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ORIGINAL PAPER

The management of large staghorn renal stones by percutaneous versus laparoscopic versus open nephrolithotomy: a comparative analysis of clinical efficacy and functional outcome

Alireza Aminsharifi[1,2] · Dariush Irani[1] · Mansour Masoumi[1] · Bahman Goshtasbi[1] · Amirhossein Aminsharifi[3] · Reza Mohamadian[1]

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Abstract The objective of this study was to analyze the outcome of percutaneous nephrolithotomy (PCNL), laparoscopic and open anatrophic nephrolithotomy (AN) for management of patients with large staghorn renal stones. We analyzed the peri-operative parameters, overall treatment costs and changes in the function of the affected kidney on technetium-99 dimercaptosuccinic acid renal scintigraphy, done before the operation and before the final follow-up visit, in 45 adults who underwent PCNL ($n = 16$) versus laparoscopic ($n = 15$) versus open ($n = 14$) AN for large staghorn renal stones. All three groups had statistically similar preoperative characteristics, including the function of the operated kidney on renal scan. On the discharge day, the PCNL group had the lowest stone-free rate (43.75 %) compared to the laparoscopic (80 %) and open AN groups (92.85 %) ($P = 0.009$). After a mean follow-up period of 12.1 months, the decrease in the function of the operated kidney was greatest in the open AN group (-8.66 ± 4.97) compared to the laparoscopic AN (-6.04 ± 6.52) and PCNL group (-2.12 ± 2.77) ($P = 0.003$). The need for ancillary procedures to manage residual stones was greatest in the PCNL group and lowest in the open AN group. A similar trend was seen in overall treatment costs ($P < 0.001$). For management of large staghorn renal stones, the more invasive the procedure, the higher the one-session stone-free rate and the lower the need for ancillary procedures; however, greater renal functional loss can be anticipated. The need for ancillary procedures is a major determining factor in the overall cost of treatment, which was highest in the PCNL group.

Keywords Percutaneous nephrolithotomy · Laparoscopy · Nephrolithotomy · Anatrophic nephrolithotomy · Staghorn renal calculi · Renal stone

Introduction

Since the mid-1980s thanks to enormous advances in endourological procedures, the surgical management of renal stones has been revolutionized. Despite these advances, however, the surgical management of large staghorn renal stones remains a challenge.

The American Urological Association guidelines for the management of staghorn calculi recommend percutaneous nephrolithotomy (PCNL) as the modality of choice and standard of practice [1].

Not only the stone burden per se but also the morphology of staghorn renal stones can significantly affect the outcome of PCNL [2–4]. The PCNL study group at the Clinical Research Office of the Endourology Society, in their worldwide study of more than 5300 PCNL procedures, reported a significantly lower rate of stone clearance after PCNL in patients with staghorn (59.9 %) versus non-staghorn renal stones (82.5 %) together with a longer operative time and higher rates of complications in the former group [3]. In staghorn stones, the morphometric characteristics are a major determining factor that influences the outcome of PCNL [2, 4]. This is in contrast to open or laparoscopic nephrolithotomy, which are little affected by

✉ Alireza Aminsharifi
aminsharifi_ar@yahoo.com

1 Department of Urology, Shaheed Faghihi Hospital, Shiraz University of Medical Sciences, Zand Street, P.O. Box 71344, Shiraz, Iran

2 Laparoscopy Research Center, Shiraz University of Medical Sciences, Shiraz, Iran

3 Toronto General Hospital, Toronto, Canada

the morphometric index of staghorn stones. Both open and laparoscopic anatrophic nephrolithotomy (AN) are based on a similar technique but are used in various surgical circumstances. Due to logistic reasons such as the availability of surgical instruments or operating room time, many centers still recommend open AN in patients with a complex-morphology staghorn renal stone [1, 5–7], and many others have proposed laparoscopic AN as a way to replicate the same procedure in a minimally invasive manner [8–13]. At our center we have the chance to offer all three modalities for management of large staghorn renal stones.

