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Pneumatic Lithotripsy versus Holmium Laser Lithotripsy in Percutaneous Nephrolithotomy for Patients with Guy's Stone Score Grade IV Kidney Stone

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Keywords
Pneumatic · Lithotripsy · Percutaneous nephrolithotomy · Laser · Staghorn calculus

Abstract
Background and Objective: The aim of this study was to compare the efficacy and reliability of holmium (Ho:YAG) laser lithotripsy (HLL) and pneumatic lithotripsy (PL) in percutaneous nephrolithotomy (PCNL) in the treatment of patients with Grade IV kidney stones based on Guy's Stone Score. ***Study Design/Materials and Methods:*** This retrospective study included 103 patients with Grade IV kidney stones out of 440 patients who underwent PCNL through HLL and PL in Second Affiliated Hospital of Shantou University Medical College, China, from January 2016 to December 2018. We analyzed preoperative, intraoperative, and postoperative variables of the patients to evaluate the efficacy and reliability of PCNL procedures. ***Results:*** Patients were categorized as Grade I, II, III, and IV, and the patients of each grade were 85 (19.32%), 39 (8.86%), 213 (48.41%), and 103 (23.41%), respectively. In Grade IV, the total operative time (min) for the PL and HLL groups was 137.7 ± 47.79 and 134.27 ± 53.38, respectively ($p = 0.744$). The variation in laboratory examination values including ΔHGB (g/L), ΔHCT, ΔPCT, and ΔCr (μmol/L) for PL and HLL groups was 19 ± 11.23/12 ± 15.42 ($p = 0.012$), 0.057 ± 0.034/0.038 ± 0.045 (0.009), 0.027 ± 0.034/0.026 ± 0.034 (0.702), and 3.07 ± 17.4/20.54 ± 65.93 (0.692), respectively. The postoperative hospitalization day was 8.94 ± 4.2 and 7.73 ± 2.75 ($p = 0.015$), respectively. As for the stone-free rate (SFR), the SFRs for PL and HLL were 48.15% ($n = 39/81$) and 59.09% ($n = 13/22$) ($p = 0.363$), respectively. ***Conclusions:*** HLL showed a comparable advantage of not only decreased postoperative hemoglobin and hematocrit but also fewer postoperative hospitalization days. Based on the results of our retrospective study, for those Grade IV kidney stone patients who have a risk of bleeding before PCNL operation, HLL can be a considerable treatment option. Besides, in consideration of reducing human care cost, HLL which showed fewer hospitalization days, would be more welcome by patients.

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Introduction

Kidney stones are common in both China and the USA. They affect 1 in 17 people in China and 1 in 11 people in the USA [1, 2]. In the past 25 years, advances in management of kidney stone disease have been made due to the improvement of treatment modalities [3]. Upper urinary tract calculi are treated with multiple surgical techniques, including extracorporeal shock wave lithotripsy, ureteroscopy, and percutaneous nephrolithotomy (PCNL) [4]. Staghorn renal calculi are one of the most complex upper urinary calculi. They are defined as large stones that occupy the renal pelvis with 1 or more calyceal extensions, and PCNL remains the treatment of choice for staghorn renal calculi [5, 6]. The technique of PCNL has undergone many modifications since its inception. Different methods of intracorporeal lithotripsy are also widely used in PCNL, including pneumatic, electrohydraulic, laser systems, and ultrasound. There are some differences according to their efficacy and applicability among these systems [7]. Nowadays, PCNL could be personalized and tailored to individual patient and surgeon factors [8]. However, it still remains a big challenge for urological surgeons because of the potential high risk of postoperative complication, especially the renal hemorrhage [9].

Therefore, different scoring systems (SS) have been developed for predicting the success rates of PCNL before the operation. Guy's Stone Score, stone size, tract length, obstruction, number of involved calices, and essence/stone density SS and Clinical Research Office of the Endourological Society are frequently used SS, and they have been introduced for clinical evaluation [10–12]. In the recent year, comparisons among different SS have been reported by many clinical researchers, and they have showed that each scoring method has its own advantage in a specific situation. And the Guy's SS remains a simple and easily applicable way compared with the other 2 SS for describing the complexity of PCNLs when pre-estimating the stone-free rate (SFR), stratifying cases between different surgical experience doctors, and reporting postoperative results [13, 14]. It comprises 4 grades, Grade IV is staghorn calculus or any stone in a patient with spina bifida or spinal injury [10]. The objective of this study was to compare the reliability and efficacy of pneumatic lithotripsy (PL) and holmium (Ho:YAG) laser lithotripsy (HLL) in PCNL in the treatment of patients with Grade IV kidney stones based on Guy's Stone Score [15].

