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Super-Pulsed Thulium Fiber Laser-Assisted Retrograde Intrarenal Surgery Is a Viable Alternative to Supine and Prone Percutaneous Nephrolithotomy for Solitary 20–30 mm Renal Stones: Clinical Outcomes, Efficacy, and Safety Analysis

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Abstract

Objective

Percutaneous nephrolithotomy (PCNL) is currently considered the standard treatment for renal stones measuring 20–30 mm. However, recent advances in thulium fiber laser (TFL) technology have expanded the role of retrograde intrarenal surgery (RIRS) in the management of larger stone burdens. This study aimed to compare the efficacy and safety of super-pulsed thulium fiber laser (SP-TFL)-assisted RIRS, supine PCNL (BS-PCNL), and prone PCNL (P-PCNL) for the treatment of solitary renal stones measuring 20–30 mm.

Materials and Methods

This retrospective study included patients who underwent surgical treatment for solitary renal stones measuring 20–30 mm at our institution between January 2020 and March 2026. A total of 260 patients were included: 65 underwent BS-PCNL, 117 underwent prone PCNL, and 78 underwent SP-TFL-assisted RIRS. The primary outcome was the stone-free rate, assessed by low-dose computed tomography (CT) one month after surgery. Secondary outcomes included operative time, hemoglobin decrease, length of hospital stay, and perioperative complications.

Results

Baseline demographic and stone-related characteristics were comparable among the three groups. Operative time was significantly longer in the prone PCNL group (92.4 ± 22.7 min; $p < 0.001$). The first postoperative day stone-free rates were 87.6%, 93.2%, and 78.2% in the BS-PCNL, prone PCNL, and RIRS groups, respectively ($p = 0.009$). However, no significant difference was observed in the final stone-free rates on the one-month CT evaluation (92.3%, 93.2%, and 89.7%, respectively; $p = 0.686$). Hemoglobin decrease was significantly lower in the RIRS group (3.2 ± 2.8, 2.9 ± 2.6, and 0.5 ± 0.4 g/dL; $p < 0.001$). Patients who underwent RIRS also had a shorter hospital stay (1.44 ± 0.77, 1.36 ± 0.68, and 1.12 ± 0.49 days; $p = 0.008$). Intraoperative and postoperative complication rates were comparable across the three groups.

Conclusion

SP-TFL-assisted RIRS is a safe and effective treatment option for solitary renal stones measuring 20–30 mm. Although early postoperative stone-free rates were lower than those achieved with PCNL, comparable one-month stone-free rates, lower blood loss, and shorter hospitalization suggest that SP-TFL-assisted RIRS may represent an effective alternative to PCNL in appropriately selected patients.

Introduction

Kidney stone disease remains a major public health concern because of its lifetime prevalence of 10–15%, high recurrence rates, and substantial healthcare costs [1]. Renal stones measuring 20–30 mm represent a particularly challenging clinical entity, as achieving an optimal balance between a high stone-free rate (SFR) and low treatment-related morbidity remains difficult.

According to the European Association of Urology (EAU) guidelines, percutaneous nephrolithotomy (PCNL) is the recommended first-line treatment for renal stones measuring ≥ 20 mm [1]. Although PCNL has long been regarded as the gold standard because of its excellent stone clearance, it is associated with procedure-related morbidity, including bleeding, injury to adjacent organs, infectious complications, and prolonged hospitalization [2]. As an alternative to conventional prone PCNL, supine PCNL has gained increasing acceptance because of several potential advantages, including improved anesthetic management, the possibility of simultaneous retrograde access, lower intrarenal pressure, and shorter operative time [3, 4].

Over the past decade, technological advances have substantially expanded the role of retrograde intrarenal surgery (RIRS) in the management of renal stones. The introduction of single-use digital flexible ureteroscopes, improvements in ureteral access sheaths, and advances in laser technology have enabled RIRS to be used effectively in patients with larger stone burdens [5]. Although single-session SFRs for stones larger than 20 mm may be lower than those achieved with PCNL, carefully selected patients can achieve satisfactory outcomes, particularly when staged or auxiliary procedures are performed when necessary [6, 7].

