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Urine Leak After Partial Nephrectomy: A Rare Complication After Robot-Assisted Partial Nephrectomy

Kwabena Nkansah-Amankra[1, *], Ameisha Tutwiler[1], Zane Giffen[1], Alberto Breda[2], Wesley Ekeruo[3], Firas Petros[1, *], Obi Ekwenna[1]

[1]Department of Urology and Kidney Transplant, The University of Toledo Medical Center and Eleanor N. Dana Cancer Center, Toledo, The United States

[2]Oncology Urology Unit, Department of Urology, Fundació Puigvert, Universitat Autònoma de Barcelona, Barcelona, Spain

[3]Department of Urology, Houston Methodist Hospital, Houston, The United States

Email address:

Kwabena.nkansah@utoledo.edu (Kwabena Nkansah-Amankra)

[*]Corresponding author

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Abstract: In this systematic review, we looked at the rate of urine leakage from the kidney after surgical removal of kidney tumors. Urine leak (UL) is a common post-operative complication of partial nephrectomy (PN). The reported incidence varies in the literature, and there are no well-established guidelines for management of UL after PN. The goal of this study is to report the incidence and most common management strategies for UL after PN. For our quantitative synthesis, a systematic review of articles related to UL after PN from April 2010 to April 2020 was performed using PubMed and EMBASE. 475 total records were found, of which 40 reported on post-operative UL. A total of 19,904 cases were included. The overall incidence of UL was 2.8% (554/20,140). UL was most common in open cases (5.01%), followed by laparoscopic (4.40%) and robotic (1.18%) PN. Thirty-one of the included studies reported on management technique for a total of 343 interventions. UL was most frequently managed non-operatively (46.6%). Other management strategies included cystoscopy with ureteral stent placement (39.4%), percutaneous drain placement (8.7%), and percutaneous nephrostomy tube placement (2.3%). Use of nephrectomy, open reconstruction, angioembolization, or ureteroscopic techniques was uncommon (3.1%). Our study revealed that UL is rare after robotic approach to PN. Many reported cases have been managed conservatively. A stepwise management strategy is recommended. Most of these leaks heal with time or with placement of a stent into the ureter after surgery. We found that urine leak is less common with robotic surgery versus open or laparoscopic surgery.

Keywords: Partial Nephrectomy, Robotic Surgery, Urine Leak, Urinoma, Urinary Fistula, Robot-Assisted Partial Nephrectomy

1. Introduction

The incidence of renal cell carcinoma continues to rise worldwide [1]. As many of these lesions are small and detected incidentally on cross-sectional imaging, the preferred management for small renal masses has shifted towards nephron-sparing surgery or active surveillance [2]. Partial nephrectomy (PN) remains an efficacious management strategy for many renal tumors. It is well tolerated by patients, demonstrating similar cure rates to radical nephrectomy [3]. PN may be accomplished through an open, robotic or laparoscopic approach, and is indicated for clinical stage T1 tumors when technically feasible with complete tumor excision [4]. The utilization of robotic PN has increased over time [5], with some evidence of decreased complication and morbidity [6].

PN, however, is associated with higher rates of perioperative complications as compared to radical nephrectomy, including postoperative hemorrhage and urine leak/fistula (UL) [7]. Of these, UL remains a clinical conundrum, with no definitive guidelines for management, although prior series have offered management algorithms [8, 9].

There have been multiple retrospective cohort analyses evaluating the rate of postoperative urine leak, either alone or in combination with other PN perioperative complications. Some of these reports also included reviews of the literature with respect to UL. Yet, there is no contemporary systematic review thoroughly reporting the incidence and most common management strategies for UL, particularly since the advent of the robotic approach. We sought to undertake such an analysis and use the results to propose a simplified management strategy for UL based on the available evidence. Finally, we highlight novel management techniques, which may serve a role in the management of refractory post-partial nephrectomy UL.

2. Methods

A systematic literature review of articles from April 2010 to April 2020 yielded a total of 475 articles. 454 articles were generated through database searching and an additional 21 articles were identified through other sources, including reference lists from other records. A PubMed/MEDLINE search using the terms “partial nephrectomy” or “nephron-sparing surgery” or “kidney-sparing surgery” and “urine leak” or “urinary leak” or “urinary fistula” or “urinary fistulae” identified 91 articles. An Embase search using the terms ‘partial nephrectomy’ or ‘nephron-sparing surgery’ or ‘kidney-sparing surgery’ and ‘urine leak’ or ‘urinary leak’ or ‘urinary fistula’ or ‘urinary fistulae’ identified an additional 363 articles, for a total of 454 articles. Articles were individually screened to identify articles of interest. Search results were evaluated according to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) [10]. Duplicates, non-English articles, and conference abstracts were excluded. See Figure 1 for our PRIMSA flow diagram revealed 209 full text articles were assessed.

