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Ultrasound Guidance to Assist Percutaneous Nephrolithotomy Reduces Radiation Exposure in Obese Patients

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Abstract

OBJECTIVE—To evaluate the impact of body mass index (BMI) on perioperative outcomes and radiation exposure for ultrasound (US)-guided percutaneous nephrolithotomy (PCNL).

PATIENTS AND METHODS—Data were prospectively collected for consecutive patients who underwent PCNL at the University of California, San Francisco, from July 2013 to November 2015. Patients were divided into 3 groups according to their BMI: <25 (normal weight), 25–29.9 (overweight), and >30 (obese) kg/m^2. Perioperative outcomes were compared between patients who underwent US-guided vs fluoroscopy-guided PCNL.

RESULTS—One hundred thirty-five patients were enrolled; 93 cases were performed under US and 42 under fluoroscopic guidance. US successfully guided renal access in 76.9% of normal weight, 79.0% of overweight, and 45.7% of obese patients ($P < .05$). Mean fluoroscopic screening time and radiation exposure dose were reduced for US compared to fluoroscopy cases across all BMI categories ($P < .05$). As BMI increased, radiation exposure dose rose disproportionately faster compared to screening time ($P < .001$). No significant differences among the BMI groups were found with regard to complication rate, hospital stay, and stone-free status.

CONCLUSION—US-guided PCNL may be more difficult in obese patients, but with its use, the overweight and obese experience the largest absolute reduction in radiation exposure. Because these patients are inherently at greater risk for radiation exposure compared to normal weight patients, they may benefit the most from adoption of US for PCNL.

In the United States, over one-third of adults are obese, defined by a body mass index (BMI) greater than 30,[1] and rates of obesity are rising worldwide. Higher stone prevalence has been reported in obese patients,[2,3] and many factors associated with obesity, including hypertension, insulin resistance, and sedentary lifestyles, have been proposed as risk factors[4]. Surgical management of renal stones in obese patients is challenging because of increased perioperative risk factors,[5] compromised visualization of stones with fluoroscopy,

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distorted anatomical landmarks, and inferior extracorporeal shockwave lithotripsy success rates.[6]

Percutaneous nephrolithotomy (PCNL) is the mainstay treatment for patients with renal stones larger than 2 cm or complex stones.[7] The most commonly applied surgical technique for PCNL utilizes fluoroscopy for visualizing the renal stone, establishing renal access, dilating the working tract, and confirming stone clearance. Many studies have demonstrated significantly higher total radiation exposure doses from fluoroscopy in obese patients. Compared to nonobese patients, obese patients are at risk for receiving 2–3 times the ionizing radiation exposure during fluoroscopy due to the higher radiation and energy required to produce the same image quality.[8,9] Surgeons and operating room staff are consequently exposed to higher radiation doses due to increased fluoroscopy time. Furthermore, the risk of exposure to the surgeon and staff may be even higher with obese patients due to increased radiation scatter with increasing tissue thickness.[10–13] Reducing radiation exposure during PCNL for obese patients may therefore be of particular clinical relevance.

The use of ultrasound (US) for PCNL effectively reduces the total ionizing radiation exposure for the procedure[14]; however, its utility in obese patients is thought to be limited because of concerns for poor image quality and difficult probe placement.[15,16] Here, we report our experience with US-guided PCNL in obese patients. The primary aim of this study is to determine how BMI impacts US-guided PCNL, radiation exposure, and perioperative outcomes.

PATIENTS AND METHODS

After approval was obtained from the Institutional Review Board, we prospectively collected data from all consecutive renal stone patients undergoing PCNL at 2 academic medical centers from July 2013 to November 2015. All procedures were performed by a single surgeon who adopted US guidance for renal tract access into their practice in May 2014. No patient was excluded during this study period.

Preoperatively, demographic data including age, sex, BMI, and baseline health status based on American Society of Anesthesiologists classification were obtained from the patients during their initial preoperative clinic visit. Radiologic evaluation prior to surgery included renal US or noncontrast computed tomography. Stone burden was determined by measuring the total stone size, and the degree of hydronephrosis was qualified using the imaging studies.

PCNL was performed prone in all cases. Intraoperatively, a 3.5-MHz convex abdominal transducer (Hitachi Aloka Medical) was used to localize the stone and perform renal access and tract dilation under US guidance. A mobile multidirectional C-arm fluoroscopy unit with an under table X-ray was used for fluoroscopic imaging if US imaging was inadequate for accurate percutaneous renal access or tract dilation. It was also used for nephrostomy tube placement, positional confirmation, and readjustment. Total fluoroscopic screening time and total radiation exposure dose were directly measured from the fluoroscopy unit.

