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Intermediate-term outcomes after robotic ureteral reconstruction for long-segment (≥4 centimeters) strictures in the proximal ureter: A multi-institutional experience

Matthew Lee[1], Ziho Lee[1], Helaine Koster[2], Minsuk Jun[3], Aeen M. Asghar[1], Randall Lee[1], David Strauss[1], Neel Patel[2], Daniel Kim[2], Sreeya Komaravolu[2], Alice Drain[3], Michael J. Metro[1], Lee Zhao[3], Michael Stifelman[2], Daniel D. Eun[1]; Collaborative of Reconstructive Robotic Ureteral Surgery (CORRUS)

[1]Department of Urology, Lewis Katz School of Medicine at Temple University, Philadelphia, PA, [2]Department of Urology, Hackensack University Medical Center, Hackensack, NJ, [3]Department of Urology, New York University Grossman School of Medicine at New York University Langone Medical Center, New York, NY, USA

Purpose: To report our intermediate-term, multi-institutional experience after robotic ureteral reconstruction for the management of long-segment proximal ureteral strictures.

Materials and Methods: We retrospectively reviewed our Collaborative of Reconstructive Robotic Ureteral Surgery (CORRUS) database to identify all patients who underwent robotic ureteral reconstruction for long-segment (≥4 centimeters) proximal ureteral strictures between August 2012 and June 2019. The primary surgeon determined the specific technique to reconstruct the ureter at time of surgery based on the patient's clinical history and intraoperative findings. Our primary outcome was surgical success, which we defined as the absence of ureteral obstruction on radiographic imaging and absence of obstructive flank pain.

Results: Of 20 total patients, 4 (20.0%) underwent robotic ureteroureterostomy (RUU) with downward nephropexy (DN), 2 (10.0%) underwent robotic ureterocalycostomy (RUC) with DN, and 14 (70.0%) underwent robotic ureteroplasty with buccal mucosa graft (RU-BMG). Median stricture length was 4 centimeters (interquartile range [IQR], 4–4; maximum, 5), 6 centimeters (IQR, 5–7; maximum, 8), and 5 centimeters (IQR, 4–5; maximum, 8) for patients undergoing RUU with DN, RUC with DN, and RU-BMG, respectively. At a median follow-up of 24 (IQR, 14–51) months, 17/20 (85.0%) cases were surgically successful. Two of four patients (50.0%) who underwent RUU with DN developed stricture recurrences within 3 months.

Conclusions: Long-segment proximal ureteral strictures may be safely and effectively managed with RUC with DN and RU-BMG. Although RUU with DN can be utilized, this technique may be associated with a higher failure rate.

Keywords: Reconstructive surgical procedures; Robotic surgical procedures; Ureter

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Corresponding Author: Matthew Lee https://orcid.org/0000-0001-9142-5714
Department of Urology, Lewis Katz School of Medicine at Temple University, 255 S 17th Street, Medical Tower 7th Floor, Philadelphia, PA 19103, USA
TEL: +1-215-875-9710, FAX: +1-215-875-9721, E-mail: matthewlee019@gmail.com

INTRODUCTION

Surgical repair of long-segment proximal ureteral strictures (LPUS) is challenging. Ureteroureterostomy alone is generally contraindicated in this setting given the difficulty in obtaining a tension-free anastomosis. Although LPUS have traditionally been managed with ileal ureter replacement (IUR) or renal autotransplantation (RA), these procedures may be technically difficult to perform and associated with considerable morbidity. Also, in contrast to reconstruction of long-segment middle and distal ureteral strictures where the bladder may be readily mobilized via psoas hitch (PH) and tubularized via Boari flap (BF), utilization of the bladder for reconstruction of LPUS is not ideal. As such, understanding techniques that may facilitate reconstruction of LPUS is important.