In the present study the outcome of PCNL, laparoscopic and open AN for the management of patients with a large staghorn renal stone were analyzed. It was specifically focused on the clinical efficacy of these procedures, their drawbacks, treatment costs and impact on the function of the affected kidney after an intermediate-term follow-up period.

Patients and methods

Ethics

Our institutional review board approved this study and written informed consent was obtained from all patients. The benefits and risks of all three procedures, the higher morbidity of the open procedure, the possible need for open conversion during a laparoscopic procedure, the possibility of premature termination of PCNL or the possible need for multisession PCNL were discussed before each operation.

Patients

During a 5 year period, March 2010–March 2015, 45 adult patients with large staghorn renal stones were prospectively enrolled in the study groups, based on their preference, and their data were analyzed. All patients had a staghorn stone that filled >80 % of the corresponding collecting system. Exclusion criteria were previous history of any abdominal (or ipsilateral flank) surgery or shock wave lithotripsy (SWL), active urinary tract infection, renal anomalies or a solitary kidney, and creatinine level >176.8 μmol/L.

All patients were examined preoperatively with abdominopelvic ultrasonography (US) and intravenous urography (IVU) to evaluate the renal anatomy and stone size (largest diameter). A technetium-99 dimercaptosuccinic acid scintigraphy (99Tc-DMSA) renal scan was done before the operation to document the function of the affected kidney. Renal function and anatomy were evaluated again at the final follow-up visit with 99Tc-DMSA scan and IVU. All patients were admitted one day before their surgery and received light bowel preparation and intravenous Ceftriaxone (1 g every 12 h) so that sterility of the urine was ensured prior to the operation. All open and laparoscopic procedures were done by A. A.; all other PCNL procedures were done by D. I. and B. G. All surgeons were adequately competent for the assigned procedure.

Surgical technique

Percutaneous nephrolithotomy

Standard PCNL was done under general anesthesia with the patient in the prone position. Percutaneous access to the lower calyx was achieved under fluoroscopic guidance, but the surgeons did not hesitate to obtain upper and midpole percutaneous accesses depending on the stone morphology. The tract was dilated up to 28 Fr and a 30-Fr Amplatz sheath was placed. Pneumatic lithotripter was used for stone fragmentation and an 18-Fr nephrostomy tube was placed in each tract after completion of the procedure.

Open and laparoscopic anatrophic nephrolithotomy

The principles of these two procedures were the same but they were used in different surgical approaches, i.e., through a large retroperitoneal intercostal flank incision or four-port transperitoneal laparoscopic surgery. In both techniques, after complete dissection of the renal pedicle the kidney was mobilized within the Gerota fascia. The renal artery was temporary clamped with an atraumatic bulldog clamp. The stone was removed en bloc through a nephrotomy incision over the Brodel line (i.e., about 2 cm posterior to the lateral convex surface of the kidney). The nephrotomy incision was closed with two rows of 2-0 polyglactin running sutures. In the laparoscopy AN group, Hem-o-lok clips (Weck closure systems, Research Triangle Park, NC, USA) were used to reinforce the sutures [8–12]. After the bulldog clamp was released, renal perfusion as well as any bleeding sites from the nephrotomy incision were checked. Thirty minutes before ligation of the renal artery and after its release, 12.5 g mannitol was infused.

Study outcomes

The demographic data of all patients were recorded. Operative data such as operative time and warm ischemia time (WIT) (in the open and laparoscopic AN groups) were also noted. Major intraoperative and postoperative complications (higher than grade 1 according to the Clavien classification [14]) and the need for any ancillary procedures for residual stones were recorded. The amount of bleeding was estimated by comparing preoperative and postoperative hematocrit levels. These values were also measured at the final follow-up visit. The presence and size of residual stones were evaluated by taking plain films and by abdominopelvic US at the time of discharge. The change in renal function in the operated kidney was calculated by subtracting the amount of radionuclide uptake in the 99tc-DMSA renal scan done preoperatively from the same measurement at the final follow-up visit.