For many years, the holmium:yttrium-aluminum-garnet (Ho:YAG) laser has been the standard energy source for intracorporeal lithotripsy. More recently, the thulium fiber laser (TFL) has emerged as a promising alternative because of its higher water absorption, reduced retropulsion, finer stone fragmentation, and greater ablation efficiency [8–10]. Both experimental and clinical studies have demonstrated the advantages of TFL over Ho:YAG laser technology. Nevertheless, evidence comparing the clinical performance of TFL-assisted RIRS with different PCNL techniques, particularly for larger renal stones, remains limited [11].

To the best of our knowledge, no previous study has simultaneously compared super-pulsed thulium fiber laser (SP-TFL)-assisted retrograde intrarenal surgery (RIRS) with both prone and supine percutaneous nephrolithotomy (PCNL) for the treatment of solitary renal stones measuring 20–30 mm. Therefore, this study aimed to compare the stone-free rates, perioperative outcomes, and complication profiles of SP-TFL-assisted RIRS, prone PCNL, and supine PCNL in patients with solitary renal stones measuring 20–30 mm.

Materials and Methods

This retrospective study included consecutive adult patients who underwent prone percutaneous nephrolithotomy (P-PCNL), supine percutaneous nephrolithotomy (BS-PCNL), or super-pulsed thulium fiber laser (SP-TFL)-assisted retrograde intrarenal surgery (RIRS) for solitary renal stones at a single tertiary referral center between January 2020 and March 2026. To minimize operator-related variability, all procedures were performed by the same experienced endourologist. The study protocol was approved by the local ethics committee (Decision No. 2022/12–27) and was conducted in accordance with the principles of the Declaration of Helsinki. Written informed consent for the surgical procedure was obtained from all patients. The choice of surgical technique was based on stone characteristics, surgeon preference, equipment availability, and patient preference after discussion of the advantages and disadvantages of each procedure

Patients with a solitary pelvic or calyceal renal stone measuring 20–30 mm in its longest diameter on preoperative non-contrast computed tomography (CT) were eligible for inclusion. Exclusion criteria were previous renal surgery, age < 18 years, congenital urinary tract anomalies, active or uncontrolled urinary tract infection, coagulopathy, concomitant ureteral stones, incomplete follow-up data, and the need for additional stone-related procedures performed at another institution.

All patients underwent routine preoperative evaluation, including complete blood count, serum biochemistry, coagulation profile, and urine culture. In patients with a positive urine culture, surgery was performed only after successful antibiotic treatment and confirmation of a sterile urine culture. Stone size was determined as the maximum diameter measured on preoperative low-dose non-contrast CT.

The primary outcome was the overall stone-free rate (SFR), assessed by low-dose CT one month after surgery. Stone-free status was defined as the absence of residual fragments or the presence of clinically insignificant asymptomatic residual fragments ≤ 3 mm. Secondary outcomes included operative time, fluoroscopy time, hemoglobin decrease, length of hospital stay, and intraoperative and postoperative complication rates. Intraoperative complications were classified according to the Satava classification, whereas postoperative complications were graded using the modified Clavien–Dindo classification. Operative time was defined as the interval from cystoscope insertion to completion of the surgical procedure. All patients underwent postoperative evaluation with kidney–ureter–bladder radiography and ultrasonography on the first postoperative day, followed by low-dose CT at one month.

Supine PCNL Technique

Supine PCNL was performed using the Barts "flank-free" modified supine position [12]. Approximately 15° of flank elevation was achieved using supports placed beneath the ipsilateral hemithorax and pelvis. Following cystoscopic placement of a 5-Fr ureteral catheter into the ipsilateral ureter, retrograde pyelography was performed. Percutaneous renal access was obtained under fluoroscopic guidance using an 18-gauge access needle (Boston Scientific Corporation, Natick, MA, USA), followed by tract dilation with Amplatz dilators up to 28 Fr. Stone fragmentation was performed using a 24-Fr rigid nephroscope (Karl Storz GmbH, Tuttlingen, Germany) and a pneumatic lithotripter. At the end of the

procedure, nephrostomy tube placement was left to the surgeon's discretion. A 4.8-Fr double-J ureteral stent was inserted in cases of renal pelvic injury or clinically significant residual stones.

Prone PCNL Technique

Prone PCNL was performed in the standard prone position. Renal access, tract dilation, nephroscope, and lithotripsy techniques were identical to those used in the supine PCNL group.