The robotic modality is particularly useful for ureteral reconstruction, and robotic ureteral reconstruction (RUR) has been increasingly utilized [1-4]. RUR maintains the inherent benefits of minimally invasive surgery and allows the surgeon to see in magnified three-dimensional vision, operate in limited anatomic spaces, and suture with precision. However, there is a paucity of literature regarding the utilization of the robotic platform for LPUS management and a lack of studies describing outcomes with intermediate-term follow-up. Herein, we present our intermediate-term, multi-institutional experience with RUR for LPUS.

MATERIALS AND METHODS

We performed an Institutional Review Board of Temple University approved (approval number: 20793) retrospective review of all consecutive patients undergoing RUR for LPUS between August 2012 and June 2019 in the Collaborative of Reconstructive Robotic Ureteral Surgery (CORRUS) database. Informed consent was obtained by all subjects when they were enrolled. It is our standard protocol to offer robotic repair for LPUS management. The procedures were performed at three institutions using the da Vinci® Surgical System (Intuitive Surgical, Sunnyvale, CA, USA). An LPUS was defined as a stricture located between the ureteropelvic junction and upper border of the sacroiliac joint measuring ≥4 centimeters based on intraoperative assessment. Although patients with strictures extending into the middle ureter (between the upper and lower sacroiliac joint borders) were included, those with strictures extending into the distal ureter (below the lower sacroiliac joint border) were excluded from our analysis as these patients are generally managed with ureteral reimplantation via PH and BF. Surgical success was assessed at each postoperative visit (which generally occur at 3 months and 12 months postoperatively, and yearly thereafter) and defined as the absence of obstruction on radiographic imaging (i.e. computerized tomography urogram and/or renal scan) and obstructive flank pain.

1. Surgical technique

We previously described our approach to patient positioning and port placement for RUR of proximal strictures [2,4]. Prior to RUR, the LPUS was delineated via retrograde and/or antegrade (if percutaneous nephrostomy tube is present) pyelography. An open-ended ureteral catheter was inserted into the strictured ureter, secured to a Foley catheter, and left on the surgical field. The primary surgeon determined the specific reconstruction technique at time of surgery based on the patient's clinical history and intraoperative findings. Stricture length was measured at time of surgery using an intraoperative ruler. We utilized the following techniques.

1) Downward nephropexy (DN)

We previously described our DN technique to help facilitate a tension-free anastomosis during RUR [2]. After incising through Gerota's fascia and peri-nephric fat, the kidney is circumferentially dissected from its capsular attachments and mobilized caudally. The posterior kidney capsule is then pexed to the psoas fascia using absorbable suture. In our experience, DN provides approximately 3 to 5 centimeters of ureteral mobilization (Fig. 1A).

2) Robotic ureteroureterostomy (RUU)

Although RUU alone is generally contraindicated for LPUS, RUU in conjunction with a DN may be utilized. After excising the stricture and performing DN, additional ureterolysis may be necessary for a tension-free anastomosis. The proximal and distal ends of healthy ureter are spatulated and re-anastomosed using absorbable sutures.

3) Robotic ureterocalycostomy (RUC)

RUC involves anastomosing healthy ureter to a lower pole renal calyx. After incising Gerota's fascia, peri-nephric fat is dissected free to expose the lower pole of the kidney. A laparoscopic ultrasound probe is utilized to localize the lower pole calyx. After dissecting out and temporarily clamping the renal artery (clamped in 1/2 cases), the lower pole of the kidney is excised to expose a calyx. An absorbable suture is used to evert the calyx urothelium. Specifically, the suture is run between the renal capsule and mucosa of the calyx in a running horizontal mattress fashion circumferentially. Each