For each patient, the overall treatment costs from the time of admission to discharge were recorded. If any secondary admission and ancillary procedure(s) were required, these costs were also added. All expenses were converted to USD using the mean currency exchange rate of each year.

Statistical analysis

Parametric statistical tests were used as long as their assumptions were met. Selected endpoints were compared between the three treatment groups with one-way ANOVA and post hoc analysis (LSD, Boneferroni) or Kruskal–Wallis H tests. To find any differences in parameters within groups, paired *t* test or Wilcoxon test was used. Chi square table and fisher's exact test were used to compare stone-free rates between three groups. SPSS® version 16.0 software was used for all data analyses.

Results

During the study period, 45 patients with large staghorn renal calculi underwent PCNL (n = 16), or laparoscopic (n = 15) or open AN (n = 14). All three groups had statistically similar preoperative characteristics such as age, body mass index, stone size, preoperative hematocrit and creatinine levels, and renal function of the operated kidney on 99Tc-DMSA renal scan (Table 1). Mean operative time was significantly shorter in the PCNL group (79.7 ± 19.2 min) than in the laparoscopic (192.3 ± 38.1 min) or open AN group (183.57 ± 22.2 min) (P < 0.001). Warm ischemia time was significantly longer in the laparoscopic AN group than in the open AN group (31.86 ± 7.46 vs. 20.92 ± 4.95 min) (P < 0.001). One patient in the laparoscopic AN group required packed cell blood transfusion (1 unit), exploratory laparotomy and splenectomy due to splenic injury (grade IIIb complication). Two patients in the PCNL group and three patients in the open AN group needed blood transfusion (2 units of packed cells in the former and 4 units in the latter group). One patient in the open AN group had an episode of unstable angina which was managed medically. None of the patients in the three groups had infectious complications in their postoperative period.

In all three groups there was a significant decrease in hematocrit level 6 h after the operation (Table 2), and this decrease was similar between the three groups (Table 3) (P = 0.07). On the discharge day, the PCNL group had the lowest stone-free rate (=no. patients without any residual stone/total no. of patients in each subgroup) (43.75 %), compared to 80 % in the laparoscopic AN and 92.85 % in the open AN groups (P = 0.009).

Mean residual stone burden on the discharge day was 0.71 ± 2.67 mm (0–10) in the open AN group,

Table 2 Comparison of preoperative versus postoperative values within groups

	PCNL (n = 16)	Laparoscopic AN (n = 15)	Open AN (n = 14)
Hematocrit level mean ± SD (%)			
Preoperative	41.28 ± 5.44	42.6 ± 3.18	41.31 ± 3.68
Postoperative	34.29 ± 5.39	38.0 ± 3.75	34.45 ± 4.57
P value	<0.001	<0.001	<0.001
Function of the operated kidney mean ± SD (%)			
Preoperative	40.35 ± 12.77	47.45 ± 7.45	42.15 ± 9.03
Postoperative	38.22 ± 12.35	41.4 ± 11.57	33.49 ± 9.84
P value	<0.001	<0.001	<0.001

PCNL percutaneous nephrolithotomy, *AN* anatrophic nephrolithotomy

Table 1 Demographic and preoperative characteristics of patients with complete staghorn renal stones

	PCNL (n = 16)	Laparoscopic AN (n = 15)	Open AN (n = 14)	*P* value
Mean age ± SD (years)	48.0 ± 8.57	47.93 ± 9.3	48.21 ± 7.87	0.99
Sex (female/male)	3/13	2/13	3/11	–
Mean body mass index ± SD (kg/m^2)	23.92 ± 2.29	25.18 ± 2.61	26.12 ± 2.46	0.59
Side (left/right)	10/6	12/3	9/5	–
Mean stone size ± SD (mm)	79.06 ± 15.63	69.8 ± 12.19	77.0 ± 14.33	0.17
Mean uptake on preoperative 99Tc-DMSA scan ± SD (%)	40.35 ± 12.77	47.45 ± 7.45	42.15 ± 9.03	0.14
Mean preoperative hematocrit ± SD	41.28 ± 5.44	42.6 ± 3.18	41.31 ± 3.68	0.85
Mean preoperative creatinine ± SD (μmol/L)	99.9 ± 26.5	99.0 ± 23.6	103.4 ± 25.6	0.28