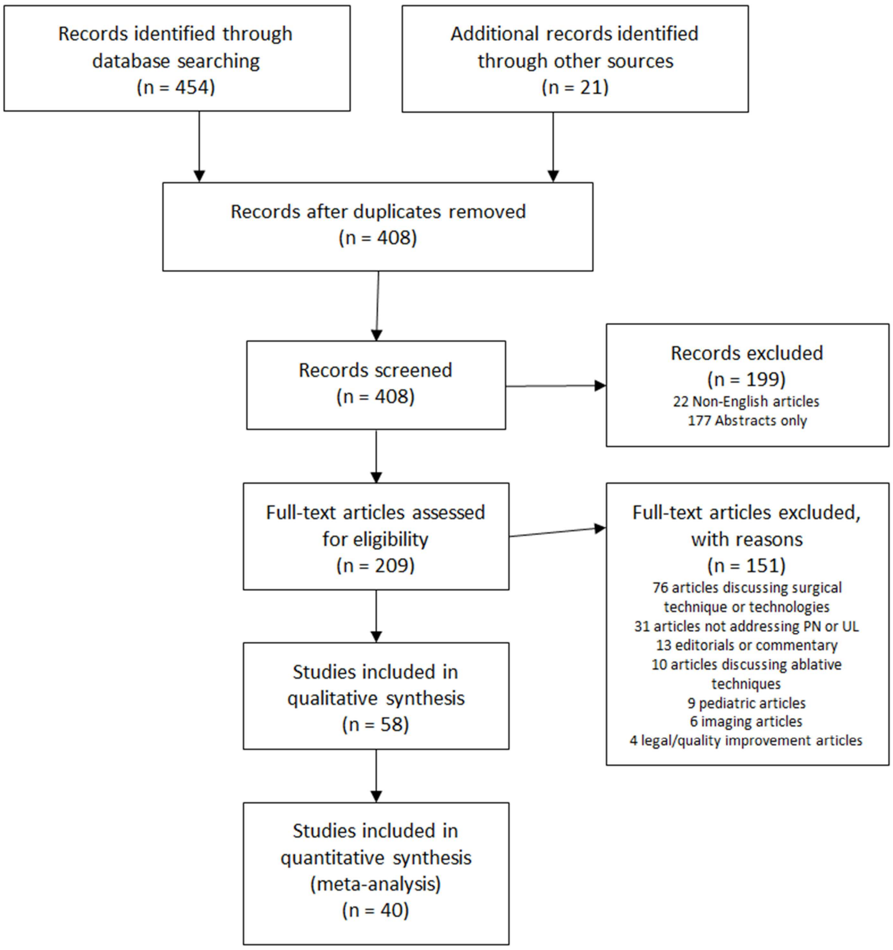

Figure 1. *PRISMA flow diagram for systematic literature review.*

A total of 58 studies were included in our qualitative analysis, including case reports and series detailing the management of post-operative urine leak (UL) or urinary fistula after partial nephrectomy. For our quantitative analysis, we included all studies that reported the incidence of post-operative urine leak in their partial nephrectomy cohort. We excluded articles that did not report on postoperative urine leak or urinary fistula. Pediatric articles were also excluded. Studies with overlapping datasets were also excluded. Articles that discussed urine leak after cryoablation or radiofrequency ablation of renal tumors were excluded. Articles describing non-standard clinical scenarios (*e.g.*, PN in setting of emphysematous pyelonephritis or partial nephrectomy for renal vein thrombi) were excluded. Studies involving the treatment of multiple ipsilateral tumors were also excluded.

In total, 40 studies were included in our quantitative analysis. These were reviewed for relevant variables including surgical technique (open, laparoscopic, or robotic), incidence of post-operative urine leak, management techniques selected for urine leak, and resolution rate. UL was not clearly defined in all included studies, but most commonly was described as persistent elevation of drain creatinine two weeks postoperatively, or symptomatic postoperative presentation with imaging findings consistent with urine leak or urinoma. Non-operative management after UL was defined as observation alone, or prolonged closed-suction drainage (with or without indwelling urethral catheter drainage), and resolution confirmation on follow-up imaging. The predictive factors of post-operative UL in univariate or multivariate analysis were also abstracted from each series. Statistical analysis was performed with chi-square tests where appropriate. An alpha value less than 0.05 was considered statistically significant.

3. Results

A total of 19, 904 cases were included. Most cases were performed robotically (N= 9,944; 50.0%) as compared to laparoscopically (N= 3,283; 16.4%) or open (N=6,787; 34.1%). The overall incidence of UL was 2.6% (523/19,904). Seven of the 40 studies [11-17] did not stratify UL complications based on surgical technique and therefore were excluded from subset analysis by surgical approach. Some reports seemed to originate from the same multicenter dataset; suspected duplicate cases were excluded. Stratified by PN approach, UL was more common in open (117/2335; 5.01%), followed by laparoscopic (85/1932; 4.40%) and least common in robotic (97/8032; 1.21%) PN.

3.1. Intervention for Urine Leak

A total of 245 interventions, including conservative management (observation with prolonged closed suction drainage, with or without indwelling urethral catheter placement) were performed for 327 UL patients. Sixteen patients underwent additional staged or multiple simultaneous interventions (e.g., percutaneous drainage and cystoscopy with ureteral stent placement). The management course of one patient was reported as unknown [13].

Twelve of the studies did not report on management strategies for UL and were therefore excluded from this analysis [9, 11, 12, 14, 15, 22-28]. UL was most commonly managed conservatively (46.6%; p<0.001). Other management strategies included cystoscopy with ureteral stent placement (39.4%), percutaneous drain placement (8.7%), and percutaneous nephrostomy tube placement (2.3%). Rarely, nephrectomy, open reconstruction, angioembolization, or ureteroscopic techniques were used for management (N=10/335; 3.0%). These management strategies are grouped into the "other" category in Figures 2 and 3. Two studies reported that the average time to intervention for patients managed with cystoscopy and stent insertion was 8.5 days (N=16) [8] and 12.2 days (N= 23) [28] after PN, respectively.

