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High Supracostal Percutaneous Nephrolithotomy Access: Assessing Safety in Access above the Eleventh Rib after Performing Preoperative Planning with Computed Tomography

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Abstract

Objective: To determine if supracostal renal access above the 11th rib during percutaneous nephrolithotomy (PCNL) is a safe option in carefully selected patients determined by preoperative computed tomography (CT) imaging. Patients and Methods: We retrospectively isolated 142 patients who underwent access above the eleventh rib during PCNL, which we term "high supracostal renal access." We then compared these patients to 113 individuals who underwent access below the twelfth rib. Renal access was achieved by the operative surgeon with fluoroscopic guidance in conjunction with pre-operative computed tomography (CT) scan. Outcomes were compared. Results: Overall surgical outcomes were equivalent when comparing high supracostal versus subcostal access sites. As expected due to proximity, pleural complications occurred in 4% of the high supracostal group (n = 6) compared with 0% of the control (subcostal) group (p = 0.035). Of these six complications, three were managed conservatively with observation and two required cardiothoracic intervention with video-assisted thoracoscopic pleural repair (1%). In the remaining case, the patient was preoperatively consented for placement of a thoracostomy tube, which was placed during the procedure, due to the difficult location of her upper pole stone and closely adjacent low-lying pleura, and the planned transpleural approach. Hospital stay was not significantly prolonged between the high supracostal access and subcostal access groups, with an average length of

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stay of 2.2 ± 2.1 days and 2.0 ± 1.9 days (p = 0.59) respectively. Conclusions: Careful, systematic preoperative planning based on CT and fluoroscopic imaging allows for a confident understanding of a "safety zone" in placement and dilatation of renal access points during PCNL. We have shown that planned upper pole renal access above the 11th rib is achievable with acceptable morbidity and excellent success rates.

Keywords

Percutaneous Nephrolithotomy, Calculi, Endoscopic Surgical Procedure

1. Introduction

Percutaneous nephrolithotomy (PCNL) is a minimally invasive surgical option for the treatment of large renal stone burden including renal calculi greater than 20 mm, staghorn calculi, upper ureteral calculi not amenable to retrograde approach, lower pole calyceal stones greater than 10 mm, and diverticular stones [1]. Gaining percutaneous access and entering the appropriate calyx are critical to the procedure [2]. The access directly relates to the ease of the procedure and subsequent success of stone clearance [3] [4]. The anatomy of the kidney often favors an approach through the superior calyx [4]. Common approach to PCNL access is below the 12th rib, however some cases have better success via a supracostal approach. Historically, urologists have preferred a subcostal approach (usually lower pole), often using interventional radiology to obtain access. This avoids pleural complications associated with supracostal access [2] [4]-[8]. However, a subcostal or lower pole approach can result in suboptimal access and reduced stone clearance [9]. Careful preoperative and intraoperative planning by an experienced surgeon can be performed to determine the renal access site(s) most advantageous for stone extraction. At times, the optimal position and angle of entry requires an approach above the costal margin, such as above the 12th rib [2] [4] [10]. Most of the older literature evaluates safety of the upper pole renal access over the 12th rib, through the 11th intercostal space [3] [11] [12] [14]-[16]. Much of the published literature advises against supracostal access unless other options are available [2] [11] [12]. Recent studies and publications have evaluated the safety and efficacy of supracostal PCNL access, usually above the 12th rib. Most have concluded that supracostal access has a slightly increased, but manageable morbidity and an unchanged patient mortality [3] [11].

This study sought to evaluate the two extreme levels of percutaneous renal access above the 11th rib, and below the 12th rib. We hypothesize that access above the 11th rib, which we term "high supracostal renal access" can be safely performed without significant increased risk beyond that of the standard supracostal access given the following two factors: It is performed by an experienced surgeon and CT scans are used to visualize patient specific anatomy ensuring a safety zone for this access. To our knowledge, there are no previous studies that have specifically analyzed access above the 11th rib in performing percutaneous nephrolithotomy. Review of literature using Pubmed and Meta-analysis was performed. Only ten major publications which defined the precise location of supracostal entry were identified, differentiating access above rib 11 or 12 [2]-[5] [11]-[16]. 88 access sites were documented to be consistent with a high supracostal technique (13% of upper pole access) after reviewing a total of 1150 supracostal access resulting in an average of only 8.9 (range 0 - 28) accesses above the 11th rib per author [2]-[5] [11]-[16]. Munver *et al*. [2] reported in 2001 a 35% overall complication rate including a 23% risk of thoracic injury in a series of 26 patients identified to have underwent a supra-11th rib puncture. High supracostal renal access is not routinely performed in the urology community.