Table 1. Classification of patients who underwent PCNL with Guy's Stone Score

Guy's Stone Score grading	Patients, *n* (%)	PL	HLL
Grade I	85 (19.32)	67	18
Grade II	39 (8.86)	29	10
Grade III	213 (48.41)	179	34
Grade IV	103 (23.41)	81	22
Total	440 (100)	356	84

PL, pneumatic lithotripsy; HLL, holmium laser lithotripsy; PCNL, percutaneous nephrolithotomy.

Patients and Methods

This retrospective study included 103 patients with Grade IV kidney stones out of 440 patients who underwent PCNL through HLL and PL in Second Affiliated Hospital of Shantou University Medical College, China, from January 2016 to December 2018. All patients were informed and signed medical informed consent before surgery and agreed to use the information and data for clinical research.

We analyzed preoperative, intraoperative, and postoperative variables of the patients who required PCNL. The preoperative factors studied included age, sex, weight, and presence of comorbidities such as diabetes and hypertension, blood and urine routine, serum Cr level, uric acid, urine culture, and stone size and burden. The imaging examination including urological ultrasound, intravenous pyelogram, and renal computer tomography were done for all patients before starting the procedure for evaluating the stone status. The Guy's Stone Score was used to evaluate the complicacy of PCNL [10]. Stone burden was estimated in mm^2 using the following formula: $\Sigma(0.785 \times \text{Length}_{max} \times \text{Width}_{max})$, the length_{max} and width_{max} of each stone were measured through preoperative imaging examination, mainly according to the renal computer tomography [16]. Intraoperative factors included puncture guidance methods, ASA status, and total operative time. ASA status was assessed by anesthetist before PCNL procedures. Total operative time was defined from the time of cystoscopy for ureteric catheterization till the fixation of the nephrostomy tube. Postoperatively, we analyzed the blood routine, serum creatinine level after surgery within 24 h, stone-free status for stone <4 mm (evaluating from abdominal radiograph of the kidneys, ureters, and bladder performed on the seventh postoperative day), postoperative complications, hospitalization day, and hospitalized and surgical expense. The decrease of postoperative hemoglobin (ΔHGB) and hematocrit (ΔHCT) was used to evaluate the blood loss during the operation. The modified Clavien system is used for grading of complications following PCNL [17].

PCNL was performed under general anesthesia. In bladder lithotomy position, a 5-Fr ureteral catheter was placed into the ipsilateral ureter via ureteroscopy and urinary catheter was inserted. The patient was then repositioned to prone position. Under fluoroscopy-guided, ultrasound-guided, or both guided methods, single percutaneous access was supplied by 18-G needle and J-tipped guidewire was placed into the collecting system over the needle. The tract dilatation was accomplished from an 8-Fr to 20-Fr fascial

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Table 2. Grade IV patient demographics and stone characteristics

Parameters	PL	HLL	*p* value
Number of patients	81	22	
Age, years	55.79±9.79	56.68±9.72	0.809
Sex			
Male	47	12	0.77
Female	34	10	
Weight, kg	56.62±9.31	60.34±8.34	0.882
Stone burden, mm^2	1,384.92±1,144.43	1,330.21±727.86	0.632
Presence of comorbidities, *n*			
Diabetes mellitus	8	5	
Hypertension	23	15	
Preoperative laboratory examination			
Serum Cr, μmol/L	108.08±44.29	134.05±101.81	0.735
Uric acid, μmol/L	388.63±117.89	372.68±96.3	0.908
Positive urine culture, *n*	13	2	

PL, pneumatic lithotripsy; HLL, holmium laser lithotripsy.

dilator, and a 20-Fr Mini-PCNL sheath was placed during the procedure [18]. Later, the hard nephroscope (Richard Wolf) was placed, and stone fragmentation was accomplished using either a pneumatic lithotripter system (Swiss LithoClast2, E.M.S. Electro Medical System S.A., Switzerland) or a holmium laser lithotripter system (Holmium Laser SRM-H3B, Shanghai Raykeen Laser Technology Co., Ltd., Shanghai, China). After stone clearance was completed, we routinely placed a nephrostomy tube for renal drainage and a double J ureteral catheter.

Statistical Analysis

The data were analyzed with Microsoft Excel software and IBM SPSS version 22. We used the χ^2 test for qualitative variables and the Student *t* test for continuous values. Normality was checked before using the *t* test. $p < 0.05$ was accepted as statistically significant.

Results

Classification of Patients with Guy's Stone Score

Patients were categorized as Grade I, II, III, and IV, and the patients of each grade were 85 (19.32%), 39 (8.86%), 213 (48.41%), and 103 (23.41%), respectively (Table 1).