Successful US-guided access was defined as using ultrasonography alone to enter the kidney through a posterior calyx and completing the procedure using this access. Estimated blood loss and total operative time, defined as the time elapsed from initial cystoscopy for stent placement until the placement of the nephrostomy tube at the end of the case, were also recorded. Postoperative outcomes, such as hematocrit change, need for blood transfusion, complications, and duration of hospital stay, were also recorded.

The patients were divided into 3 categories based on BMI (kg/m^2) using World Health Organization standards: <25 (normal weight), 25–29.9 (overweight), and >30 (obese).[17] All data were descriptively stratified by BMI categories using mean, standard deviation, and percentage values. Results of each BMI category were compared to the other BMI categories with the chi-square test for qualitative outcomes such as complication rate and stone-free status. For quantitative outcomes such as operative time and hematocrit change, *t* test and analysis of variance were used. A *P* value <.05 was considered statistically significant. The analyses were performed with STATA 13.1 software (StataCorp, College Station, TX).

RESULTS

A total of 135 patients were enrolled in the study, with 93 cases performed under US and 42 under fluoroscopy guidance. Fluoroscopy cases were consecutively performed between July 2013 and May 2014. After that point, all cases were performed with an attempt at renal access using US guidance. Of these 93 US guidance procedures, the overall mean age was 51.7 years, 55 (59.1%) were female, and 38 (40.9%) were male. Based on BMI categories, 39 (41.9%) patients were of normal weight (mean BMI of 21.4 ± 2.5 kg/m^2), 19 (20.4%) patients were overweight (mean BMI of 26.7 ± 1.5 kg/m^2), and 35 (37.7%) patients were obese (mean BMI of 37.9 ± 9.0 kg/m^2). Based on preoperative imaging, in US-guided cases, the mean stone size was 33.2 ± 22.4 mm, with the majority of renal units demonstrating no or mild hydronephrosis; this was not statistically significantly different compared to patients who underwent fluoroscopy-guided PCNL. Staghorn stones were found in approximately 25% of all cases. Preoperative parameters including age, sex, American Society of Anesthesiologists status, stone laterality, stone location, stone size, and severity of hydronephrosis did not differ between each BMI patient group. These results are summarized in Table 1.

Intraoperatively, percutaneous access was successfully attained in all cases (Table 2). The percentage of access successfully achieved using US decreased significantly in the obese cohort, with successful punctures performed in 76.9% and 79.0% of the normal and overweight groups, respectively, and 45.7% in the obese group ($P < .05$). Mean total operative time was 145.6 ± 48.0 minutes for this US group, which was not statistically significantly different across BMI categories or compared to fluoroscopically guided cases. In both the US and fluoroscopy groups, mean fluoroscopic screening time was steady across BMI categories but showed significant difference compared to fluoroscopic group. However, mean radiation exposure dose significantly increased with increasing BMI in both groups.

To understand how radiation dose changed relative to fluoroscopic screening time as a function of BMI, we calculated the ratio of radiation exposure to fluoroscopic screening time for each case performed with either US or fluoroscopic guidance. These ratios were then plotted with BMI as a continuous variable to see how the ratio changed as BMI increased. As can be seen in Figure 1, this ratio rose steadily for both techniques as a function of increasing BMI, reflective of a disproportionate increase in radiation dose for every unit of increased screening time.

In the postoperative period, only 1 patient required a blood transfusion in each of the US and fluoroscopy groups, which accounts for a 1.1% and 2.4% transfusion rate for each group, respectively. For patients who underwent US-guided PCNL, mean postoperative serum creatinine level was 1.06 mg/dL and mean loss of hematocrit was 3.5%; these 3 parameters did not differ between each BMI group. Postoperative complications occurred in 10 cases (10.8%), the majority of which were categorized as grade 2 complications according to the Clavien-Dindo classification of surgical complications[18]. No differences in surgical complication rates were found among the BMI groups ($P = .99$). Mean hospital stay was 2.9 days without any significant difference among the groups ($P = .42$). Using plain film kidneys, ureters, and bladder radiograph (KUB), renal US, and fluoroscopic nephrostogram imaging performed the first day after surgery, residual stones were seen in 21 cases (22.6%) with no significant difference between the BMI groups ($P = .62$). Nine patients (9.7%) required secondary procedures after PCNL to manage residual fragments and this rate did not significantly vary across the BMI groups ($P = .87$). Postoperative outcomes are summarized in Table 3.