AN anatrophic nephrolithotomy, PCNL percutaneous nephrolithotomy, *99 Tc-DMSA* technetium-99 dimercaptosuccinic acid scintigraphy, *SD* standard deviation

Table 3 Perioperative and postoperative variables in patients with complete staghorn renal stones managed by three modalities

	PCNL ($n = 16$)	Laparoscopic AN ($n = 15$)	Open AN ($n = 14$)	*P* value
	$P < 0.001$			
Mean operative time ± SD (min)	79.7 ± 19.2	192.3 ± 38.1	183.57 ± 22.2	<0.001
		$P < 0.001$		
Mean warm ischemia time ± SD (min)	–	31.86 ± 7.46	20.92 ± 4.95	<0.001
	$P = 0.03$		$P = 0.16$	
Mean postoperative–preoperative function of the operated kidney ± SD (%)	–2.12 ± 2.77	–6.04 ± 6.52	–8.66 ± 4.97	0.003
		$P = 0.001$		
Mean 6 h postoperative–preoperative hematorcrit ± SD	–6.99 ± 2.79	–4.6 ± 3.42	–6.8 ± 4.02	0.07
			$P < 0.001$	
Mean hospital stay (days)	3.56 ± 0.62	3.53 ± 0.91	5.85 ± 1.29	<0.001
		$P < 0.001$		
Mean follow-up period (months)	12.21 ± 2.71	12.13 ± 3.48	12.1 ± 1.89	0.99
Stone composition				
Calcium oxalate	8/16 (50 %)	7/15 (46.6 %)	7/14 (50 %)	
Calcium oxalate + Uric acid	2/16 (12.5 %)	3/15 (20 %)	3/14 (21.4 %)	
Magnesium ammonium phosphate	4/16 (25 %)	4/15 (26.6 %)	3/14 (21.4 %)	
Not available	2/16 (12.5 %)	1/15 (6.67 %)	1/14 (7.1 %)	

PCNL percutaneous nephrolithotomy, *AN* anatrophic nephrolithotomy

2.86 ± 6.89 mm (0–25) in the laparoscopic AN group and 7.21 ± 8.6 mm (0–30) in the PCNL group ($P = 0.01$). On average, 95.34 % of the stone burden was cleared by one-session of open AN, whereas laparoscopic AN cleared 95.34 % and PCNL cleared 91.61 % of the stone burden in one-session ($P = 0.07$).

Mean follow-up period was 12.21 months in the PCNL group, 12.13 months in the laparoscopic AN group and 12.1 months in the open AN group. In all three groups, the function of the operated kidney was significantly reduced at the final follow-up visit (Table 2) and the decrease in renal function was greatest in the open AN group (−8.66 ± 4.97), followed by the laparoscopic AN (−6.04 ± 6.52) and PCNL group (−2.12 ± 2.77) ($P = 0.003$) (Table 3). Renal function preservation was significantly higher in PCNL group in comparison with both laparoscopic and open AN groups, however, the renal function preservation was statistically similar between laparoscopic versus open AN groups (Table 3). There was no correlation between mean WIT and mean stone size, or between either of these two parameters and the decrease in the function of the affected kidney. All renal units were completely functional at the final follow-up IVU study, with significant relief of obstruction in all patients.

The need for ancillary procedures to manage residual stones was greater in the PCNL group (6 sessions of SWL and 3 sessions of re-PCNL), whereas in the laparoscopic AN group 2 sessions of SWL and 1 session of PCNL were required as ancillary procedures. In the open AN group 1 patient required 1 session of adjuvant SWL. All patients became stone-free after these ancillary procedures. Therefore, the need for ancillary procedures is inversely related to the invasiveness of the stone surgery technique.

