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Comparative assessment of multiple-tract vs single-tract percutaneous nephrolithotomy

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Abstract

Introduction: To investigate the efficacy and safety of multi-tract percutaneous nephrolithotomy (PNL) against the benchmark of the single-tract approach.

Methods: A retrospective analysis of 391 consecutive PNL procedures was conducted in our tertiary referral center between April 2016 and March 2020. Clinical outcome parameters such as stone-free rate, operation time, postoperative complications according to Clavien–Dindo, length of hospital stay and time to ipsilateral recurrence resulting in active treatment were assessed.

Results: Multi-tract PNL and single-tract PNL were performed in 37 (9%) and 354 (91%) cases respectively. At baseline, compared to single-tract PNL, multi-tract PNL cases were characterized by significantly larger stone burden (2.62 vs 0.97 cm^3, $P < .00$), lower Hounsfield units (HU) (751 vs 1017 HU, $P < .01$), a more complex S.T.O.N.E. (size, tract length, obstruction, number of calyces, essence) score ($P < .00$) and a higher rate of high-risk stone formers (59 vs 19%, $P < .00$). Analysis of outcome revealed shorter operation time and length of hospital stay for single-tract PNL compared to multi-tract PNL ($P < .01$). However, the difference in terms of stone-free rates (92% vs 88%), complication rates (43% vs 28%) and time to active retreatment due to ipsilateral recurrence was not statistically significant ($P > .05$).

Conclusion: In this retrospective single-center analysis, a multi-tract PNL has been proved to be an efficient and safe expansion of single-tract PNL for large stone burden and complex kidney stone disease. Future prospective research should focus on the procedure's potential effectiveness in reducing the number of interventions until stone-free status in patients with massive stone disease.

KEYWORDS

multiple-tract, percutaneous nephrolithotomy, staghorn calculi

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1 | INTRODUCTION

Percutaneous nephrolithotomy (PNL) is accepted as a first-line treatment modality for staghorn calculi and renal stones of size more than 2 cm.[1,2] Stone formation associated with anatomical abnormalities, diseases, genetic determination and drugs characterizes high-risk stone formers, which have an increased prevalence for formation of multiple calculi, large stone burden or staghorn stone.[2]

To achieve stone-free status in patients with complex stone disease remains a challenging goal. Stone distribution, stone volume, the anatomy of the pelvicalyceal system, comorbidities and the surgeon's experience determine the number of accesses or the number of interventions.[3–5] Due to technical progress of PNL instruments and an increasing surgical experience over the last decades, multiple-tract PNL came into broader use.[6–9] In view of the limited multiple tract literature published so far originating from few high-volume stone centers with highly experienced endourological surgeons, multiple-tract PNL appears to be both well established with proven advantages over single-tract PNL and at the same time underutilized for the fear of complications associated with multiple punctures at one stage.[3,5,7,10–13] Retrospective case series have represented the majority of data on multiple-tract PNL for the last decade.[14–19] Currently an increasing number of retrospective analyses have tried to compare multiple- with single-tract PNL.[8,12,20–22]

However, a larger volume of data on efficacy, safety and follow-up is needed to strengthen the understanding of advantages and limitations of multi-tract PNL against the benchmark of the single-tract approach. Therefore, the objective of the current study is to compare safety and efficacy of multiple- with single-tract PNL.

2 | MATERIALS AND METHODS

A retrospective review of all PNL consecutively performed at a single tertiary referral center between March 2016 and March 2020 was conducted. The patient's data were retrieved from the hospital information system. The study adhered to local ethical standards and was approved by the research ethics committee (REC) of Rhineland-Palatinate (REC # 2021–16238).