DISCUSSION

Increased intraoperative radiation exposure during PCNLs performed on obese patients is an important point of consideration. Torrecilla Ortiz et al reported the relationship between BMI, fluoroscopic screening time, and radiation exposure dose. Their prospective study of 255 PCNLs performed with fluoroscopic guidance demonstrated that total radiation dose increases along with BMI.[8] Torrecilla Ortiz et al’s study demonstrated an increased radiation dose with increasing BMI despite no significant difference in total fluoroscopic screening time among the BMI groups. Our present study showed the same trend to be the case for patients who underwent either US- or fluoroscopy-guided PCNL. We also repeated our analysis on the total cohort of 135 patients and found, similar to Torrecilla Ortiz et al, that as BMI increased, radiation dose increased ($P < .05$) without a statistically significant change in fluoroscopy screening time ($P = .06$).

We attribute increased radiation exposure rates with increasing BMI despite stable fluoroscopy screening times to automatic exposure rate control. Automatic exposure rate control automatically adjusts the radiation dose to optimize image quality. In obese patients, larger radiation doses are required to penetrate thicker tissues to produce the same image quality[19]. For example, by doubling the tissue thickness, a resultant 10-fold increase in the number of photons is required to produce the same image quality.[20] Thus, for the same amount of fluoroscopic screening time, when performing fluoroscopically guided procedures for obese patients, both patients and intraoperative personnel are exposed to a much higher total radiation doses. Reducing procedural radiation exposure and fluoroscopic screening time for obese patients, therefore, has particularly valuable implications for patients and staff.

With the incorporation of US, our study demonstrated significantly reduced total fluoroscopic screening times and radiation doses across all BMI categories for US-guided procedures compared to traditional fluoroscopy-guided procedures. In addition, when looking across BMI categories within each technique, screening time was unchanged but radiation exposure dose rose steadily with BMI. Taken together, these two findings demonstrate that applying US guidance to PCNL for overweight and obese patients may ultimately have the greatest impact in reducing radiation exposure in the patients and the intraoperative staff. At 38.3 mGy, the absolute reduction of radiation exposure was the greatest in obese patients, from 52.6 to 22.3 mGy, compared to a reduction of 9.5 mGy, from 15.6 to 6.1 mGy, in normal-weight patients. By trending the ratio of radiation exposure dose to fluoroscopic screening time with BMI as a continuous variable in Figure 1, we sought to capture this concept, highlighting the fact that although in obese patients, US-guided percutaneous access may be the most difficult to successfully obtain, these are the patients that may see the greatest benefit in reduced radiation exposure.

Patients in the overweight category warrant particular discussion as they help highlight these concepts. Between overweight and obese patients, success for US-guided puncture decreased from 79% to 46%. To achieve safe percutaneous access in cases where US was unsuccessful, fluoroscopy was used to additionally guide the needle into the kidney. This might partially account for the increased fluoroscopic screening time and radiation dose experienced in the obese compared to the overweight patient group. However, screening time only increased by 20% from 53.8 to 63.2 seconds for US-guided procedures whereas radiation exposure dose nearly tripled from 9.3 to 22.3 mGy. On top of that, despite success rates for US-guided access being similar between the normal and overweight patients, fluoroscopic screening time and radiation exposure were significantly higher in the overweight group compared to the normal-weight group. This patient BMI category illustrates the value of US for reducing radiation exposure as the BMI increases.

From a clinical outcomes perspective, our study is largely aligned with most studies examining the safety of PCNL in obese patients. Prior publications evaluating fluoroscopy-guided PCNL have demonstrated no relationship between BMI and the rate of major postoperative adverse outcomes such as change in hemoglobin, hospital stay, stone-free rate, complication rate, and need for secondary procedures.[8,21–25] The clinical outcomes across BMI groups from our study for procedures performed under both ultrasonographic and fluoroscopic guidance were unchanged. One might expect more complications following PCNL in obese patients due to preoperative comorbidities and intraoperative challenges, but as we, and others, have shown, PCNL can be performed safely and effectively in obese patients.