2. Materials and Methods

This retrospective review was conducted within a single academic hospital. All data was collected from patients' office charts, operative reports, and electronic medical, emergency department and hospital records. Each patient underwent percutaneous nephrolithotomy from March 2008 to March 2011 with data extending three months preoperative to six months postoperative. All patients' radiographic images were reviewed by a urologist and documentation was based upon the most sensitive modality available per patient. Non-contrast CT is the preferred modality followed by KUB [17]. Post-procedure KUB radiographs were only permitted in patients proven to have radiopaque stones based upon the scout preoperative CT images. All procedures were evaluated without up-front exclusion and each case was conducted by a single experienced endourologist with resident assistance. Patients with positive preoperative urine cultures received antibiotics for approximately one week based on culture sensitivity data.

Excluded patients were those who had dilated percutaneous renal access through the eleventh intercostal space as a solitary access or in conjunction with a lower access. The remainder of the patients included had either percutaneous access above the eleventh rib (with or without additional dilated access) or exclusively below the twelfth rib. 142 patients experienced high supracostal renal access while 113 patients subcostal access (single or multiple). Outcome data was then compared between the two "extreme groups," those at highest and lowest risk for pleural injury after PCNL.

3. Surgical Procedure

Under general anesthesia, with the patient supine, flexible cystoscopy was performed and a 0.035 french Sensor wire (Boston Scientific; Boston, MA) was advanced up the ureter. An open-ended six French ureteral catheter (Cook Biotech; West Lafayette, IN) was placed retrograde over the wire and advanced into the renal pelvis. The patient was repositioned prone and prepped in standard fashion. Percutaneous access was obtained by a single urologic surgeon or under his direct supervision by a resident urologist using fluoroscopy with bedside C-arm and a modified combination approach of triangulation and "bulls-eye" techniques [18]. Renal access was performed after preoperative planning using CT imaging and the creation of a radiograph guided skin template mapping the renal collecting system, rib location, and specific stone location. Preoperative access utilized CT scan to identify the "safe zone of entry," preferred angle of entry to stone location, skin to renal parenchyma measurement, and skin to stone or calyx measurement in order to choose the best approach for stone retrieval. At the time of needle access, the posterior inferior lung border was identified via fluoroscopy. Many procedures required multiple access sites based on size and location of the stone, however no access was placed outside the predetermined safe zone of entry. Once a guide wire was placed into the collecting system, skin incision was performed and the tract dilated using sequential 8 - 10 french dilators (Boston Scientific; Boston, MA). A second wire was placed so that a safety wire could be maintained alongside the working wire. A 30 French 17 cm balloon dilating catheter (Boston Scientific; Boston, MA) was used to further dilate the tract to allow passage of a 30/34 French Amplatz sheath (Boston Scientific; Boston, MA) to maintain the working port for the nephrolithotomy. Standard PCNL procedure was then performed using standard stone fragmentation and extraction techniques. Flexible nephroscopy and antegrade ureteroscopy were always performed to visualize all calyces prior to concluding the case to ensure complete removal or to assess residual burden and iatrogenic trauma. Nephrostomy tube and/or stent was placed if deemed appropriate.

4. Statistical Analysis

Descriptive statistics and univariate analysis was used. Categorical variables were compared using chi-square/ Fishers exact test and continuous variables were compared using two sample t-test. Data was analyzed using SAS (SAS Institute; Cary, NC version 9.2) and all p values < 0.05 were considered statistically significant.

5. Results

High supracostal access with needle puncture and tract dilation initiated above the 11th rib alone or in conjunction with additional access was performed in 142 patients including 62 (43%) men and 80 (56%) women with mean age of 49 +/− 15 (range 20 - 85). The procedure was performed on the left in 65 (45%) patients and the right in 77 (54%). 53 partial or complete staghorn calculi were treated. The average size of the largest stone was 19 mm +/− 12 (range 6 - 67 mm). The mean total unilateral stone burden was 36 mm +/− 31 (range 8 - 190 mm). The majority of cases necessitating PCNL, especially with multiple or high access, had complicated stones such as large staghorn and/or infected calculi.