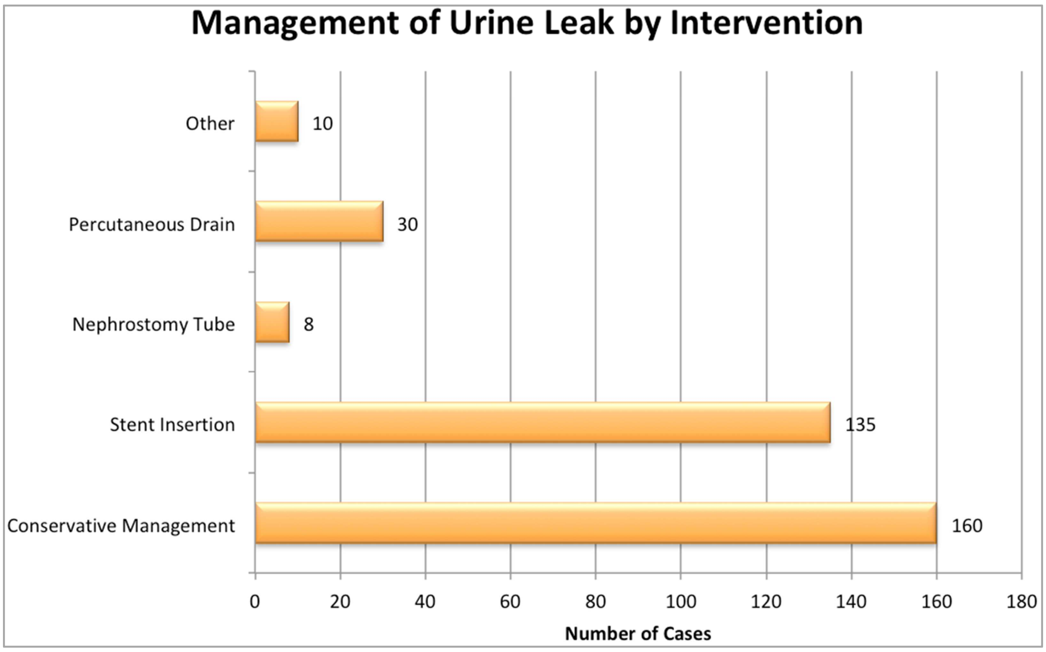

Figure 2. *Number of cases (N = 343) managed conservatively, with stent insertion, with nephrostomy tube insertion, with percutaneous drain insertion, and by other means, respectively. Other management strategies included nephrectomy (immediate or delayed), open reconstruction, angioembolization, or ureteroscopic management.*

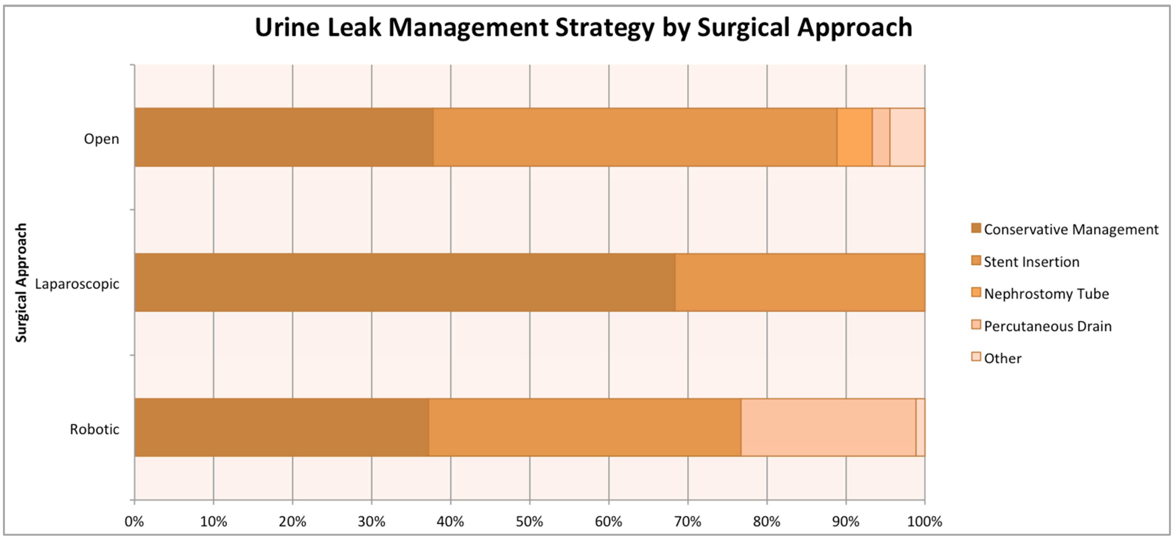

Figure 3. *Management strategy for each surgical approach. The most common intervention in the laparoscopic and robotic groups was conservative management. Stent insertion was more common in open procedures.*

Of the 31 studies that reported on management strategy of UL following PN, three [9, 11, 16, 17, 29] did not stratify management strategy by case type. Therefore, the 26 remaining studies were including in an analysis of UL management. Conservative management was the most common approach for robotic and laparoscopic PN, while cystoscopy with ureteral stent insertion was used for the majority of open PN (all p <0.001).