Our study is unique in that it is the only one of its kind to prospectively evaluate the impact of BMI on outcomes for US-guided PCNL. Applying US guidance to PCNL in obese patients has raised concerns in the past. Inferior visualization of renal and perirenal anatomy in obese patients due to absorption of US energy by thick subcutaneous, paranephric, and perinephric adipose tissue is thought of as a barrier to its adoption and widespread use.[26] Although obtaining successful renal access with US guidance may indeed represent a challenge especially in obese patients, we submit that the gained benefits of significantly reduced radiation exposure are particularly significant in this patient population for both patient and intraoperative staff safety. Furthermore, as the largest absolute radiation reductions are seen in overweight and obese patients, the adoption of US for PCNL may produce the most clinical impact in these cases.

Some limitations should be recognized in our study. Although prospective, our study was observational in nature and therefore naturally occurring demographic differences between BMI subgroups in regard to certain preoperative parameters may have introduced bias into our results. Additionally, our inability to detect statistical significance for some parameters such as fluoroscopic screening time and radiation exposure may be secondary to our small sample size. Also, a technical limitation in our study is that radiation exposure for each patient was an estimate derived from the fluoroscopy machine dose and time of exposure. However, this study represents a starting point for evaluating the adoption of US guidance in obese patients undergoing PCNL along with the associated challenges, pitfalls, and benefits. With ongoing US-guided PCNL data collection at our institutions, we expect to publish follow-up studies with larger cohorts in the future.

CONCLUSION

In our series, using US guidance to assist in PCNL was particularly beneficial for treating obese patients with renal stones. Our institutions' experience demonstrated that complication rates and postoperative parameters were largely unchanged in obese patients undergoing PCNL with US guidance. Across all BMI categories, US-guided PCNL was associated with significantly lower radiation exposures. Importantly, the largest absolute reductions in radiation exposure were seen in overweight and obese patients; therefore, the adoption of US for PCNL may produce the most clinical impact and value in these cases.

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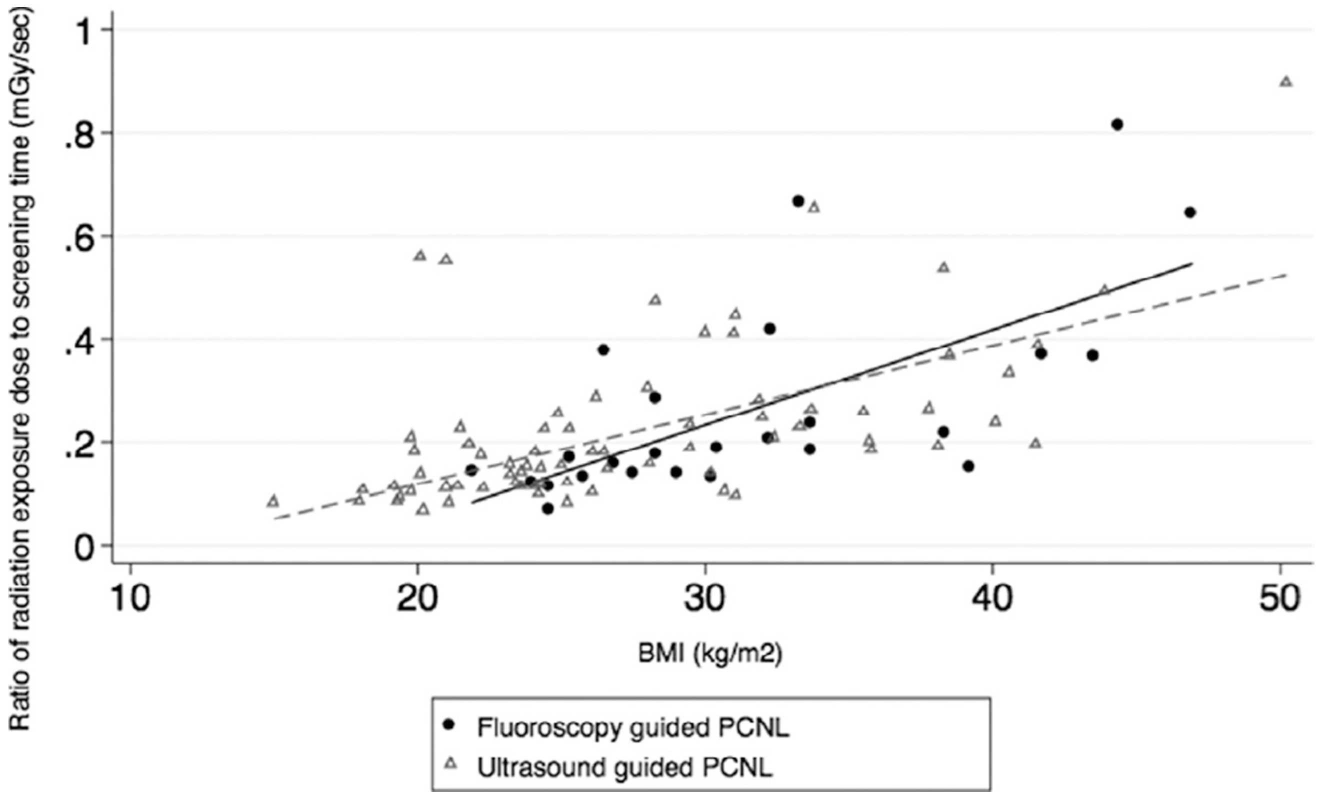