113 patients underwent subcostal PCNL access below the 12^{th} rib. This included 50 (44%) men and 63 (55%) women with a mean age of 49 +/− 16 (range 10 - 87). The procedure was on the right side in 54 (47%) patients and the left in 59 (52%) patients. 35 partial or complete staghorn calculi were treated. Average size of the largest

stone was 15 mm +/− 8 (range 6 - 60 mm), and the mean total unilateral stone burden was 29 mm +/− 27 (range 6 - 157 mm).

Patient demographic information, co-morbidities, prior urologic stone procedures, and preoperative urine culture were compared (**Table 1**) (**Table 2**), yielding no difference between the two groups.

Operative time, fluoroscopy time, procedural blood loss, and hospital course were compared (**Table 3**). The mean operative time in the high supracostal access (HSA) group is 124.3 minutes (range 42 - 255), which is significantly longer than the subcostal group at 112.6 minutes (range 38 - 217) (p = 0.03). However the average size of the largest stones was 3.03 millimeters greater in the HSA group (p = 0.02) with a greater average total stone burden of 7.0 millimeters (p = 0.06) (**Figure 1**). Blood loss experienced in the HSA group was 45 milliliters (range 20 - 200) compared to 54 milliliters (range 20 - 400, p = 0.19). There was no statistical difference in postoperative length of hospitalization with mean stay of 2.2 +/− 2.0 (range 1 - 13) days for high supracostal and 2.0 +/− 1.9 (range 1 - 13) days for subcostal access.

Table 1. Patient preoperative criteria.

	High Supracostal Access (N = 142)	Subcostal Access (N = 113)	p Value
Age	49 (20% - 85%)	50 (10% - 87%)	0.85
BMI	32 (14% - 66%)	34 (15% - 75%)	0.36
Prior Lithotripsy	41 (29%)	28 (25%)	0.46
Prior Endoscopy	31 (22%)	25 (22%)	>0.99
Pre-op Urine Culture			
Not Done	21 (15%)	15 (13%)	
Negative	92 (65%)	75 (66%)	0.93
Positive	28 (20%)	23 (20%)	

Table 2. Patient cormorbidities.

	High Supracostal Access (N = 142)	Subcostal Access (N = 113)	p Value
HTN	78 (55%)	49 (44%)	0.07
HLD	33 (23%)	22 (19%)	0.47
DM	39 (27%)	20 (18%)	0.07
CAD	11 (7.7%)	8 (7.1%)	>0.99
CHF	2 (1.4%)	0	0.50
TOBACCO	41 (29%)	36 (32%)	0.61
HYPERCALCEMIA	1 (0.70%)	0	>0.99
RECURRENT UTI	19 (13%)	24 (21%)	0.10
CKD	**16 (11%)**	**5 (4.4%)**	**0.048**
COPD	6 (4.2%)	3 (2.6%)	0.74
HYPOTHYROID	**13 (9.1%)**	**20 (18%)**	**0.043**
SPINA BIFIDA	5 (3.5%)	6 (5.3%)	0.54
URINARY DIVERSION	7 (4.9%)	9 (7.9%)	0.32
Prior PCNL	25 (18%)	18 (16%)	0.72

Table 3. Operative parameters.

	High Supracostal Access (N = 142)	Subcostal Access (N = 113)	p Value
Operative Time (min)	**124 +/− 48 (42 - 255)**	**112 +/− 39 (38 - 217)**	**0.03**
Fluoroscopy Time (sec)	79 +/− 66 (39 - 422)	77 +/− 52 (30 - 224)	0.77
Hospital Course (days)	2.2 +/− 2.0 (1 - 13)	2.0 +/− 1.9 (1 - 13)	0.59
Blood Loss (ml)	45 +/− 43 (20 - 200)	54 +/− 56 (20 - 400)	0.19