RIRS Technique

All RIRS procedures were performed in the lithotomy position. Following cystoscopic placement of a guidewire into the ipsilateral ureter, a 9.5-Fr ureteral access sheath was advanced under fluoroscopic guidance. A 7.5-Fr digital flexible ureteroscope was then introduced into the collecting system. When necessary, lower pole stones were relocated to a more favorable calyx using a nitinol basket before laser lithotripsy. If advancement of the ureteral access sheath was unsuccessful, a 4.8-Fr double-J ureteral stent was inserted, and the procedure was postponed for 2–4 weeks.

Stone fragmentation was performed using a super-pulsed thulium fiber laser (Quanta Fiber Dust, Quanta System, Samarate, Italy). Dusting was the preferred fragmentation strategy in all cases using low-energy, high-frequency settings (0.1 J and 300 Hz). At the completion of the procedure, a 4.8-Fr double-J ureteral stent was routinely placed in all patients and removed cystoscopically 2–4 weeks later.

Statistical Analysis

Continuous variables are presented as mean ± standard deviation (SD), whereas categorical variables are presented as frequencies and percentages. The distribution of continuous variables was assessed using the Kolmogorov–Smirnov test. Normally distributed variables were compared using one-way analysis of variance (ANOVA), followed by Bonferroni-adjusted post hoc analysis. Variables that did not follow a normal distribution were analyzed using the Kruskal–Wallis test. Categorical variables were compared using the Pearson chi-square test or Fisher's exact test, as appropriate. Statistical analyses were performed using IBM SPSS Statistics for Windows, version 22.0 (IBM Corp., Armonk, NY, USA). A two-sided p value < 0.05 was considered statistically significant.

Results

A total of 260 patients were included in the study: 65 underwent BS-PCNL, 117 underwent prone PCNL, and 78 underwent SP-TFL-assisted RIRS. Baseline demographic and stone-related characteristics were comparable among the three groups. There were no significant differences in age (p = 0.420), sex distribution (p = 0.913), body mass index (p = 0.143), or ASA score (p = 0.833). Likewise, stone size (p = 0.255), stone density (p = 0.485), stone location (p = 0.748), previous stone surgery (p = 0.964), stone opacity (p = 0.393), and the degree of hydronephrosis (p = 0.983) were similar across the groups. Baseline demographic and stone characteristics are summarized in Table 1.

The mean operative time differed significantly among the three groups and was longest in the prone PCNL group (80.2 ± 15.1, 92.4 ± 22.7, and 82.7 ± 17.4 min for the BS-PCNL, prone PCNL, and RIRS groups, respectively; $p < 0.001$). Bonferroni-adjusted post hoc analysis demonstrated significantly longer operative times in the prone PCNL group than in both the BS-PCNL ($p < 0.001$) and RIRS groups ($p = 0.001$), whereas no significant difference was observed between the BS-PCNL and RIRS groups ($p = 0.446$). Fluoroscopy time was comparable among the groups ($p = 0.127$). Double-J stent placement was significantly more frequent in the RIRS group, whereas nephrostomy tubes were used exclusively in the PCNL groups (both $p < 0.001$). According to the Satava classification, intraoperative complication rates were 23.1%, 19.6%, and 12.8% in the BS-PCNL, prone PCNL, and RIRS groups, respectively, with no significant between-group difference ($p = 0.262$). Surgical outcomes are presented in Table 2.

The stone-free rates on the first postoperative day were 87.6%, 92.3%, and 78.2% in the BS-PCNL, prone PCNL, and RIRS groups, respectively ($p = 0.016$). Pairwise analysis showed that this difference was attributable to the comparison between the prone PCNL and RIRS groups ($p = 0.009$), whereas no significant differences were observed between the BS-PCNL and prone PCNL groups ($p = 0.303$) or between the BS-PCNL and RIRS groups ($p = 0.185$). At one month, low-dose CT demonstrated final stone-free rates of 92.3%, 93.2%, and 89.7%, respectively, with no significant difference among the groups ($p = 0.686$).

Among patients undergoing PCNL, stone-free rates after the initial percutaneous access were similar between the BS-PCNL and prone PCNL groups (81.5% vs. 74.3%, $p = 0.359$). A second percutaneous tract was required in 12 patients (18.5%) in the BS-PCNL group and 28 patients (23.9%) in the prone PCNL group. Three patients (2.6%) in the BS-PCNL group additionally underwent endoscopic combined intrarenal surgery (ECIRS).

Postoperative complications, classified according to the modified Clavien–Dindo system, were comparable among the groups. No significant differences were observed in Grade I ($p = 0.923$), Grade II ($p = 0.411$), or Grade IIIa complications ($p = 0.972$).