Figure 1.

Correlation between BMI and ratio of radiation exposure dose to fluoroscopic screening time. To examine the rate of change for radiation exposure dose relative to fluoroscopic screening time, a ratio of these two parameters was calculated for each case. These ratios were plotted as a function of BMI as a continuous variable. Cases performed under fluoroscopic guidance are labeled with black circles and cases performed under ultrasound guidance are labeled with white triangles. Linear regression lines for both sets of data are seen as solid black and dashed lines, respectively. The Pearson coefficient of correlation for fluoroscopic cases was $r^2 = 0.45$ and for ultrasound cases $r^2 = 0.33$, with resultant *P* values of <.001 for each.

Table 1

Patient preoperative characteristics

	US Guidance						
Parameters	**Normal Weight (BMI <24.9) N = 39**	**Overweight (BMI 25–29.9) N = 19**	**Obese (BMI >30) N = 35**	***P* Value**	**US Guidance Total n = 93**	**Fluoroscopy Guidance Total n = 42**	***P* Value**
BMI (kg/m^2), mean ± SD (range)	21.4 ± 2.5 (15.0–24.9)	26.7 ± 1.5 (25.0–29.5)	37.9 ± 9.0 (30.0–78.8)	<.05	28.7 ± 9.4	30.4 ± 7.6	.31
Age (years), mean ± SD	51.2 ± 17.1	56.7 ± 13.8	49.7 ± 12.9	.26	51.7 ± 15.0	54.4 ± 13.7	.33
Gender (%)							
Female	25 (64.1)	9 (47.4)	21 (60.0)	.47	55 (59.1)	27 (64.3)	.57
Male	14 (35.9)	10 (52.6)	14 (40.0)		38 (40.9)	15 (35.7)	
ASA status (%)							
Class 1	9 (23.1)	2 (10.5)	2 (5.7)	.17	13 (14.0)	5 (11.9)	.18
Class 2	17 (43.6)	12 (63.2)	15 (42.8)		44 (47.3)	28 (66.7)	
Class 3	13 (33.3)	5 (26.3)	17 (48.6)		35 (37.6)	9 (21.4)	
Class 4	0	0	1 (2.9)		1 (1.1)	0	
Preoperative creatinine (mg/dL), mean ± SD	1.13 ± 0.69	1.00 ± 0.45	0.92 ± 0.32	.25	1.02 ± 0.53	0.91 ± 0.33	.25
Preoperative hematocrit (%), mean ± SD	37.0 ± 6.0	40.6 ± 5.1	39.4 ± 5.7	.07	38.7 ± 5.8	39.1 ± 5.5	.72
Stone laterality (%)							
Left	25 (64.1)	10 (52.6)	15 (42.9)	.19	50 (53.8)	23 (54.8)	.91
Right	14 (35.9)	9 (47.4)	20 (57.1)		43 (46.2)	19 (45.2)	
Stone type (%)							
Caliceal	10 (25.6)	3 (15.8)	9 (25.7)	.11	22 (23.7)	12 (28.6)	.46
Pelvic	6 (15.4)	9 (47.4)	8 (22.9)		23 (24.7)	11 (26.2)	
Staghorn	12 (30.8)	1 (5.3)	13 (37.1)		26 (28.0)	10 (23.8)	
Ureteral	4 (10.2)	2 (10.5)	1 (2.9)		7 (7.5)	6 (14.3)	
Multiple	7 (18.0)	4 (21.0)	4 (11.4)		15 (16.1)	3 (7.1)	
Stone size (mm), mean ± SD	36.9 ± 29.1	23.3 ± 12.1	34.6 ± 15.9	.09	33.2 ± 22.4	32.3 ± 17.5	.80
Degree of hydronephrosis (%)							
None	18 (46.1)	7 (36.9)	15 (42.9)	.59	40 (43.0)	19 (45.2)	.82
Mild	11 (28.2)	10 (52.6)	11 (31.4)		32 (34.4)	12 (28.6)	
Moderate	7 (18.0)	2 (10.5)	6 (17.1)		15 (16.1)	9 (21.4)	