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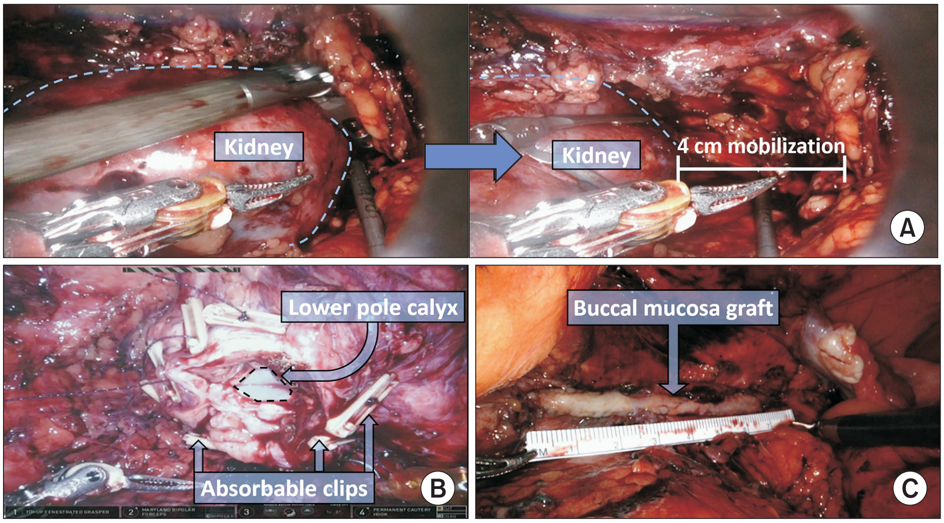

Fig. 1. (A) Image showing kidney (outlined with dotted lines) prior to downward nephropexy and after 4-centimeter downward mobilization. (B) This image shows an exposed calyx (outlined with dotted lines) after excising the lower pole of the kidney during robotic ureterocalycostomy. The proximal end of the healthy ureter will be anastomosed to the lower pole calyx using absorbable sutures. (C) This image shows a 7-centimeter buccal mucosa graft onlayed over a ventral ureteral defect and anastomosed to the ureter in running fashion.

time the suture exits the renal capsule, an absorbable clip is placed to cinch the kidney and assist with hemostasis (Fig. 1B). After excising the stricture, the healthy ureteral end is spatulated and anastomosed to the calyx using absorbable sutures.

4) Robotic ureteroplasty with buccal mucosa graft (RU-BMG)

We previously described two major techniques for RU-BMG [4,5]. The onlay technique involves making a longitudinal incision on the strictured ureter and anastomosing a BMG to the defect using absorbable sutures (Fig. 1C). The augmented anastomotic technique involves excising the strictured ureter, anastomosing a posterior plate of healthy ureter using absorbable suture, and anastomosing a BMG to the remaining defect using absorbable sutures. The onlay technique is primarily used when the stricture is narrowed and the augmented anastomotic technique is used when the stricture is obliterative. The BMG is harvested by hydrodissecting the buccal mucosa with lidocaine with epinephrine and excising it off of the buccinator muscle. Graft length is determined by intracorporeally measuring the ureteral defect; graft width is 10–15 millimeters.

2. Adjunctive techniques

1) Omental/peri-nephric fat flap

An omental or peri-nephric fat flap may be wrapped around the reconstructed ureter and pexed in place to supplement healing. The omental wrap involves mobilizing a broad-based pedicle of the greater omentum from the right or left side. The peri-nephric fat flap involves incising Gerota's fascia and peri-nephric fat at the lateral margin of the kidney and carrying the dissection medially to mobilize the flap.

2) Indocyanine green (ICG)

Intraureteral or intravenous ICG was utilized under near-infrared fluorescence at the discretion of the primary surgeon as a real-time contrast agent during RUR.

3) Stent placement

A nephroureteral stent was placed in all cases. After completing half of the ureteral anastomosis, a guidewire is introduced via the previously placed open-ended ureteral catheter. A 6-French double J stent is placed over the wire and into the ureter in retrograde fashion.