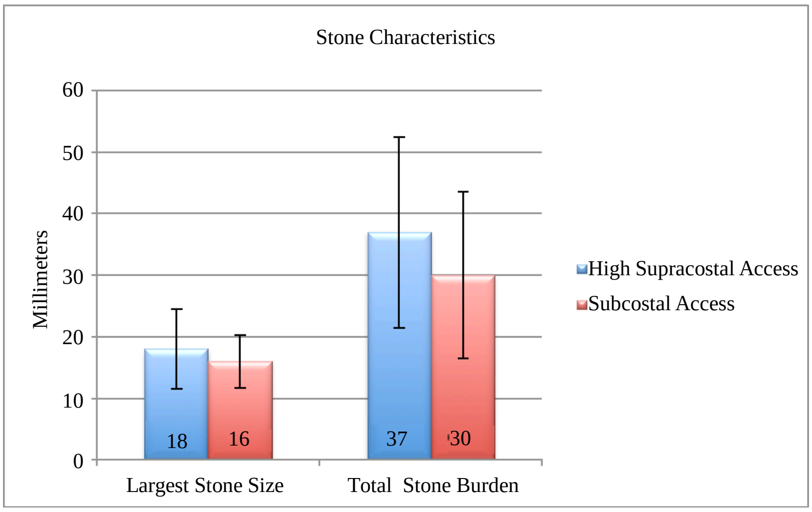

Figure 1. Stone characteristics: showing mean size of largest single kidney stone and total stone burden for the operative kidney, including standard deviation.

Strict criteria were used in determining stone free rates (**Table 4**) with comparative imaging studies in the pre- and postoperative periods. CT was utilized 54% of the time while KUB 46% for radiopaque stones. A complete stone free rate, defined as allowing no visible stone fragments on post-operative imaging, was 82%. A clinical stone free rate, defined as fragments < 2 mm retained, was 87%.

There was no significant difference in the overall complication rate (**Table 5**) or renal function (**Figure 2**) when comparing high supracostal versus subcostal puncture and dilated access sites. Chest X-ray was performed post-operatively after upper-pole puncture only if there was clinical suspicion of pleural or lung injury. Pleural complications were statistically greater with higher level of access, as the overall incidence of clinically significant hydrothorax/pleural effusion was 4% (n = 6) versus 0% in the subcostal puncture ($p = 0.035$). Of these six complications of pleural breach and subsequent hydrothorax, three were managed conservatively with observation and two required cardiothoracic intervention with video-assisted thoracoscopic surgery (VATS) (1.4%, $p = 0.5$). The remaining case required thoracostomy tube because pleural injury was difficult to avoid due to patient's body habitus, anatomy and stone position. The patient consented to chest tube placement pre-operatively and chest tube was placed during procedure. Hospital stay was not significantly prolonged as a result of pleural injury.

Collecting system disruption was significantly more common in the subcostal punctures ($p = 0.04$). These collecting system tears were visualized intraoperatively and diagnosed either endoscopically or by end-procedure nephrostogram. There were 11 (7.8%) collecting system tears in the high supracostal group and 18 (16%) in the subcostal group.

Pararenal postoperative fluid collection was more common in subcostal access, however; this was not statistically significant. Hematoma occurred in 4% (n = 5) of subcostal cases versus 2% (n = 3) in high supra-costal cases ($p = 0.5$). Urinoma developed in 1.7% (n = 2) of subcostal cases versus 0.7% (n = 1) with high supra-costal access ($p = 0.6$). There was a higher rate of both fever and UTI in the high supracostal access at 8% (n = 12) versus 6% (n = 7) ($p = 0.5$). Bacteremia/sepsis (based on ICD-9 diagnostic coding) occurred more in subcostal access group with 5% (n = 6) versus 2% in the high supracostal group (n = 3) ($p = 0.2$), although this difference was not statistically significant. Six of the nine patients had preoperative positive urine cultures requiring treatment. There was a greater rate of blood transfusions in the subcostal access group with 5.3% versus 3.5% in the HSA group ($p = 0.5$). There were nearly equivocal rates of postoperative ileus (1.4% vs 0.88%, $p \geq 0.9$), pneumonia (1.4% vs 1.7%, $p \geq 0.9$), and wound infections (0.7% vs 0%, $p \geq 0.9$) in HSA versus subcostal access. There were no incidents of DVT, PE, myocardial infarction, hepatic or splenic injury, and no visceral organ injury. Death occurred in two patients, each with a complicated history of chronic infections and previous septic admissions, due to post-operative sepsis resulting in cardiopulmonary arrest. Both individuals were poor surgical candidates operated on to address their complex stones that were deemed to be the nidus for recurrent septic admissions.