Hemoglobin decrease differed significantly among the groups and was lowest in the RIRS group (3.2 ± 2.8, 2.9 ± 2.6, and 0.5 ± 0.4 g/dL for the BS-PCNL, prone PCNL, and RIRS groups, respectively; $p < 0.001$). Post hoc analysis demonstrated significantly lower hemoglobin decrease in the RIRS group than in both PCNL groups (both $p < 0.001$), whereas no difference was observed between the BS-PCNL and prone PCNL groups ($p = 0.389$).

The length of hospital stay was significantly shorter in the RIRS group (1.44 ± 0.77, 1.36 ± 0.68, and 1.12 ± 0.49 days for the BS-PCNL, prone PCNL, and RIRS groups, respectively; $p = 0.008$). Pairwise comparisons showed significant differences between RIRS and BS-PCNL ($p = 0.004$) and between RIRS and prone PCNL ($p = 0.013$), whereas no significant difference was observed between the two PCNL groups ($p = 0.430$). The duration of nephrostomy tube placement was similar between the BS-PCNL and prone PCNL groups (1.26 ± 0.56 vs. 1.25 ± 0.69 days, $p = 0.916$). Postoperative outcomes are summarized in Table 3.

Discussion

Renal stones measuring 20–30 mm remain one of the most challenging clinical scenarios in endourology because treatment should provide both a high stone-free rate (SFR) and low procedure-related morbidity. Although current European Association of Urology guidelines continue to recommend percutaneous nephrolithotomy (PCNL) as the first-line treatment for stones ≥ 20 mm [1], recent technological advances have considerably expanded the role of retrograde intrarenal surgery (RIRS). In the present study, we compared SP-TFL-assisted RIRS with both supine and prone PCNL. Our findings demonstrated that although RIRS achieved lower early postoperative SFRs, the final SFR assessed by low-dose CT at one month was comparable among the three treatment modalities. Moreover, SP-TFL-assisted RIRS was associated with significantly lower hemoglobin loss and a shorter hospital stay.

To our knowledge, this is one of the largest comparative studies evaluating SP-TFL-assisted RIRS against both prone and supine PCNL for solitary renal stones measuring 20–30 mm. Although several previous studies have compared conventional PCNL with Ho:YAG-assisted RIRS, direct comparisons of SP-TFL-assisted RIRS with both PCNL approaches remain scarce. Therefore, our findings provide additional evidence regarding the clinical effectiveness and safety of SP-TFL technology in the management of larger renal stones.

Operative time was significantly longer in the prone PCNL group than in both the supine PCNL and RIRS groups. This finding is consistent with previous meta-analyses demonstrating shorter operative times with the supine approach, largely because patient repositioning is avoided, anesthetic management is facilitated, and simultaneous retrograde access can be performed when necessary [13, 14]. Interestingly, operative times were comparable between the supine PCNL and RIRS groups, suggesting that SP-TFL-assisted RIRS can be performed with similar procedural efficiency in appropriately selected patients.

The most important finding of the present study is that the difference in early postoperative SFR disappeared at the one-month follow-up. Although prone PCNL achieved significantly higher SFRs on the first postoperative day, no significant differences were observed among the three groups on low-dose CT performed one month after surgery. This finding has important clinical implications. While PCNL provides superior immediate stone clearance, the high dusting efficiency of SP-TFL appears to facilitate spontaneous passage of clinically insignificant residual fragments, resulting in final SFRs comparable to those achieved with PCNL. Our results are consistent with previous reports demonstrating superior single-session SFRs with PCNL for renal stones measuring 20–40 mm, whereas cumulative success rates become comparable after additional procedures or spontaneous fragment passage [6, 15]. Collectively, these findings suggest that SP-TFL-assisted RIRS may represent a reasonable alternative to PCNL in carefully selected patients with moderate-to-large renal stone burdens.

One of the most clinically relevant findings of this study was the significantly lower hemoglobin decrease observed in the RIRS group. Because RIRS avoids percutaneous renal access, it has consistently been associated with a lower risk of bleeding than PCNL [16–18]. In addition, patients treated with RIRS had a significantly shorter hospital stay, further supporting its lower overall perioperative morbidity. These

advantages may be particularly important for patients at increased risk of bleeding, including those receiving anticoagulant therapy, patients with a solitary kidney, elderly individuals, and those with significant medical comorbidities. Therefore, when clinically appropriate, SP-TFL-assisted RIRS may offer meaningful perioperative benefits without compromising final treatment success.