RESULTS

Patient demographics and perioperative outcomes are summarized in Table 1. Of 20 patients, 4 (20.0%) underwent RUU with DN, 2 (10.0%) underwent RUC with DN, and 14 (70.0%) underwent RU-BMG. Stricture etiology varied from iatrogenic (80.0%), idiopathic (10.0%), impacted stone (5.0%) or radiation-induced (5.0%) causes. Median stricture length was 4 centimeters (interquartile range [IQR], 4–4; maximum, 5), 6 centimeters (IQR, 5–7; maximum, 8), and 5 centimeters (IQR, 4–5; maximum, 8) for patients undergoing RUU with DN, RUC with DN, and RU-BMG, respectively. One of two patients (50.0%) undergoing RUC with DN and 3/14 (21.4%) undergoing RU-BMG previously failed ureteral reconstruction.

Median operative time and estimated blood loss were 173 minutes (IQR, 161–214) and 125 milliliters (IQR, 45–238), 341 minutes (IQR, 310–372) and 200 milliliters (IQR, 200–200), and 272 minutes (IQR, 200–323) and 100 milliliters (IQR,

Table 1. Patient demographics and perioperative outcomes

Variable	RUU with DN (n=4)	RUC with DN (n=2)	RU-BMG (n=14)	Overall (n=20)
Age (y)	66 (58–69)	50 (39–60)	60 (43–68)	63 (42–69)
Body mass index (kg/m^2)	26 (22–30)	31 (30–32)	28 (25–35)	29 (25–33)
History of failed ureteral reconstruction	0 (0.0)	1 (50.0)	3 (21.4)	4 (20.0)
Stricture etiology				
Iatrogenic	3 (75.0)	2 (100.0)	11 (78.6)	16 (80.0)
Idiopathic	1 (25.0)	0 (0.0)	1 (7.1)	2 (10.0)
Impacted stone	0 (0.0)	0 (0.0)	1 (7.1)	1 (5.0)
Radiation	0 (0.0)	0 (0.0)	1 (7.1)	1 (5.0)
Stricture length (cm)	4 (4–4)	6 (5–7)	5 (4–5)	5 (4–5)
Location of stricture				
Proximal	4 (100.0)	1 (50.0)	12 (85.7)	17 (85.0)
Proximal and middle	0 (0.0)	1 (50.0)	2 (14.3)	3 (15.0)
Operative time (min)	173 (161–214)	341 (310–372)	272 (200–323)	273 (175–327)
Estimated blood loss (mL)	125 (45–238)	200 (200–200)	100 (50–100)	100 (50–200)
Intraoperative complications	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Length of stay (day)	2 (2–2)	7 (5–10)	2 (2–3)	2 (2–3)
Postoperative major (Clavien>2) complications	0 (0.0)	1 (50.0)	1 (7.1)	2 (10.0)
Surgical success	2 (50.0)	2 (100.0)	13 (92.9)	17 (85.0)
Follow-up (mo)	37 (14–67)	41 (32–49)	24 (14–39)	24 (14–51)

Values are presented as median (IQR) or number (%).
This table shows information regarding patient demographics and perioperative outcomes associated with each robotic reconstruction procedure.
RUU, robotic ureteroureterostomy; DN, downward nephropexy; RUC, robotic ureterocalycostomy; RU-BMG, robotic ureteroplasty with buccal mucosa graft; IQR, interquartile range.

50–100) for patients undergoing RUU with DN, RUC with DN, and RU-BMG, respectively. The renal artery was clamped in 1/2 (50.0%) patients undergoing RUC with DN (warm ischemia time was 17 minutes). There were no intraoperative complications reported. Median length of stay was 2 days (IQR, 2–2), 7 days (IQR, 5–10), and 2 days (IQR, 2–3) for patients undergoing RUU with DN, RUC with DN, and RU-BMG, respectively. Overall, 2/20 (10.0%) patients experienced short-term (≤30 days) major (Clavien>2) postoperative complications. One patient developed gluteal compartment syndrome requiring emergent fasciotomy after a 394-minute RU-BMG. One patient developed a urinary leak requiring temporary percutaneous nephrostomy tube drainage after RUC with DN. At a median follow-up of 24 months (IQR, 14–51), 17/20 (85.0%) cases were successful. All three patients who developed stricture recurrences were diagnosed ≤3 months postoperatively by renal scan. Two patients were managed with balloon dilation and one patient has been chronically managed with nephroureteral stent exchanges.