Each patient received a preoperative computed tomography (CT) scan for measurement of stone burden, assessment of topographic anatomy, therapy planning and stone analysis by Hounsfield units (HUs). Patients' baseline characteristics included gender, age, laterality, stone burden, S.T.O.N.E. (size, tract length, obstruction, number of calyces, essence) score,[23] HUs, high-risk stone formers, prior stone treatment, Charlson comorbidity index (CCI),[24] preoperative hemoglobin and creatinine count. Stone burden was measured in cm^3 which was software-calculated by Sectra's radiologic workstation IDS7 volume measurement tool (Sectra AB, Linköping, Sweden). In case of multiple calculi volumes were added up. Patients were characterized as high-risk stone formers following the definition of the European Association of Urology guidelines on urolithiasis.[2] CCI was analyzed as a categorical variable. The PNL systems used had sheath diameters of 16.5/17.5 F and a 12 F nephroscope (MIP M series, Karl Storz, Tuttlingen, Germany). Stones were disintegrated by pneumatic lithotripsy (Swiss Lithoklast, E.M.S. Electro Medical Systems, Nyon, Suisse). Perioperative and clinical outcome parameters were recorded as follows: number of tracts, PNL concomitant with ureterorenoscopy, stone-free status, operation time, 90-day postoperative complications,[25] hemoglobin drop and creatinine increase, postoperative nephrostomy drainage, length of hospital stay (LOS), additional endourological procedures, ipsilateral stone recurrence resulting in endourological retreatment, time to retreatment due to ipsilateral recurrence. Stone-free status was assessed intraoperatively by the surgeon's endoscopic and fluoroscopic view, which was confirmed postoperatively by ultrasound and in cases with nephrostomy drainage also by kidney-ureter-bladder radiography with contrast agent through the nephrostomy tube. Postoperative CT scan was ordered by the surgeon only in cases with impaired endoscopic view or complex pelvicalyceal anatomy. Insertion of a nephrostomy tube was indicated only in cases of intraoperatively proven urinary extravasation, since urinary drainage of the pelvicocalyceal system was standardly protected by leaving the evacuated occlusion ureteral catheter (IMP-medical, Karlsruhe, Germany), in place for 2 days postoperatively. Standard of care (SOC) also included perioperative antibiotic prophylaxis using a third generation cephalosporine, at least 2 days inpatient care postoperatively without analysis of chemical stone composition and the aim to achieve stone-free status in a single stage.

Variables were examined for normal distribution using Lilliefors test. Thus, for descriptive analysis median and interquartile range (IQR) were mandatory. Continuous variables were tested using Wilcoxon–Mann–Whitney *U* test. Categorical variables were analyzed using Chi-square or Fisher's exact test. Kaplan–Meier estimation and log-rank test according to Peto–Pike were used for analysis of time to recurrence. Level of significance was set to <.05. Bias Software (Epsilon, Frankfurt, Germany) was used for statistical analyses.[26]

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TABLE 1 Patients' baseline characteristics of 391 percutaneous nephrolithotomy procedures

Variable	Multi-tract n = 37 (9%)	Single-tract n = 354 (91%)	*P* value
Male	17	234	<.05
Female	20	120	
Left kidney	22	209	1.0
Right kidney	15	145	
Age, y, median [IQR]	53 [39–69]	57 [44–67]	.6
Stone burden, cm^3, median [IQR]	2.62 [1.07–9.99]	0.97 [0.52–1.75]	<.00
Hounsfield units, median [IQR]	751 [544–944]	1017 [682–1259]	<.01
S.T.O.N.E. score			<.00
- Low (4–5), n (%)	0 (0)	39 (11)	
- Moderate (6–8), n (%)	14 (38)	228 (64)	
- High (9–11), n (%)	23 (62)	87 (25)	
High-risk stone formers, n (%)	22 (59)	69 (19)	<.00
- Drugs/diseases associated and genetically determined, n (%)	7 (18)	37 (10)	
- Anatomical abnormalities associated, n (%)	15 (41)	35 (10)	
Prior stone treatment, n (%)	21 (57)	205 (58)	1.0
Charlson comorbidity index, n (%)			.5
- 0-2	17	186	
- ≥3	20	166	
Preoperative hemoglobin	13.6 [12.4–14.8]	14.1 [12.9–15.2]	>.05
Preoperative creatinine	0.89 [0.8–1.16]	0.88 [0.78–1.03]	.5

Continuous variables are presented as median and interquartile range [IQR] S.T.O.N.E., size, tract length, obstruction, number of calyces, essence.

3 | RESULTS

In total, 391 PNL procedures in 357 patients (37 multi-tract and 354 single-tract PNL) were collected. Of these, 37 were multiple-tract and 354 single-tract PNL. Patients' baseline characteristics are presented in Table 1. The group which underwent multiple-tract PNL was characterized by significantly larger stone burden with lower HUs, higher S.T.O.N.E. score, a larger number of high-risk stone formers and a higher proportion of female patients. Both groups represented a highly pretreated population, each with >50% of patients having experienced previous active stone removing treatment ($P > 1.0$).

Outcome parameters of 391 percutaneous nephrolithotomy (PNL) procedures are presented in Table 2. Multi-tract PNLs were characterized by a median of two tracts, ranging from two to six. Multiple-tract PNL demonstrated significantly longer operating room (OR) time, a longer length of hospital stay and a higher rate of postoperative nephrostomy drainage ($P < .01$), whereas stone-free rates and complication rates were not different between groups ($P > .05$). A detailed description of multiple-tract cases is presented in Appendix S1. At a median follow-up of 21.4 months, frequency of and time to ipsilateral stone recurrence resulting in endourological retreatment did not differ between groups ($P > .05$, Table 3).