A similar trend was seen in the overall treatment costs in each of the three groups (571.7 ± 154.6 USD in the PCNL group, 479.2 ± 116.7 USD in the laparoscopic AN group, and 426.8 ± 47 USD in the open AN group) ($P < 0.001$).

Discussion

In the last three decades the surgical management of renal stones has been dramatically transformed owing to tremendous improvements in endourologic procedures. At centers of excellence, the use of open stone surgery (OSS) has fallen to less than 5 % of all cases [15]. Despite these advances, the management of large staghorn renal stones remains challenging due to their specific morphometry and natural course (i.e., a high rate of recurrence and infection-related complications) [1]. In the modern era of minimally invasive management strategies, SWL, PCNL and laparoscopy have been used to manage large staghorn renal stones, and PCNL has become the standard of care with which all other modalities should be compared [1, 16]. In their 17 year analysis of 773 patients with staghorn renal stones who were managed with "multiperc" PCNL, Desai et al. found that PCNL for staghorn stones requires special training and experience. After multisession PCNL procedures, the stone clearance rate increased gradually from 81 to 93 % as experience accumulated [17].

It recently became evident that the outcome of PCNL monotherapy for these stones is influenced by their morphometric characteristics [2, 4]. With a higher stone burden and morphometric class, multiple tracts and multiple sessions of PCNL or multimodal therapy are usually required. Akman et al. evaluated the long-term outcome of PCNL monotherapy for staghorn stones in 272 kidneys. They found a one-session stone-free rate of 76.5 %, and in almost 80 % of their patients renal function improved or remained stable after a mean follow-up period of 37.3 months. However, stone recurrence (31.2 %) and growth (63.2 %) were challenges in their series [18]. Similar promising results with both single- and multiple-tract PCNL in terms of the preservation of the kidney function have been reported in other series [19, 20]. Function as determined with radionuclide renal scans improved or remained stable in 84–100 % of these kidneys after long-term follow-up. However, multitract PCNL may be associated with a higher rate of major complications than single-tract PCNL (28.4 vs. 13.9 %) [21], and as many as 18–27 % of patients may need blood transfusion after PCNL for staghorn stones [19, 22].

In contrast to PCNL, the outcome of AN does not seem to be affected by the morphometric characteristics of the staghorn stone. Therefore, many centers still consider open AN [1, 5–7, 23, 24] and laparoscopic or robot-assisted AN [8–13] as suitable alternative modalities for these patients. The one-session stone-free rate after open AN ranges from 80 to 100 % according to various studies [1, 5, 12], and stone-free rates after laparoscopic AN have improved from 60 % in an initial series [8] to between 80 and 90.9 % in more recent studies [9, 11, 12]. Renal ischemia and its associated functional impairment have traditionally been a major concern during AN for staghorn stones. Although renal function generally improves after AN relieves the obstruction, several studies have reported losses of function between 7 and 27 % after open or laparoscopic AN [6, 12, 24].

A few studies have compared the outcome of OSS versus PCNL in patients with staghorn stones. Assimos et al. were the first to compare AN ($n = 10$) with PCNL with or without SWL ($n = 27$) in these patients. Although complications were similar, the more favorable outcome in terms of one-session stone-free rate, shorter hospital stay and lower costs led the authors to recommend AN as a viable option in these cases [25]. In 2000, Rassweiler et al. reported their comparison between the outcome of PCNL + SWL ($n = 186$, 35 cases of large staghorn stones) with their experience with open surgery before the endourology era ($n = 83$, 27 cases of large staghorn stones). While stone-free rate at discharge was significantly higher after open surgery (80 vs. 31 %), these rates converged after a 3 year follow-up period (72 % for open surgery versus 60 % for PCNL + SWL). They found minimally invasive procedures reliable, safe and effective for management of staghorn calculi [26]. In contrast to these studies, Al-Kohlany et al. [27], in a randomized clinical trial, compared the outcome of PCNL ($n = 43$, from single-tract, single-session to multitract multisession) with OSS ($n = 45$, pyelolithotomy in 89 % and AN in 11 % of cases). Stone-free rates (49 % for PCNL vs. 66 % for OSS) and the preservation of renal function (91 % for PCNL vs. 86.7 % for OSS) were similar; however, intraoperative complications were significantly more frequent in the OSS group, and these patients had a longer convalescence and recovery period [27]. As noted, in contrast to the present study, the OSS group studied by