Surgical techniques are summarized in Table 2. Of patients undergoing RU-BMG, 8/14 (57.1%) underwent an onlay type and 6/14 (42.9%) underwent an augmented anastomotic type RU-BMG. Two of six patients (33.3%) undergoing augmented anastomotic RU-BMG required concomitant DN. None of the cases required conversion to an open technique. Overall, intraureteral ICG was utilized in 9/20 (45.0%) patients (4 who underwent RUU with DN, 1 who underwent RUC with DN, and 4 who underwent RU-BMG), and intravenous ICG was utilized in 7/20 (35.0%) patients (all underwent RU-BMG). An omental flap was utilized in all patients undergoing RU-BMG. An omental flap was utilized in 1/2 (50.0%) patients and a peri-nephric fat flap was utilized in 1/2 (50.0%) patients undergoing RUC with DN.

DISCUSSION

Surgical management of LPUS not amenable to ureteroureterostomy alone is challenging. Furthermore, a paucity of literature exists regarding reconstruction of such strictures. Traditionally, LPUS have been managed with IUR or RA. However, IUR requires expertise in bowel reconstruction and increases the likelihood of bowel-related morbidity [6,7]. In a retrospective analysis, Roth et al. [6] found that 31/108 (28.7%) patients undergoing IUR experienced short-term postoperative complications, including urinary tract infection, ileus, urine leak, myocardial infarction, and respiratory failure. Long-term complications included hyperchloremic metabolic acidosis (3.7%), small bowel obstruction (8.3%), fis-

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Table 2. Surgical techniques

Variable	RUU with DN (n=4)	RUC with DN (n=2)	RU-BMG (n=14)	Overall (n=20)
RU-BMG technique				
Onlay type	-	-	8 (57.1)	-
Augmented anastomotic type	-	-	6 (42.9)	-
Concomitant DN	-	-	2 (14.3)	-
Conversion to open technique	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
ICG usage				
Intraureteral	4 (100.0)	1 (50.0)	4 (28.6)	9 (45.0)
Intravenous	0 (0.0)	0 (0.0)	7 (50.0)	7 (35.0)
Omental wrap	0 (0.0)	1 (50.0)	14 (100.0)	15 (75.0)
Peri-nephric wrap	0 (0.0)	1 (50.0)	0 (0.0)	1 (5.0)

Values are presented as number (%).
This table highlights specific information regarding each robotic reconstruction technique utilized.
RUU, robotic ureteroureterostomy; DN, downward nephropexy; RUC, robotic ureterocalycostomy; RU-BMG, robotic ureteroplasty with buccal mucosa graft; ICG, indocyanine green; -, not available.

tula formation (5.6%) and reoperation (20.4%).

RA requires expertise in transplant principles and increases the likelihood of vascular morbidity. In a bi-institutional review of 51 patients undergoing 54 RAs over a 27-year period, Cowan et al. [8] noted that short-term major complications including septic shock and graft thrombosis occurred in 14.8% and long-term major complications including graft loss and renal artery dissection occurred in 5.5%. Although robotic IUR [9] and RA [10] experiences have also been reported, we believe that the morbidities and technical difficulties associated with these procedures are similar regardless of approach.

Although PH and BF are more commonly used for middle and distal ureteral reconstruction, they may also be utilized for proximal ureteral reconstruction. Mauck et al. [11] reported that 9/10 (90.0%) patients undergoing PH and BF for proximal strictures were successful at a mean follow-up of 12.8 months. Concomitant DN was required in 5/10 (50.0%) cases. Stricture lengths were not reported [11]. Despite these promising results, we do not routinely perform these techniques for LPUS. Rather than replace healthy distal ureter with tubularized bladder, we prefer to preserve it when possible. Also, using PH and BF for LPUS involves creating a large bladder flap, which may adversely affect postoperative bladder capacity and urinary function. Mauck et al. [11] reported that 17% of patients undergoing proximal stricture repair developed *de novo* irritative voiding complaints requiring anticholinergic medications.