4 | DISCUSSION

In this retrospective analysis multiple-tract PNL demonstrated equal safety and efficacy compared to the single-tract approach. Significant disadvantages of multiple-tract PNL were a longer OR time, a longer length of hospital stay and a higher rate of postoperative nephrostomy drainage.

Stone treatment has become increasingly sophisticated over the last decades. Multiple-tract PNL has been introduced to be a promising approach to further reduce the necessity for open stone surgery and to potentially reduce the number of endourologic stages in patients with high and complex stone burden.

The patient population, where multiple-tract is a reasonable approach, is characterized by massive stone burden,[8,12,14,20,22] a high number of high-risk stone formers[22,27] and a larger rate of infectious or radiolucent

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TABLE 2 Outcome parameters of 391 percutaneous nephrolithotomy (PNL) procedures

Variable	Multiple-tract n = 37	Single-tract n = 354	*P* value
PNL concomitant with URS, n (%)	13 (35)	110 (31)	0.7
- ECIRS, n (%)	3 (23)	5 (5)	0.04
- Antegrade removal of a ureteral stone / fragment, n (%)	2 (15)	7 (6)	0.2
- Stone push back, n (%)	3 (23)	27 (25)	1.0
- Retrograde removal of a ureteral stone, n (%)	1 (8)	24 (22)	0.5
- Confirmation of stone-free ureter, n (%)	4 (31)	39 (35)	1.0
- Intrarenal repositioning to the lower calyx, n (%)	0 (0)	8 (7)	0.6
Stone-free, n (%)	34 (92)	312 (88)	.7
OR time, h:min [IQR]	2:48 [2:21–3:06]	1:54 [1:32–2:24]	<.00
Postoperative complications, n (%)	16 (43)	98 (28)	>.05
Clavien–Dindo I	8	54	
Clavien–Dindo II	7	23	
Clavien–Dindo IIIa	0	18	
Clavien–Dindo IIIb	0	0	
Clavien–Dindo IV	0	3	
Clavien–Dindo V	1	0	
Postoperative computed tomography, n (%)	2 (5)	22 (6)	1.0
Postoperative hemoglobin drop, mg/dL [IQR]	1.55 [0.95–2.58]	1.2 [0.5–2.0]	>.05
Postoperative creatinine increase, mg/dL [IQR]	0.01 [−0.1–0.16]	0.04 [−0.05–0.14]	.3
Length of hospital stay, d [IQR]	4 [3–6]	3 [2–4]	<.01
Ancillary endourological procedures due to residual stone burden, n (%)	2 (5)	28 (8)	.8
SWL	0	1	
URS	0	15	
ECIRS	0	8	
PNL	2	4	
Postoperative nephrostomy drainage, n (%)	20 (54)	91 (26)	<.01

Multi-tract PNLs were characterized by a median of two tracts, ranging between two and six tracts. Continuous variables are presented as median and interquartile range [IQR] ECIRS, endoscopic combined intrarenal surgery; OR, operating room; SWL, shock wave lithotripsy; URS, ureteroscopy.

TABLE 3 Follow-up data of 391 percutaneous nephrolithotomy (PNL) procedures

Variable	Multi-tract n = 37	Single-tract n = 354	*P* value
Ipsilateral stone recurrence resulting in endourological retreatment	3 (8)	15 (4)	.5
Mean time to retreatment due to ipsilateral stone recurrence, mo	42.6	45.5	.2

stones[22] and our data are in line with these well-described features. Patients who need to undergo PNL are heavily pretreated for urolithiasis, but in our data there was no significant difference between multiple-tract (57%) and single-tract patients (58%). This finding is in line with Huang et al. where urolithiasis pretreatment was found in 51% and 41.5% of patients receiving multiple-tract and single-tract PNL.[22]

Nephrolithometry scores, although well established in general PNL literature, have not been introduced in multiple-tract publications yet. In our multiple-tract group, S.T.O.N.E. score was significantly higher compared to patients who received single-tract PNL, providing once more evidence that nephrolithometry scores by including both stone burden and the patient's anatomy, including number of affected calyces and tract length, appear to be valid tools in indicating the complexity to achieve full percutaneous stone clearance.[28,29] Interestingly, our data demonstrated a significant predominance of female patients in the multiple-tract group (1.2:1.0) although gender distribution female-to-male of the whole cohort was 1.0:1.8. A slight but not significant increase of the share of female patients in multiple-tract cases could also be identified in the data of Huang et al.[22] The high percentage of high-risk stone formers among multiple-tract cases, characterized by congenital or acquired conditions supposed to be equally distributed between men and women, might explain this finding. In the same way, Fei et al. and Zhu et al. presented almost balanced proportions of male and female patients in their multiple-tract series.[15,18]