The introduction of thulium fiber laser technology has substantially improved the efficiency of endoscopic stone surgery. Experimental studies have demonstrated that TFL provides higher stone ablation efficiency, reduced retropulsion, and finer stone fragmentation than the conventional Ho:YAG laser [8–10]. These technical advantages have been supported by several clinical studies reporting high SFRs and favorable safety profiles with TFL-assisted RIRS [19–22]. Nevertheless, concerns have been raised regarding the potential increase in intrarenal temperature during prolonged laser activation [23, 24]. In the present study, no clinical complications suggestive of thermal injury were observed. The routine use of a ureteral access sheath together with low-energy, high-frequency laser settings likely contributed to maintaining adequate irrigation and intrarenal cooling. These findings further support the safety of SP-TFL when appropriate surgical techniques and laser settings are used [25].

The present study has several limitations. First, its retrospective design is inherently subject to selection bias. Second, this was a single-center study, which may limit the generalizability of the findings. In addition, treatment allocation was based on shared decision-making between the surgeon and the patient rather than randomization, introducing the possibility of selection bias despite comparable baseline characteristics among the study groups. We also did not evaluate treatment costs, which may be particularly relevant for RIRS because of the use of disposable instruments. Furthermore, stone composition was not available for analysis and therefore could not be evaluated as a potential confounding factor.

Despite these limitations, the study has several important strengths. To our knowledge, it represents one of the largest comparative series evaluating SP-TFL-assisted RIRS against both prone and supine PCNL for solitary renal stones measuring 20–30 mm. All procedures were performed by a single experienced endourologist, thereby minimizing operator-related variability. Furthermore, all patients underwent low-dose CT one month after surgery to assess stone-free status. Compared with ultrasonography or kidney–ureter–bladder radiography, CT provides a more accurate assessment of residual stone fragments and reduces the likelihood of overestimating treatment success. These methodological strengths enhance the reliability of our findings.

Conclusion

In this study, supine PCNL, prone PCNL, and SP-TFL-assisted RIRS achieved comparable one-month stone-free rates in the treatment of solitary renal stones measuring 20–30 mm. Although early postoperative stone-free rates were higher after PCNL, this difference was no longer evident at the one-month CT evaluation. SP-TFL-assisted RIRS was associated with significantly lower hemoglobin decrease and a shorter hospital stay, indicating a more favorable perioperative safety profile.

These findings suggest that, in experienced centers and with appropriate patient selection, SP-TFL-assisted RIRS represents a safe and effective alternative to PCNL for selected patients with solitary 20–30 mm renal stones while offering the potential advantages of lower perioperative morbidity. Nevertheless, prospective, multicenter, randomized controlled studies are required to confirm these findings and to better define the optimal treatment strategy for different patient populations.

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. The study was approved by the Ethics Committee of Health Sciences University Tepecik Training and Research Hospital (No. 2022/12-27).

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Conflict of interest

The authors have no conflicts of interest to declare that are relevant to the content of this article

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Tables

Table 1. Demographic data and stone characteristics

Parameter	BS-PCNL (n=65)	P-PCNL (n=117)	SP-TFL RIRS (n=78)	P value
Sex (female/male)	25/40	43/74	31/47	0.913[a]
BMI	24.4 ± 2.9	24.8 ± 2.9	23.57 ± 6.4	0.143[b]
Age	43.9 ± 16.2	40.8 ± 14.6	42.1±15.3	0.420[b]
ASA score				0.833[a]
1	45	74	55	
2	17	38	20	
3	3	5	3	
Previous surgery				0.801[c]
ESWL	2	3	3	
URS	3	4	5	
PCNL	4	9	6	
Open surgery	0	0	0	
Stone opacity (opaque/nonopaque)	59/6	100/17	71/7	0.393[a]
Stone density (HU)	949.84 ± 306.7	896.63 ± 272.5	921.76 ± 294.2	0.485[b]
Stone localization				0.748[c]
Lower	25	52	25	
Middle	5	8	7	
Upper	3	4	5	
Pelvis	32	53	41	
Stone size (mm)	22.48 ± 2.5	23.17 ± 2.9	22.8 ± 2.7	0.255[b]
Hydronephrosis (no/mild/severe)	30/30/5	51/56/10	35/38/5	0.983[a]

BMI: body mass index; HU: Hounsfield unit; PCNL: percutaneous nephrolithotomy; RIRS: retrograde intrarenal surgery; URS: ureteroscopy; ESWL: extracorporeal shock wave lithotripsy; ASA: American Society of Anesthesiologists; BS-PCNL: Barts supine percutaneous nephrolithotomy, P-PCNL: prone percutaneous nephrolithotomy and SP-TFL: superpulsed thulium fiber laser

* Bonferroni correction was applied in post-hoc pairwise comparisons (α=0.017).