Al-Kohlany et al. consisted of a heterogeneous group of patients treated with pyelolithotomy and AN.

In the present study, all currently available modalities for the surgical management of large staghorn renal stones were compared in terms of surgical outcome, effect on renal function and treatment costs. To ensure the homogeneity of the sample, only patients with large staghorn stones were enrolled and interestingly, on average, more than 90 % of the stone burden was cleared by one-session of PCNL. It was found that although a significantly higher stone-free rate could be anticipated after open or laparoscopic AN compared to PCNL (92.85 % for open AN, 80 % for laparoscopic AN, 43.75 % for PCNL), in contrast, mean renal function loss was significantly lower in the PCNL group (−2.12 % for PCNL, −6.04 % for laparoscopic AN, −8.66 % for open AN). Therefore, the more invasive the procedure, the higher the stone-free rate but the greater the functional loss.

Difficulties during laparoscopic AN such as the 2-dimensional view of the laparoscopy, lack of tactile sensation, problems with localization of the Brodel line and longitudinal instead of radial nephrotomy make it a challenging procedure in comparison with open AN. Unsurprisingly, WIT was significantly lower during open AN than during laparoscopic AN. However, no correlation between WIT and the decrease in renal function after the operation was found. Moreover, despite the shorter WIT in open AN, the degree of functional loss was similar in open and laparoscopic AN. Although the small sample size of both groups precludes drawing of any definite conclusions, the process of preconditioning during laparoscopic procedures may have played a role in protecting the kidney against a longer WIT [28].

In consonance with previous studies, more than half of the patients in our PCNL group required ancillary procedures for their residual stones, which led to an overall higher cost of treatment. In other words, procedures that are not affected by the morphometric characteristics of the stone may incur lower costs to health care systems. It is noteworthy that we did not use flexible scopes during PCNL which might have affected the overall stone-free rate. The results of our 3-arm comparative study showed that in terms of stone-free rate, costs and renal function loss, laparoscopic AN can be considered a potentially good trade-off procedure between the "least invasive" endoscopic PCNL procedure of and the "maximally invasive" open AN technique. However, given the high rate of recurrence in patients with staghorn stone, invasive procedures such as anatrophic nephrolithotomy may make future procedures more difficult.

Some limitations of this study should be considered. Like many previous series, the admittedly small sample size in each treatment group is a major limitation. Our small sample sizes reflect the highly selective inclusion criteria for enrolling patients in each treatment group as a means to ensure homogeneity. In the three groups, plain films and US were used for detection of the residual stones despite a more sensitive modality such as computerized tomography scan. Although WIT is a major concern in kidney surgery, the plausible protective effect of pneumoperitoneum and preconditioning against ischemia–reperfusion injury during laparoscopy may be significant and deserves further study. Moreover, as several studies have shown, the removal of staghorn stones and resulting relief from obstruction give renal function the best chance to recover, a consideration that may compensate for the detrimental effects of warm ischemia in the long-term. Moreover, in contrast to stone fragmentation in PCNL, during AN the stone can be extracted en bloc. This difference may theoretically result in a lower rate of long- term recurrence and is a topic that merits further investigation. Finally, although there are evidences that the number of surgical procedures is one of the main determinants of the decreased quality of life indices in patients with urolithiasis [29], overall patient satisfaction and quality of life after stone management remain hot topics in the field of complex urolithiasis [30].

