catheters 10 days post-operatively. Because bladder ruptures may be treated by maintaining an indwelling urinary catheter while the bladder heals, the fact that these patients' bladders healed despite use of a BSD suggests that BSD use does not substantially impair bladder healing.¹³

In human patients with upper urinary tract TCC, nephroureterectomy with removal of the bladder cuff surrounding the ipsilateral ureter is the standard of care.¹⁴ Laparoscopic nephroureterectomy is associated with decreased post-operative pain, shorter hospitalization, and faster recovery time compared to the open procedure in people.²³ Similarly, laparoscopic-assisted cystotomy in dogs is associated with decreased number of doses of analgesic post-operatively compared to open cystotomies.²⁴ Given the documented benefits of laparoscopic bladder surgery in humans and dogs, future studies are indicated to evaluate whether laparoscopic cystectomy may be associated with similar advantages compared to open cystectomy. Achieving a watertight seal via intracorporeal suturing presents a technical challenge.¹³ Thus, the ability of the BSD to seal bladder tissue may improve the feasibility of laparoscopic partial cystectomy. Intracorporeal suturing of bladder tissue has been previously demonstrated in the dog and could be used to augment the sealed cystectomy site laparoscopically.²⁵ Nonetheless, the relatively high incidence of gap formation along the sealed cystectomy in this study may increase the technical challenges of laparoscopic cystectomy and warrants further investigation.

In summary, the BSD effectively seals canine bladder tissue and provides a means for performing a sealed partial cystectomy. Augmentation of the sealed cystectomy site with a simple continuous pattern increased the risk of initial leakage but reduced the risk of catastrophic failure at clinically relevant intraluminal pressures. Further study is indicated to evaluate sealed cystectomy in the clinical setting and the effects of BSD use on bladder healing. Additional research is warranted to evaluate whether sealed partial cystectomy may improve the feasibility of laparoscopic partial cystectomy for treatment of apical bladder masses.

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Figure 1. Photograph showing sealed partial cystectomy using a bipolar sealing device without (A) and with (B) augmentation of the sealed cystectomy site with a simple continuous suture pattern using a 4-0 absorbable monofilament suture.

Figure 2. Photograph showing gap formation along the sealed partial cystectomy site following initial BSD activation. Gaps were addressed by repositioning the BSD jaws immediately caudal to the gap site and re-activating.

Figure 3.
Photograph showing catastrophic failure along seam of sealed partial cystectomy.

Figure 4.
Photograph showing initial leakage of dyed isotonic saline along suture holes of sutured sealed partial cystectomy.

Figure 5. Violin plot of initial leak pressures of sutured and non-sutured sealed partial cystectomies. The median is indicated by the dashed line; dotted lines represent the 25% and 75% quartiles.

Figure 6.

Violin plot of leak pressures of sutured and non-sutured sealed partial cystectomies at catastrophic failure. The median is indicated by the dashed line; dotted lines represent the 25% and 75% quartiles.

Figure 7.

Representative photomicrograph of a sealed partial cystectomy from a fully sealed region (A) and a non-sealed (leak) region (B). The black bars indicate the measured crush site at the location of BSD activation (A=2930 μm ; B=2443 μm) and the gray bar measures the affected bladder adjacent to the crush site (A=3058 μm ; B=4241 μm). Scale bar is 500 μm . Hematoxylin and eosin stain.

Figure 8.

Representative photomicrograph including a region of coagulation adjacent to BSD activation site and a region of more distant normal bladder. A. The epithelium is absent and the connective tissue and vessels within the lamina propria and muscularis propria are smudgy, hyalinized, and indistinct (coagulated). The smooth muscle bundles appear normal. B. The transitional epithelium is present and the connective tissues, vessels, and muscle bundles all appear normal. Hematoxylin and eosin stain.