[a] Pearson Chi-square, [b] One-Way ANOVA, [c] Fisher- exact test

Note: The values are presented as mean+/-SD and n (%).

Table 2. Operative data

Parameter	**BS-PCNL (n=65)**	**P-PCNL (n=117)**	**SP-TFL RIRS (n=78)**	**p value**
Operation side (right/left)	26/39	52/65	29/39	0.844 [a]
Operation time (min)	80.2 ± 15.1	92.4 ± 22.7	82.7 ± 17.4	**<0.001** [b]
Fluoroscopy time (min)	3.53 ± 1.4	3.4 ± 1.2	3,12 ± 1.2	0.127 [b]
Double-J stent placement	4 (6.1%)	9 (7.7%)	78 (100%)	**<0.001** [a]
Nephrostomy placement	61 (93.8%)	108 (92.3%)	0 (0%)	**<0.001**
Intraoperative complications	15 (23.1%)	23 (19.6%)	10 (12.8%)	0.262 [a]
Satava 1	12 (18.5%)	16 (14.0%)	8 (10.2%)	
Satava 2	3 (4.6%)	7 (6.0%)	2 (2.6%)	

BS-PCNL: Barts supine percutaneous nephrolithotomy, P-PCNL: prone percutaneous nephrolithotomy; SP-TFL: superpulsed thulium fiber laser, RIRS: retrograde intrarenal surgery

* Bonferroni correction was applied in post-hoc pairwise comparisons (α=0.017).

[a] Pearson Chi-square, [b] One-Way ANOVA, [c] Fisher- exact test

Note: The values are presented as mean+/-SD and n (%).

Table 3: Post-operative data and complications

Parameter	BS-PCNL (n=65)	P-PCNL (n=117)	SP-TFL RIRS (n=78)	p value
Complications	11 (16.9%)	23 (19.6%)	11 (14.1%)	0.606 [a]
Clavien–Dindo Grade 1	6 (9.2%)	13 (11.1%)	8 (10.3%)	0.926 [c]
Fever	4	9	6	
Creatinine elevation	2	4	2	
Clavien–Dindo Grade 2	4 (6.2%)	8 (6.8%)	2 (2.6%)	0.420 [c]
Blood transfusion	3	6	0	
UTI	1	2	2	
Clavien–Dindo Grade 3a	1 (1.5%)	2 (1.7%)	1 (1.3%)	0.961 [c]
Double-J stent placement	1	1	1	
Angioembolization	0	1	0	
Hemoglobin decrease (g/dL)	3.2 ± 2.8	2.9 ± 2.6	0,5 ± 0,4	**<0.001** [b]
Hospital length of stay (day)	1.44 ± 0.77	1.36 ± 0.68	1,12 ± 0,49	**0.008** [b]
Nephrostomy duration (day)	1.26 ± 0.56	1.25 ± 0.69	-	-
Stone-free after first access	53 (81.5%)	87 (74.3%)	-	-
Second access (PCNL)	12	28	-	-
ECIRS (PCNL)	3	0	-	
Stone-free rates (Postoperative 1. day)	57 (87.6%)	108 (92.2%)	61 (78.2%)	**0.016** [a]
Overall stone-free rates (Postoperative 1. month)	60 (92.3%)	109 (93.2%)	70 (89.7%)	0.686 [a]

BS-PCNL: Barts supine percutaneous nephrolithotomy; P-PCNL: prone percutaneous nephrolithotomy; SP-TFL: superpulsed thulium fiber laser; RIRS: retrograde intrarenal surgery and UTI: Urinary tract infection

* Bonferroni correction was applied in post-hoc pairwise comparisons (α=0.017).

[a] Pearson Chi-square, [b] One-Way ANOVA, [c] Fisher - exact test

Note: The values are presented as mean+/-SD and n (%).