3.2. Risk Factors for Urine Leak

Of the studies included, 10 identified at least one statistically significant predictor of UL on univariate or multivariate analysis. An additional case series that modeled risk factors for UL was included in this analysis [30]. The most common predictors were estimated blood loss (EBL), open surgical approach, tumor size, and warm ischemia time (WIT) (Figure 4). Other risk factors for UL post PN included tumor complexity, operative time, WIT, endophytic mass, and intraoperative collecting system injury, among others. Of these, the most commonly reported factor for post-operative UL was EBL > 400 mL placing the patient at an especially higher risk in one study [39]. In general, these factors suggest that more complex cases result in more frequent UL.

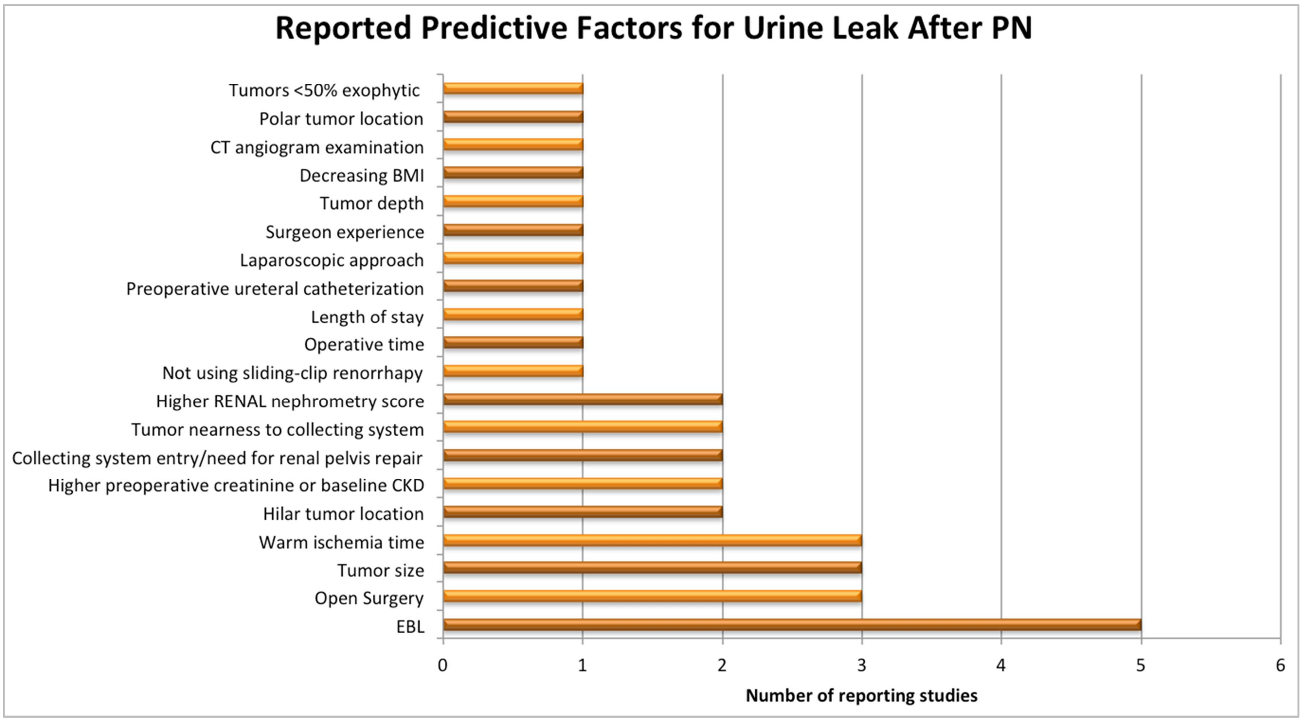

Figure 4. *Statistically significant (p<0.05) predictive factors in univariate or multivariate analyses reported in eleven series of UL after PN. Estimated blood loss (EBL) was the most common predictive factor described.*

4. Management of Urine Leak

This series is, to our knowledge, the largest meta-analysis evaluating UL after PN. We identified an overall UL rate of 2.67%, which narrows the substantial range reported in the historic literature of 0 to 33% [8]. As with previous reports [9, 32], we note a decreased rate of UL with the robotic PN 1.21% compared to 5.01% in open PN. This may be attributed to improvements in intracorporeal sutured reconstruction with increasing use of a sliding clip renorrhaphy techniques, and improved efficiency of renorrhaphy with barbed suture. [9, 59].

Many of the UL cases reported over the past decade were managed conservatively. Conservative management as defined in several studies included observation for spontaneous resolution, prolonged indwelling bladder catheter or closed suction drainage beyond normal postoperative duration, and pain management. Of the 53.4% of cases that were not managed conservatively, interventions including cystoscopy with ureteral stent placement, percutaneous drain placement, or percutaneous nephrostomy were required.

There were refractory cases that necessitated further surgical intervention in the form of angioembolization, open reconstruction, ureteroscopic ablation, or nephrectomy. Also reported in the literature include large bore dilation of the ureter via the placement of multiple double J stents or a large bore 14 to 16 F Malecot catheter into the collecting system via a retrograde approach, in combination with indwelling catheter bladder decompression, in order to maximize drainage and promote urinary fistula healing [32, 33]. Girard et al. noted fistula resolution in three patients using this management pathway [32].