Our intermediate-term, multi-institutional study suggests that LPUS may be safely and effectively managed using RUR. With regards to safety, RUU with DN, RUC with DN, and RU-BMG were associated with low perioperative morbidity. Two of twenty patients (10.0%) experienced short-term major complications. The patient who developed compartment syndrome after a 394-minute RU-BMG required emergent fasciotomy. This extended operative time could be attributed to the extensive lysis of adhesions and ureterolysis required in this patient who had significant retroperitoneal fat (body mass index=39) and peri-ureteral fibrosis. The patient who developed a urinary leak after RUC with DN was successfully managed with temporary percutaneous nephrostomy tube drainage.

Furthermore, RUU with DN, RUC with DN and RU-BMG do not involve bowel or vascular reconstruction. Although RUC involves resecting the lower pole of a kidney, this technique has been associated with low morbidity. Srivastava et al. [12] analyzed 72 patients undergoing open or laparoscopic ureterocalycostomy and noted a relatively low rate of major complications, including urinary leakage (5.6%) and transfusions (2.8%). Also, although RU-BMG involves harvesting oral mucosa, its safety during urologic reconstruction has been well-established. In a systematic review evaluating BMG site morbidity, Markiewicz et al. [13] noted a 4.0% complication rate, with majority of complications including scarring and bleeding. Although we believe that IUR and RA should be in the reconstructive urologist's armamentarium for LPUS, such procedures should only be utilized after exhausting less technically demanding and morbid options. Also, in contrast to PH and BF, RUU with DN, RUC with DN, and RU-BMG allow for preservation of healthy distal ureter.

With regards to efficacy, 17/20 (85.0%) patients undergoing RUR for LPUS were successful at a median follow-up of 24 months (IQR, 14–51). Two of four patients (50.0%) undergoing RUU with DN were successful at a median follow-up of 37 months (IQR, 14–67). One explanation for this high failure rate could be the increased degree of ureterolysis required for RUU with DN. The importance of minimizing ureteral dissection to avoid disrupting the fragile ureteral blood supply cannot be overemphasized. During RUU with DN, after excising the stricture, both proximal and distal healthy ureteral ends may necessitate mobilization for a tension-free anastomosis. However, ureterolysis may be limited during RUC with DN as the lower pole calyx is generally lower than the renal pelvis. Also, ureterolysis may be limited to the diseased segment of ureter during onlay type RU-BMG, as the strictured ureter is incised rather than transected. Lastly, ureterolysis may be limited in an augmented anastomotic type RU-BMG, as only a plate of ureter must be anastomosed. Although our results are limited by a small sample size (n=4), they suggest that RUU with DN may be associated with limited efficacy for LPUS. Additionally, patients undergoing RUU with DN did not receive a concomitant omental/peri-nephric fat wrap, which may have adversely affected ureteral healing. Further studies with larger patient cohorts are necessary to evaluate these relationships.

Two of two patients (100.0%) undergoing RUC with DN were successful at a median follow-up of 41 months (IQR, 32–49). Ureterocalycostomy is a well-established technique that has been associated with satisfactory outcomes. In the aforementioned study by Srivastava et al. [12], 50/72 (69.4%) patients undergoing open or laparoscopic ureterocalycostomy were successful at a mean follow-up of 60.3 months. Stricture lengths and utilization of concomitant DN were not reported [12]. Given the added morbidity with resecting the lower pole of the kidney, we generally avoid utilizing RUC with DN when possible. However, this technique is required when there is significant scarring and/or fibrosis at the renal pelvis, which renders it unsuitable for use.