Table 4. Stone free rates.

	High Supracostal Access (N = 127)	Subcostal Access (N = 103)
Complete Stone Free	104 (82%)	85 (83%)
Clinically Stone Free	112 (88%)	89 (86%)

Table 5. Complications.

	High Supracostal Access (N = 142)	Subcostal Access (N = 113)	p Value
PTX	0	0	NA
Blood Transfusion	5 (3.5%)	6 (5.3%)	0.54
UTI	12 (8.5%)	7 (6.2%)	0.45
Illeus	2 (1.4%)	1 (0.88%)	>0.99
PNA	2 (1.4%)	2 (1.8%)	>0.99
Pleural Effusion (Total)	**6 (4.2%)**	**0**	**0.035**
Pleural Effusion Req VATS	2 (1.4%)	0	0.50
Pleural Effusion Req Thoracotomy Tube	1 (0.70%)	0	>0.99
MI	0	0	NA
Cardiac Arrhythmia	3 (2.1%)	1 (0.88%)	0.63
Minor Pulmonary (Dyspnea)	1 (0.70%)	0	>0.99
Bacteremia/Sepsis	3 (2.1%)	6 (5.3%)	0.19
Wound Infection	1 (0.70%)	0	>0.99
Collecting System Tear	11 (7.8%)	18 (16%)	0.040
Seroma	0	0	NA
Hematoma	3 (2.1%)	5 (4.4%)	0.47
Urinoma	1 (0.70%)	2 (1.8%)	0.59
Respiratory Failure	1 (0.70%)	2 (1.8%)	0.59
Fever	12 (8.5%)	7 (6.2%)	0.50
Urinary Retention	0	2 (1.8%)	0.20
Death	1 (0.70%)	1 (0.88%)	>0.99
DVT/PE	0	0	NA

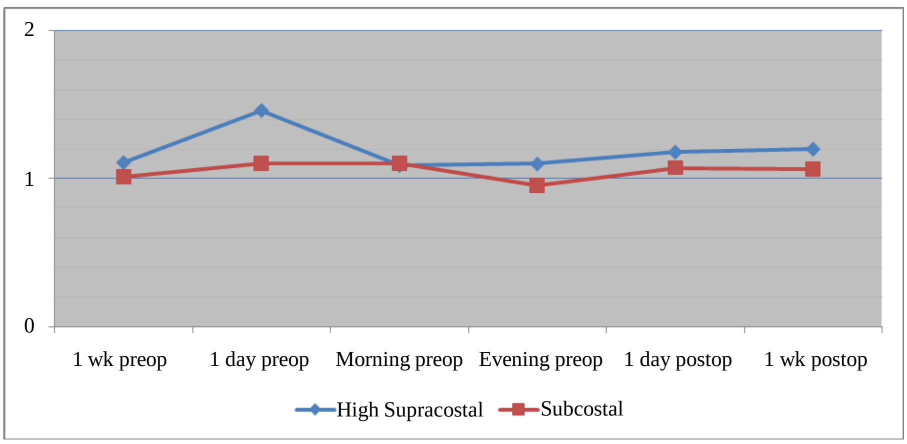

Figure 2. Perioperative renal function: mean serum creatinine levels pre and post op.

6. Discussion

To our knowledge, this is the first study to specifically evaluate the safety and efficacy of the high supracostal access technique above the 11th rib. Traditionally, supracostal renal access is avoided due to increased risk of pleural complication; however, it should not be excluded as a potential access point [7] [8]. In our experience and the experience of others, supracostal access allows a more direct route to the stone thereby decreasing collecting system injury and blood loss while improving procedure efficacy [10]. Upper pole access provides a straight tract along the long axis of the kidney [2] [13], allowing excellent exposure of the superior calyceal, renal pelvic, upper ureteral and lower pole calyceal contents [4] [19]. We observed an increase in iatrogenic trauma to the collecting system and increased blood loss in the subcostal group, and an improved clinical stone clearance rate in the high supracostal group. We believe that the improvement in collecting system tears in the HSA group compared to the subcostal group was due to the favorable angle of entry to the pelvis gained with upper pole access leading to a more direct puncture, less torque on the kidney, and less manipulation for stone extraction.