Other novel management strategies noted in case reports included endoscopic fulguration or percutaneous glue or sealant injection, which were employed in patients who would be poor candidates to undergo further major surgery. Gorsi et al. described successful closure of a post-PN fistula with percutaneous beta-cyanoacrylate glue under computed tomography (CT) guidance [34]. There have been multiple prior reports of percutaneous tissue adhesive application for treatment of urinary fistula [35, 36]. Chu et al. described endoscopic fulguration and fibrin glue application via retrograde ureteroscopic approach [37]. Successful closure with retrograde fibrin instillation alone has been reported. Fibrin glue injection via fistula tract has also been described for nephrocutaneous fistula closure after PN with success [37]. Patients with UL secondary to an excluded calyx during renorrhaphy should have caliceal obstruction relieved via percutaneous or endoscopic approach [38].

Selective angioembolization, when available, offers another minimally-invasive management strategy compared to the morbidity of nephrectomy or open reconstruction, and has been implemented successfully in the literature for multiple UL cases refractory to treatment with stent or nephrostomy tube [39].

4.1. Current Management Algorithms

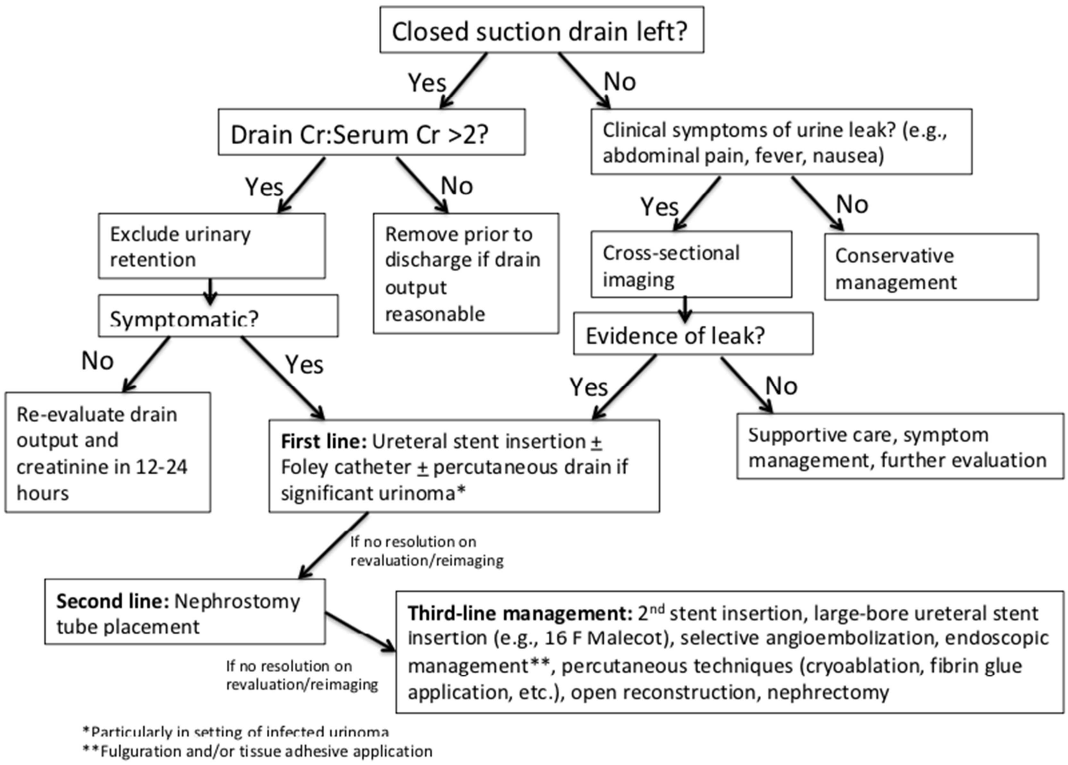

Figure 5. *Proposed algorithm for management of urinary leak status post partial nephrectomy.*

4.2. Proposed Management Algorithm

In light of these findings, we propose below an algorithm (Figure 5) to aid guide clinical decision-making in the management of UL after PN. Regardless of approach, the goal is to optimize drainage of the collecting system to promote urinary fistula healing and closure. Although many partial nephrectomies are associated with a drain placement, multiple studies included here have described omitting drain placement after PN without increase in postoperative complications [19, 20]. In such cases, the first step once clinical signs and symptoms are concerning for leak is to obtain cross-sectional imaging as appropriate (computed tomography scan with and without contrast with delayed images preferred). Endoscopic ureteral stent insertion with indwelling catheter bladder decompression is commonly the next step when UL is confirmed. The majority cases should resolve with double J stent insertion or nephrostomy tube placement [40]. In cases where there is already a closed suction drain in place, drain fluid-to-creatinine ratio offers a viable way to determine presence of a leak. A value above 2 mg/dL is concerning in the absence of concomitant urinary retention. For cases recalcitrant to first and second-line approach, it is reasonable to offer a third line management strategy as described above. We would favor attempts at endoscopic or percutaneous management prior to proceeding with reconstruction or nephrectomy.