Thirteen of fourteen patients (92.9%) undergoing RU-BMG were successful at a median follow-up of 24 months (IQR, 14–39). RU-BMG has become our preferred technique for LPUS management as it is associated with low patient morbidity and excellent outcomes [4,5]. In a previous multi-institutional study, we reported that 17/19 (89.5%) patients undergoing RU-BMG for complex proximal and middle ureteral strictures were successful at a median follow-up of 26 months. Median stricture length was 4 (range 2-8) centimeters. Two of nineteen patients (10.5%) experienced a major postoperative complication [4]. A small subset of patients from this prior study had a proximal stricture that measured ≥4 centimeters and were included in this current series after updating their data over a longer, intermediate-term follow-up. Also, as previously mentioned, RU-BMG minimizes the need for an extensive ureterolysis. For narrowed strictures, only the strictured segment of ureter needs to be dissected prior to onlaying the BMG over the defect (onlay type). For obliterative strictures, the ureter only needs to be mobilized enough to allow for anastomosis of a plate of healthy ureter (augmented anastomotic type). The degree of mobilization required to bring together a plate of healthy ureter is less than that required to bring together a circumferential anastomosis. Given the limited experience with RU-BMG, further studies evaluating long-term outcomes are necessary.

Our study has many limitations. Given our study's retrospective and descriptive nature, our results are only hypothesis-generating and further studies are needed to evaluate the safety and efficacy of RUR versus other techniques for LPUS management. Also, although we report the largest experience evaluating RUR for LPUS, our experience is limited by a small sample size (n=20). Since LPUS formation is uncommon, continued multi-institutional efforts are necessary to generate larger patient cohorts.

CONCLUSIONS

LPUS may be safely and effectively managed with RUC with DN and RU-BMG. Although RUU with DN may be utilized, this technique may be associated with a higher failure rate. Further collaborative studies with larger patient cohorts are necessary to further evaluate the efficacy of RUR for LPUS management.

CONFLICTS OF INTEREST

Matthew Lee, Ziho Lee, Helaine Koster, Minsuk Jun, Aeen M. Asghar, Randall Lee, David Strauss, Neel Patel, Daniel Kim, Sreeya Komaravolu, and Alice Drain have no competing financial interests. Michael J. Metro is a consultant and speaker for Endo Pharmaceuticals, Coloplast and Boston Scientific. Lee Zhao is a consultant for Intuitive Surgical. Michael Stifelman is a lecturer for Intuitive, on the Scientific Advisory Board for CONMED, a consultant for VTI Medical, and performs educational activities for Ethicon. Daniel D. Eun is a paid speaker, consultant, and proctor for Intuitive Surgical, a consultant for Johnson and Johnson, performs support for trainees for Hitachi Aloka, and is a founder/part owner of Melzi Corp.

AUTHORS' CONTRIBUTIONS

Conception and design: Matthew Lee, Ziho Lee, Michael

J. Metro, Lee Zhao, Michael Stifelman, and Daniel D. Eun. Data acquisition: Matthew Lee, Ziho Lee, Helaine Koster, Minsuk Jun, Aeen M. Asghar, Randall Lee, David Strauss, Neel Patel, Daniel Kim, Sreeya Komaravolu, and Alice Drain. Data analysis and interpretation: Matthew Lee and Ziho Lee. Drafting the manuscript: Matthew Lee and Ziho Lee. Critical revision of the manuscript for scientific and factual content: Matthew Lee, Ziho Lee, Helaine Koster, Minsuk Jun, Aeen M. Asghar, Randall Lee, David Strauss, Neel Patel, Daniel Kim, Sreeya Komaravolu, Alice Drain, Michael J. Metro, Lee Zhao, Michael Stifelman, and Daniel D. Eun. Statistical analysis: Matthew Lee. Supervision: Matthew Lee, Ziho Lee, Michael J. Metro, Lee Zhao, Michael Stifelman, and Daniel D. Eun.

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