Parameters	US Guidance				US Guidance Total n = 93	Fluoroscopy Guidance Total n = 42	*P* Value
	Normal Weight (BMI <24.9) N = 39	Overweight (BMI 25–29.9) N = 19	Obese (BMI >30) N = 35	*P* Value			
Severe	3 (7.7)	0	3 (8.6)		6 (6.5)	2 (4.8)	

ASA, American Society of Anesthesiologists; BMI, body mass index; SD, standard deviation; US, ultrasound.

Table 2

Intraoperative parameters

Parameters	Normal Weight (BMI <24.9)	Overweight (BMI 25–29.9)	Obese (BMI >30)	*P* Value	Total Cases
Success in puncture with US guidance (%)	30/39 (76.9)	15/19 (79.0)	16/35 (45.7)	<.05	61/93 (65.6)
Operative time (minutes), mean ± SD					
US	144.2 ± 45.7	125.1 ± 30.8	158.8 ± 54.8	.06	145.6 ± 48.0
Fluoroscopy	124.6 ± 41.2	167.2 ± 60.9	155.7 ± 54.7	.17	151.6 ± 55.1
***P* value**	.23	<.05	.85		0.53
Total cases	143.1 ± 49.4	142.7 ± 49.6	160.0 ± 56.1	.20	
Fluoroscopic screening time (seconds), mean ± SD					
US	38.4 ± 34.1	52.8 ± 48.2	63.2 ± 62.9	.15	49.7 ± 49.0
Fluoroscopy	157.8 ± 74.1	132.3 ± 76.1	143.1 ± 65.9	.82	142.6 ± 68.3
***P* value**	<.05	<.05	<.05		<0.05
Total cases	53.7 ± 56.8	80.4 ± 69.4	90.5 ± 73.8	.06	
Radiation exposure dose (mGy), mean ± SD					
US	6.1 ± 6.0	9.3 ± 9.5	22.3 ± 34.0	<.05	12.3 ± 21.8
Fluoroscopy	15.6 ± 8.4	26.1 ± 22.1	52.6 ± 38.5	<.05	38.7 ± 34.1
***P* value**	<.05	<.05	<.05		<0.05
Total cases	7.1 ± 6.9	17.0 ± 18.2	33.2 ± 38.1	<.05	

Abbreviations as in Table 1.

Table 3

Postoperative parameters

Parameters	US Guidance						
	Normal Weight (BMI < 24.9) n = 39	Overweight (BMI 25–29.9) n = 19	Obese (BMI >30) n = 35	*P* Value	US Guidance Total n = 93	Fluoroscopy Guidance Total n = 42	*P* Value
Transfusion requirement, case (%)	0	0	1 (2.9)	.43	1 (1.1)	1 (2.4)	.56
Postop. creatinine (mg/dL), mean ± SD	1.22 ± 0.83	0.88 ± 0.34	0.98 ± 0.34	.09	1.06 ± 0.60	0.94 ± 0.36	.25
Postoperative hematocrit reduction (%), mean ± SD	3.5 ± 5.3	2.3 ± 4.3	4.0 ± 4.5	.48	3.5 ± 4.8	2.8 ± 3.9	.43
Postoperative complication, case (%)	4 (10.3)	2 (10.5)	4 (11.4)	.99	10 (10.8)	3 (7.1)	.51
Hospital stay (days), mean ± SD	3.0 ± 1.2	2.6 ± 0.9	3.0 ± 1.1	.42	2.9 ± 1.1	2.9 ± 1.8	.99
Residual stones, case (%)	11 (28.2)	2 (10.5)	8 (22.9)	.62	21 (22.6)	7 (16.6)	.53
Second procedure requirement, case (%)	3 (7.7)	2 (10.5)	4 (11.4)	.87	9 (9.7)	5 (11.9)	.74

Abbreviations as in Table 1.