5. Study Limitations

First, the inherent biases present in a review of retrospective studies are acknowledged. Several of the included studies were not specifically designed or powered to assess the incidence of postoperative UL Further, there are many studies that report PN outcomes and complications, including UL, without specifically addressing the incidence and management of urinary fistulae. Our review included many of these reports from the past decade but may have omitted some papers that report on UL.

It is possible that some of our included multicenter studies draw from the same patient populations. Admittedly, the included studies were of varying quality and evidence levels. It would be expected that a variety of surgical techniques were used in this very large analysis, and different surgical approaches (e.g., hand-assist versus pure laparoscopic PN) were not evaluated or controlled for. Further, the workup and detection of UL varied between reports. The use of closed-suction drains after PN was also variable. It is not surprising that the included study with the highest leak rate (16.5%) had one of the strictest definitions of UL ("continued urine output from the drain after postoperative day 2"). [44] In some other papers, leaks were only detected when a symptomatic postoperative patient presented.

Given the rarity of these cases, there is no prospective data on UL management. This offers a challenge when developing recommendations for management for these complex cases. Likewise, without an assessment for size of urinomas, it is difficult to establish an objective, tangible endpoint for which clinicians should be concerned for possible potential unresolved leak. While many studies performed follow-up imaging, some cases were considered resolved with cessation of symptoms. Of course, UL may be asymptomatic in many cases and therefore underreported in the literature and our analysis. Additional prospective studies of novel UL management, including endoscopic and percutaneous ablation, are needed, although may be ethically and technically difficult to perform.

6. Conclusions

Post-PN UL remains a clinically challenging paradigm. We report the largest known meta-analysis on this complication and demonstrate a significantly lower rate of UL in robot-assisted PN. EBL, larger tumor size, open surgery, and longer warm ischemia time predict UL in the literature. A large number of reported cases in the past decade have been managed conservatively. A simplified management algorithm that prioritizes a stepwise approach and slowly escalates intervention strategy appears best in managing this relatively rare complication.

Table 1. *Studies used in qualitative analysis (N=20,981 cases). Listed are the total number of cases by surgical approach, the incidence of post-operative urine leak (UL), management strategies employed for UL, and statistically significant predictive factors for UL (if applicable).*

Series	**Year (s) of study cases**	**Study type**	**N, total**	**N, robotic (%)**	**N, laparoscopic (%)**	**N, open (%)**	**Postoperative urine leak (%)**	**Management Technique**	**Predictive Factors for Urine Leak (p<0.05)**	**Study Notes**
Peyton 2020 [9]	2009-2017	Retrospective review, single institution	975	313 (32.1%)	0	661 (67.8%)	23/975 (2.3%): 3/314 (0.96%) in RPN and 20/661 (3.0%) in OPN	10/23 (44%) conservative management; 9/23 (39%) stent placement; 3/23 (13%) PCNT; 1 (4%) percutaneous drainage; 1/23 (4%) delayed nephrectomy, For	Open surgery, EBL, Not using sliding-clip renorrhaphy	NA

Series	Year (s) of study cases	Study type	N, total	N, robotic (%)	N, laparoscopic (%)	N, open (%)	Postoperative urine leak (%)	Management Technique	Predictive Factors for Urine Leak (p<0.05)	Study Notes
								RPN specifically, 2 patients conservative and 1 with stent insertion.		
Delto 2019 [41]	2009-2018	Retrospective review of prospectively maintained database	463	463 (100%)	0	0	1/463 (0.2%)	1/1 (100%) Stenting and percutaneous drainage	NR	All cases performed with early unclamping technique; patient with leak underwent simultaneous pyelolithotomy for partial staghorn calculus
Kahn 2019 [19]	NR	Prospective, single center study	100	100 (100%)	0	0	1/100 (1%)	1/1 (100%) percutaneous drain	NR	Prospective cohort study of drain omission during RAPN
Mari 2019 [11]	2013-2016	Prospective multicenter	2584	981 (38.0%)	717 (27.7%)	886 (34.3%)	1.1% of patients (~11 patients)	0.2% conservative management; 0.9% stent placement or PCNT	Not specifically evaluated	Prospective study to develop nomogram to predict postoperative complications
Mehra 2019 [42]	2011-2018	Single center retrospective review	55	13 (23.6%)	14 (25.4%)	28 (50.9%)	4/55 (7.3%) total: 1/13 (7.8%) RPN; 2/14 (14.3%) LPN; 1/26 (3.8%) OPN	4/4 (100%) double J stent insertion and Foley catheterization	NR	NA
Erlich 2017 [8]	1988-2013	Single center retrospective review	752	0	363 (48.3%)	389 (48.3%)	21/752 (2.8%)	16/21 (76.2%) stent insertion, 1 (4.8%) with additional PCNT placement and 1 (4.8%) with additional percutaneous drain placement; 4/21 (19%) conservative management; 1/21 (4.8%) nephrectomy	Hilar masses and higher preoperative creatinine levels on univariate analysis; none on multivariate analysis	Univariate and multivariate analysis of retrospective data
Jelley 2017 [28]	2010-2015	Single center retrospective review	159	77 (48.4%)	0	82 (51.6%)	0/159 (0%)	NA	NA	NA
Malkoc 2017 [21]	2009-2015	Single center retrospective review	110	54 (49.1%)	0	56 (50.9%)	4/110 (3.6%) overall: 1/54 (1.2%) RPN and 3/56 (5.4%) OPN	NR	NR	Study of tumors >7 cm in diameter
Veeratterapillay 2017 [22]	2012-2015	Multicenter retrospective review	250	250 (100%)	0	0	5/250 (2%)	NR	NR	NA
Wang 2017 [43]	2007-2014	Retrospective review of prospectively maintained	280	190 (50%)	0	190 (50%)	14/280 (5%): 4/190 (2.1%) RPN group and 10/190	Overall: 9/14 (64.3%) conservative management;	NR	Retrospective matched-pairs analysis