With regard to perioperative outcome data, comparative studies published so far demonstrated inhomogeneous results. With a high concordance between studies, a longer OR time for multiple-tract was recorded and our data correspond to these findings.[20–22] Furthermore, literature revealed convincing stone-free rates for multiple-tract PNL varying from 78% to 95%,[20,21] whereas single-tract groups had slightly lower clearance rates ranging from 70% to 100%.[20,21] Stone-free rates of our cohorts were in these ranges. To note, only one patient treated with multiple-tract PNL with an enormous initial stone burden of 93.9 cm^3 missed achievement of stone-free status after three stages with three, five and six accesses and a residual stone volume of 0.175 cm^3. Current literature revealed there was a significant difference for the need of ancillary procedures in 53%–57% vs 17–24% of single-tract vs multiple-tract PNL. In contrast, we report relatively low rates of ancillary procedures ranging from 5% to 8% with no significant difference between groups. Currently available literature on multiple-tract PNL lacks structured reporting of complications. Bleeding and hemoglobin drop have been reported to be significantly stronger in multiple-tract PNL.[21,22] In our data, although numerically larger, there was no significantly stronger hemoglobin drop in the multi-tract cohort and complication rates did not significantly differ. It is important to note that in contrast to single-tract PNL, complications of multiple-tract PNLs were mainly Clavien–Dindo grades I and II. However, one multiple-tract PNL-related death occurred on postoperative day 6 after refractory hemorrhage with futile radiologic embolization and cardiac arrest during induction of anesthesia for emergency nephrectomy in a 53-year old female patient with a history of urolithiasis-related urosepsis, adrenal insufficiency and multiple severe comorbidities (CCI = 9). Once more, this case emphasizes the importance of unbiased preoperative clinical judgment, whether active stone removing treatment or conservative treatment – if necessary secured by permanent percutaneous urinary drainage – might be a patient's most appropriate option.[30]

Length of hospital stay was significantly longer in our multiple-tract group, which was mostly driven by the higher number of postoperative urinary drainages by nephrostomy tube. Cho et al., by reporting no difference in LOS in a multi-tract cohort of 30 patients, and two current feasibility studies investigating multiple-tract as a day surgery and an overnight surgery, point to the possibility that there is not necessarily the need for a longer LOS for patients with multiple-tract PNL.[8,13,18] However, in view of the critical characteristics of our multiple-tract patients with 54% CCI ≥3 and 59% features of high-risk stone formers, typical PNL-associated hemoglobin drop ≥1 mg/dL and median OR time of nearly 3 hours in general anesthesia, our SOC remains inpatient postoperative care for 2 days.

Another concern addressed by available literature is deterioration of renal function.[20] In line with a bundle of studies representing the majority of published multiple-tract cases, we did not find a significantly different impact of the two approaches on renal function.[8,21,22,31]

Ipsilateral symptomatic recurrence of stone disease has been reported to occur in 15.4% of patients at 21.4 months follow-up.[32] Recurrence rates of our single- and multiple-tract cohort also at a median follow-up of 21.4 months were at lower levels, varying between 4% and 8% respectively, which might be favorably influenced by our institution's standard of postoperative induction of general preventive measures and pharmacological recurrence prevention in cases with great stone burden.

Some limitations of the present study have to be mentioned. With its retrospective nature, the study does not provide randomized head-to-head data. Thus, the questions of reduction of stages by multiple-tract PNL in massive stone burden or complication rates of one stage vs the sum of complications of multiple stages remain unsolved. Since multiple-tract PNL is only relevant in a minority of approximately 10% of PNL patients, the number of cases of the multiple-tract group is relatively small. Summed up, only approximately 379 multiple-tract cases have been reported in five current comparative studies, facing a majority of 1258 single-tract cases.[8,20–22,31] As a consequence, realization of prospective randomized research appears challenging.

However, we feel that with our current work, we add evidence to the important topic of multiple-tract PNL, representing distinct features of urolithiasis patients harboring massive stone burden at a large European tertiary referral

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center. Our data contribute to strengthening the evidence for multiple-tract PNL to be considered as an effective and safe expansion of PNL in those patients who would not achieve stone-free status through only one access.

In this retrospective single-center analysis, multiple-tract PNL proved to be an efficient and safe expansion of PNL for large stone burden and complex kidney stone disease. Future prospective research would be beneficial to further define the procedure's potential effectiveness in reducing the number of stages and its impact on complication rates until stone-free status is achieved in patients with extensive stone disease.

AUTHOR CONTRIBUTIONS

All authors are in agreement with the content of the manuscript. All authors contributed significantly to this work in terms of study concept, collection of data, analyses and statistics and writing, editing and reviewing the manuscript.

CONFLICT OF INTEREST

The authors report no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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