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Compliance with ethical standards

Conflict of interest All authors have no conflict of interest.

Ethical approval All procedures performed in this study were in accordance with the ethical standards of the Shiraz University of Medical Sciences research committee and with the 1964 Helsinki declaration and its later amendments.

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References

1. Preminger GM, Assimos DG, Lingeman JE, Nakada SY, Pearle MS, Wolf JS Jr, AUA Nephrolithiasis Guideline Panel (2005) Chapter 1: AUA guideline on management of staghorn calculi: diagnosis and treatment recommendations. J Urol 173:1991–2000
2. Mishra S, Sabnis RB, Desai M (2012) Staghorn morphometry: a new tool for clinical classification and prediction model for percutaneous nephrolithotomy monotherapy. J Endourol 26:6–14
3. Desai M, De Lisa A, Turna B, Rioja J, Walfridsson H, D'Addessi A, Wong C, Rosette On Behalf Of The Croes Pcnl Study Group J (2011) The clinical research office of the endourological society percutaneous nephrolithotomy global study: staghorn versus nonstaghorn stones. J Endourol 25:1263–1268

4. Mishra S, Sabnis RB, Desai MR (2012) Percutaneous nephrolithotomy monotherapy for staghorn: paradigm shift for 'staghorn morphometry' based clinical classification. Curr Opin Urol 22:148–153
5. Matlaga BR, Assimos DG (2002) Changing indications of open stone surgery. Urology 59:490–493
6. Assimos DG (2001) Anatrophic nephrolithotomy. Urology 57:161–165
7. Ramakrishnan PA, Al-Bulushi YH, Medhat M, Nair P, Mawali SG, Sampige VP (2006) Modified anatrophic nephrolithotomy: a useful treatment option for complete complex staghorn calculi. Can J Urol 13:3261–3270
8. Simforoosh N, Aminsharifi A, Tabibi A, Noor-Alizadeh A, Zand S, Radfar MH, Javaherforooshzadeh A (2008) Laparoscopic anatrophic nephrolithotomy for managing large staghorn calculi. BJU Int 101:1293–1296
9. Zhou L, Xuan Q, Wu B, Xiao J, Dong X, Huang T, Chen H, Zhu Y, Wu K (2011) Retroperitoneal laparoscopic anatrophic nephrolithotomy for large staghorn calculi. Int J Urol 18:126–129
10. Giedelman C, Arriaga J, Carmona O, de Andrade R, Banda E, Lopez R, Preminger G, Sotelo RJ (2012) Laparoscopic anatrophic nephrolithotomy: developments of the technique in the era of minimally invasive surgery. J Endourol 26:444–450
11. Simforoosh N, Radfar MH, Nouralizadeh A, Tabibi A, Basiri A, Mohsen Ziaee SA, Sarhangnejad R, Abedinzadeh M (2013) Laparoscopic anatrophic nephrolithotomy for management of staghorn renal calculi. J Laparoendosc Adv Surg Tech 23:306–310
12. Aminsharifi A, Hadian P, Boveiri K (2013) Laparoscopic anatrophic nephrolithotomy for management of complete staghorn renal stone: clinical efficacy and intermediate-term functional outcome. J Endourol 27:573–578
13. King SA, Klaassen Z, Madi R (2014) Robot-assisted anatrophic nephrolithotomy: description of technique and early results. J Endourol 28:325–329
14. Clavien PA, Barkun J, de Oliveira ML, Vauthey JN, Dindo D, Schulick RD, de Santibañes E, Pekolj J, Slankamenac K, Bassi C, Graf R, Vonlanthen R, Padbury R, Cameron JL, Makuuchi M (2009) The Clavien-Dindo classification of surgical complications: five-year experience. Ann Surg 250:187–196