Series	Year (s) of study cases	Study type	N, total	N, robotic (%)	N, laparoscopic (%)	N, open (%)	Postoperative urine leak (%)	Management Technique	Predictive Factors for Urine Leak (p<0.05)	Study Notes
		single-center database					(5.3%) OPN group	5/14 (35.7%) stent insertion. RPN: 2/4 (50%) conservative management; 2/4 (50%) stent insertion OPN: 7/10 conservative management; 3/10 stent		
Zaid 2017 [14]	2001-2012	Single center retrospective review	1763	170 (10%)	196 (11%)	1407 (79%)	77/1764 (4%) – not stratified by technique	NR	NR	NA
Janda 2016 [44]	2008-2014	Single center retrospective review	232	232 (100%)	0	0	2/232 (0.9%)	2/2 (100%) stent insertion	NR	Comparative analysis of RPN for T1a vs T1b+ tumors
Peyronnet 2016 [18]	2006 - 2014	Retrospective multicenter study	1800	937 (52.1%)	0	863 (47.9%)	56/1800 (3.1%)	NR	0	Retrospective study comparing open vs robotic partial nephrectomies with regards to perioperative and oncologic outcomes
Potretzke 2016 [31]	NR	Retrospective review of prospectively maintained multicenter database	1791	1791 (100%)	0	0	14/1791 (0.78%)	8/14 (57%) percutaneous drain [removed after median 8 days (range 4-13)]; 9/14 (64%) stent placement [removed after median 21 days (range 8-83)]	Tumor size; hilar tumor location; need for renal pelvis repair; operative time; warm ischemia time	8 (57%) of urine leak patients required admission
Ramirez 2016 [23]	2011-2015	Retrospective review of prospectively maintained single-center database	714	545 (76.3%)	0	169 (23.7%)	2/714 (2.8%): 1/545 (0.18%) RPN and 1/169 (0.6%) OPN	NR	NR	NA
Carneiro 2015 [27]	2000-2014	Retrospective review of prospectively maintained single-center database	347	44 (12.7%)	303 (87.3%)	0	3/347 (0.8%): 3/303 (1%) LPN and 0 RPN	NR	NR	NR
Ganpule 2015 [45]	2010-2013	Retrospective chart review	57	57 (100%)	0	0	6/57 (10.5%)	3/6 (50%) conservative management; 3/6 (50%) stent insertion	NR	NA
Satkunasivan 2015 [46]	2009-2013	Retrospective single-center experience	179	179 (100%)	0	0	6/179 (3.4%)	6/6 (100%) conservative management with prolonged JP drainage	NR	Study of superselective clamping during RPN and unclamped RPN
Bigot 2014 [18]	1998-2012	Retrospective multicenter	168	3 (1.8%)	11 (6.5%)	154 (91.7%)	10/168 (6.0%)	10/10 (100%) stent placement	NR	Evaluation of functional and

Series	Year (s) of study cases	Study type	N, total	N, robotic (%)	N, laparoscopic (%)	N, open (%)	Postoperative urine leak (%)	Management Technique	Predictive Factors for Urine Leak (p<0.05)	Study Notes
		study								oncologic outcomes for tumors > 7 cm
Hu 2014 [47]	2006-2013	Retrospective multicenter study	227	227 (100%) (all retroperitoneal RPN)	0	0	3/227 (1.3%)	3/3 (100%) stent insertion	NR	NA
Kopp 2014 [15]	2002-2012	Two-center retrospective cohort study	80	0	2 (2.5%)	78 (97.5%)	8/80 (10%)	"combination of stents and percutaneous drains"	NR	NA
Tomaszewski 2014 [29]	2007-2013	Retrospective review of prospectively maintained database	831	476 (57.3%)	0	355 (42.7%)	54/831 (6.5%)	22/54 (40.7%) stent; 4/54 (7.4%) PCNT; 8/54 (14.8%) percutaneous drain; 5/54 (9.3%) nephrectomy, reconstruction, or angioembolization	Collecting system entry; hospital length of stay; EBL; WIT; open surgery	Median leak duration 63 days (range 8-230 days)
Vittori 2014 [48]	2010-2011	Observational multicenter study	303	105 (36.6%)	0	198 (65.3%)	12/303 (4%): 1/105 (1%) RPN cases and 11/198 (5.6%) OPN cases	8/12 (67%) stent insertion; 3/12 (25%) conservative management; 1/12 (8.3%) nephrectomy	NR for urine leak. Open surgical approach associated with increased overall postsurgical complications.	NA
Zargar 2014 [12]	1999-2012	Retrospective review	1019	452 (44.4%)	567 (55.6%)	0	31/1019 (3%)	NR	Preoperative ureteral catheterization; laparoscopic approach; presence of moderate to severe CKD; tumor nearness to collecting system; EBL; surgeon experience	Comparison of intra-operative ureteral catheterization on leak rate
Abaza 2013 [20]	2008-2012	Retrospective review of prospectively maintained database	150	150 (100%)	0	0	2/150 (1.3%)	1/2 (50%) Foley catheter insertion with resolution in 1 week; 1/2 (50%) percutaneous drain	NR	NA
Alyami 2013 [49]	2003 – 2011	Retrospective review of prospectively maintained database	52	0	52 (100%)	0	4/52 (7.7%)	3/4 (75%) stent insertion; 1/4 (25%) conservative management	NR	Study of masses > 4 cm in diameter only
Mathieu 2013 [24]	2009-2011	Retrospective multicenter study	240	240 (100%)	0	0	3/240 (1.3%)	NR	NR	NA
Tanagho 2013 [50]	2007-2011	Multi-center analysis of prospectively maintained databases	886	886 (100%)	0	0	10/886 (1.1%)	3/10 (30%) ureteral stent placement; 2/10 (2%) percutaneous drain; 5/10 (50%) conservative management	NR	NA
Porpiglia 2013		Retrospective	206	0	206 (100%)	0	1/206 (0.5%)	1/1 (100%)	NR	NA