This study evaluated the two extremes of renal access considered to be at highest and lowest risk, above the 11th rib and below the12th rib [7] [8]. With appropriate training, experience, preoperative planning, and minimal upper pole renal torque/manipulation, these results are reproducible. It is also important to differentiate between clinically significant pleural breach [4] and symptomatic pleural effusion and report these complication rates appropriately to ensure that outcome data does not reflect clinically insignificant pleural findings noted on routinely performed post-operative imaging studies. As we continue to prospectively collect our data we have noted that in the last 100 supracostal accesses performed since this study was conducted, there has been only one pleural complication, which was predicted pre-operatively and managed with a chest tube.

The focus of the planning PCNL access should be less concerned with using the bony anatomy of the ribs as traditional cutanous landmarks and more focused on actual individual internal patient anatomy and the overall best approach for stone access and retrieval. This information is readily available in the preoperative CT imaging. Determination of access point(s) should be based on the stone location and patient anatomy as opposed to the level of costal puncture. Obtaining a percutaneous tract to the mid/upper portion of the renal collecting system without violating the pleura is complicated by the close proximity of the superior margin of the kidneys to the pleural bases [3]. At our institution, careful and systematic preoperative and surgical planning based on CT and fluoroscopic imaging allows for a confident understanding of the "safety zone" in placement and dilatation of access points. Because of this practice, we have observed upper pole renal access routinely placed without significant complications. We have developed a high level of comfort in creation of a tract above the11th and 12th ribs if the thoraco-abdominal anatomy allows.

The advantages of upper-pole access into the renal collecting system include direct access to the upper-pole calyces, ureteropelvic junction, and proximal ureter, and the ability to perform antegrade endopyelotomy for UPJ obstruction if necessary [2]-[4] [10]. In addition, since thorough nephroscopy is possible along the long access of the kidney with upper pole access, less movement of the nephroscope is required and the amount of trauma and bleeding is decreased [2] [3] [5] [10] [13]. Lastly, upper pole access has been shown to be advantageous in the treatment of obese patients and those with horseshoe kidneys [13].

7. Limitations

This single-surgeon retrospective study is subject to inherent biases. The single surgeon's technique evolved over time with gained with time and practice. Secondly, post-operative imaging was not standardized, as some cases utilized CT while others KUB. However, studies have shown that KUB is adequate for following radiopaque stones. Thirdly, nearly all the HSA cases also had additional access in either the mid or lower poles due to the few cases with isolated HSA access. Lastly, it is difficult to determine whether certain complications were associated with creation of the access tract or with the renal surgery itself since these two maneuvers were performed as a single procedure.

8. Conclusion

High supracostal access is a safe and effective option in selected patients and does not carry an unacceptable increase in morbidity when compared to subcostal access. In addition, it is possible to decrease complications with HSA in appropriate patients selected by the evaluation of preoperative imaging. Upper pole access is an excellent option due to better visualization providing a straight tract along the long axis of the kidney [2] [13], increased stone clearance rates, and facilitating an atraumatic approach to the collecting system [4] [13] [16]. The option of accessing a kidney above the costal margin should not be ignored when managing large or complex renal calculi.

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Key of Definitions for Abbreviations

cm = Centimeters
BMI = Body Mass Index
CAD = Coronary Artery Disease
CHF = Congestive Heart Failure
CKD = Chronic Kidney Disease
COPD = Chronic Obstructive Pulmonary Disease
CT = Computed Tomography
DM = Diabetes Mellitus
DVT = Deep Vein Thrombosis
HLD = Hyperlipidemia
HSA = High Supracostal Access
HTN = Hypertension
KUB = Kidneys Ureter Bladder (x-ray)
MI = Myocardial Infarction
Min = Minutes
mL = Milliliters
mm = Millimeters
PCNL = Percutaneous Nephrolithotomy
PE = Pulmonary Embolism
PNA = Pneumonia
PTX = Pneumothorax
SAS = Statistical Analysis System
Sec = Seconds
UPJ = Uretero-Pelvic Junction
UTI = Urinary Tract Infection
VATS = Video-Assisted Thoracoscopic Surgery