15. Hruza M, Schulze M, Teber D, Gözen AS, Rassweiler JJ (2009) Laparoscopic techniques for removal of renal and ureteral calculi. J Endourol 23:1713–1718
16. Tu¨rk C, Knoll T, Petrik A, Sarica K, Straub M, Seitz C (2012) EAU guidelines on urolithiasis, European association of urology. Available at: http://www.uroweb.org/gls/pdf/20_Urolithiasis_LR%20March%2013%202012.pdf
17. Desai M, Jain P, Ganpule A, Sabnis R, Patel S, Shrivastav P (2009) Developments in technique and technology: the effect on the results of percutaneous nephrolithotomy for staghorn calculi. BJU Int 104:542–548
18. Akman T, Binbay M, Kezer C, Yuruk E, Tekinarslan E, Ozgor F, Sari E, Aslan R, Berberoglu Y, Muslumanoglu AY (2012) Factors affecting kidney function and stone recurrence rate after percutaneous nephrolithotomy for staghorn calculi: outcomes of a long-term followup. J Urol 187:1656–1661
19. El-Nahas AR, Eraky I, Shokeir AA, Shoma AM, El-Assmy AM, El-Tabey NA, El-Kappany HA, El-Kenawy MR (2011) Long-term results of percutaneous nephrolithotomy for treatment of staghorn stones. BJU Int 108:750–754
20. Moskovitz B, Halachmi S, Sopov V, Burbara J, Horev N, Groshar D, Nativ O (2006) Effect of percutaneous nephrolithotripsy on renal function: assessment with quantitative SPECT of (99 m)Tc-DMSA renal scintigraphy. J Endourol 20:102–106
21. Akman T, Sari E, Binbay M, Yuruk E, Tepeler A, Kaba M, Muslumanoglu AY, Tefekli A (2010) Comparison of outcomes after percutaneous nephrolithotomy of staghorn calculi in those with single and multiple accesses. J Endourol 24:955–960
22. El-Nahas AR, Eraky I, Shokeir AA, Shoma AM, el-Assmy AM, el-Tabey NA, Soliman S, Elshal AM, el-Kappany HA, el-Kenawy MR (2012) Factors affecting stone-free rate and complications of percutaneous nephrolithotomy for treatment of staghorn stone. Urology 79:1236–1241
23. González J (2011) Anatrophic nephrolithotomy: is it really an obsolete procedure. Arch Esp Urol 64:289–296 **(abstract)**
24. Kijvikai K, Leenanupunth C, Sirisriro R, Lertsithichai P (2004) Comparative study of renal function between standard and modified anatrophic nephrolithotomy by radionuclide renal scans. J Med Assoc Thai 87:704–708
25. Assimos DG, Wrenn JJ, Harrison LH, McCullough DL, Boyce WH, Taylor CL, Zagoria RJ, Dyer RB (1991) A comparison of anatrophic nephrolithotomy and percutaneous nephrolithotomy with and without extracorporeal shock wave lithotripsy for management of patients with staghorn calculi. J Urol 145:710–714
26. Rass weiler J, Renner C, Eisenberger F (2000) Management of staghorn calculi: critical analysis after 250 cases. Braz J Urol 26:463–478
27. Al-Kohlany KM, Shokeir AA, Mosbah A, Mohsen T, Shoma AM, Eraky I, El-Kenawy M, El-Kappany HA (2005) Treatment of complete staghorn stones: a prospective randomized comparison of open surgery versus percutaneous nephrolithotomy. J Urol 173:469–473
28. Adamy A, Favaretto RL, Nogueira L, Savage C, Russo P, Coleman J, Guillonneau B, Touijer K (2010) Recovery of renal function after open and laparoscopic partial nephrectomy. Eur Urol 58:596–601
29. Bensalah K, Tuncel A, Gupta A, Raman JD, Pearle MS, Lotan Y (2008) Determinants of quality of life for patients with kidney stones. J Urol 179:2238–2243
30. Keeley FX Jr, Assimos DG (2009) Clinical trials of the surgical management of urolithiasis: current status and future needs. Adv Chronic Kidney Dis 16:65–69