Series	Year (s) of study cases	Study type	N, total	N, robotic (%)	N, laparoscopic (%)	N, open (%)	Postoperative urine leak (%)	Management Technique	Predictive Factors for Urine Leak (p<0.05)	Study Notes
[51]	2001-2012	review of prospectively maintained database						ureteral stent insertion		
Wheat 2013 [25]	1998-2008	Retrospective review of prospectively maintained database	336	0	336 (100%)	0	12/336 (3.6%)	NR	Larger tumor diameter; larger tumor depth; closer proximity to collecting system	NA
Ficarra 2012 [52]	2008-2010	Multi-center retrospective review	347	347 (100%)	0	0	2/347 (0.6%)	2/2 (100%) stent insertion	NR	NA
Long 2012 [16]	NR	Retrospective review of prospectively maintained database	46	5 (10.9%)	0	41 (89.1%)	6/46 (13.0%)	1/6 (16.7%) conservative management, 5/6 (83.3%) stent insertion	NR	Evaluation of PN for renal masses ≥ 7 cm
Lucas 2012 [53]	2003-2010	Retrospective single-center review	96	27 (28.1%)	15 (15.6%)	54 (56.3%)	4/96 (4.2%) total; 1/27 (3.7%) RPN, 0 LPN, 3/54 (5.6%) OPN	3/4 (75%) prolonged flank drain; 1/4 (25%) Foley catheter and flank drain	NR	NA
Stroup 2012 [26]	2003-2011	Multi-center retrospective review	284	31 (10.9%)	100 (35.2%)	153 (53.9%)	19/284 (6.7%): 1/31 (3.2%) RPN; 3/100 (3%) LPN; 15/153 (9.8%) OPN	NR	Increasing RENAL nephrometry score; decreasing BMI; open surgical technique	NA
Bylund 2011 [54]	2003-2009	Retrospective single institution	104	0	104 (100%) (hand-assisted)	0	2/104 (1.9%)	2/2 (100% conservative management)	NR	Evaluation of hand-assisted LPN without formal collecting system closure
Mues 2011 [55]	2007-2009	Retrospective review of prospectively maintained database	100	0	100 (100%)	0	3/100 (3%)	3/3 (100%) stent insertion	NR	NA
Pierorazio 2011 [56]	2006-2011	Retrospective single-center database review	150	48 (32%)	102 (68%)	0	8/150 (5.3%) total: 2/48 (4.2%) RPN cases and 6/102 (5.9%) LPN cases	8/8 (100%) ureteral stent insertion	NR	NA
Spana 2011 [57]	2006-2009	Multicenter retrospective review	450	450 (100%)	0	0	7/450 (1.6%)	3/7 (42.8%) percutaneous drain; 3/7 (42.8%) conservative management with prolonged Foley catheter; 1/7 (14.2%) stent insertion	NR	NA
Kundu 2010 [13]	1989-2007	Retrospective review of prospectively maintained database	1118	0	94 (8%)	1023 (92%)	52/1118 (4.6%)	36/52 (69%) conservative management; 8/52 (8%) stent placement; 1 (2%) urethral catheter; 1 (2%) stent and percutaneous	Median tumor size; EBL; WIT	NA

Series	Year (s) of study cases	Study type	N, total	N, robotic (%)	N, laparoscopic (%)	N, open (%)	Postoperative urine leak (%)	Management Technique	Predictive Factors for Urine Leak (p<0.05)	Study Notes
Scoll 2010 [58]	2007-2009	Prospectively maintained database	100	100 (100%)	0	0	2/100 (2%)	drain; 1 (2%) ureteroscopy; 1 (2%) unknown 1/2 (50%) managed with stent (was secondary to ureterolithiasis); 1/2 (50%) conservative management	NR	NA

CKD = chronic kidney disease. EBL = estimated blood loss. LPN = laparoscopic partial nephrectomy. NR = not reported. NA = not applicable. OPN = open partial nephrectomy. PCNT = percutaneous nephrostomy tube. RPN = robot-assisted partial nephrectomy. WIT = warm ischemia time.

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