Grade IV Patients' Preoperative Demographics and Stone Characteristics

The number of Grade IV patients in the PL and HLL groups was 81 and 22, respectively. They are 2 heterogeneous groups regarding the number of patients reviewed. The mean patient age (years), male:female ratio, weight (kg), and stone burden (mm^2) for PL and HLL groups were 55.79 ± 9.79/56.68 ± 9.72, 47:34/12:10, 56.62 ± 9.31/60.34 ± 8.34, and 1,384.92 ± 1,144.43/1,330.21 ± 727.86, respectively. The number of patients with diabetes mellitus and hypertension in the PL group was 8 and 23, while it was 5 and 15 in the HLL group, respectively. According to the preoperative laboratory examination, the levels of serum Cr (μmol/L) and uric acid (μmol/L) in the PL and HLL groups were 108.08 ± 44.29/134.05 ± 101.81 and 388.63 ± 117.89/372.68 ± 96.3, respectively. The number of positive urine cultures in the PL group was 13, and 2 in the HLL group (Table 2).

Comparison of Intraoperative Parameters between HLL and PL Groups

The ASA status evaluated by the anesthetist showed the numbers of PL and HLL patients in Level I, II, and III were 4/1, 63/17, and 14/4 ($p = 0.993$), respectively. Four puncture guidance methods, including fluoroscopy-guided, ultrasound-guided, fluoroscopy + ultrasound-guided, and preoperative renal fistula, were used in operation, and the numbers of patients for the PL and HLL groups were 14/1, 21/13, 43/7, and 3/1, respectively. Total operative time (min) for the PL and HLL groups was 137.7 ± 47.79 and 134.27 ± 53.38, respectively ($p = 0.744$). The variation in laboratory examination values, including ΔWBC ($\times 10^9$/L), ΔHGB (g/L), ΔHCT, ΔPLT ($\times 10^9$/L), ΔPCT, and ΔCr (μmol/L) for the PL and HLL groups was 2.79 ± 4.634/1.61 ± 4.69 ($p = 0.082$), 19 ± 11.23/12 ± 15.42 ($p = 0.012$), 0.057 ± 0.034/0.038 ± 0.045 (0.009), 30.94 ± 39.87/21.59 ± 38.42 (0.631), 0.027 ± 0.034/0.026 ± 0.034 (0.702), and 3.07 ± 17.4/20.54 ± 65.93 (0.692), respective-

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Table 3. Comparison of intraoperative and postoperative parameters between HLL and PL

Parameters	PL	HLL	*p* value
ASA status, *n*			
Grade I	4	1	0.993
Grade II	63	17	
Grade III	14	4	
Puncture guidance methods, *n*			
Fluoroscopy guided	14	1	0.026*
Ultrasound guided	21	13	
Fluoroscopy + ultrasound guided	43	7	
Preoperative renal fistula	3	1	
Total operative time, min	137.7±47.79	134.27±53.38	0.744
Variation of laboratory examination			
ΔWBC, $\times 10^9$/L	2.79±4.634	1.61±4.69	0.082
ΔHGB, g/L	19±11.23	12±15.42	0.012*
ΔHCT	0.057±0.034	0.038±0.045	0.009*
ΔPLT, $\times 10^9$/L	30.94±39.87	21.59±38.42	0.631
ΔPCT	0.027±0.034	0.026±0.034	0.702
ΔCr, μmol/L	3.07±17.4	20.54±65.93	0.692
Postoperative hospitalization days, *n*	8.94±4.2	7.73±2.75	0.015*
SFR	48.15% (39/81)	59.09% (13/22)	0.363
Total hospitalized expense (CNY)	18,497.85±8,324.86	20,208.48±7,329.33	0.338
Surgical expense (CNY)	1,122.12±915.03	1,128.6±1,096.08	0.218

PL, pneumatic lithotripsy; HLL, holmium laser lithotripsy; SFR, stone-free rate. * $p < 0.05$.

ly. It showed that the decreases in postoperative hemoglobin and hematocrit were statistically significantly lower in the HLL group.

Comparison of Postoperative Parameters between HLL and PL Groups

Postoperative hospitalization days for the patients who underwent PL and HLL were 8.94 ± 4.2 and 7.73 ± 2.75 ($p = 0.015$). Postoperative hospitalization days were statistically significantly fewer in the HLL group. Total hospitalized expense (CNY) and surgical expense (CNY) for each of the study groups were 18,497.85 ± 8,324.86/20,208.48 ± 7,329.33 ($p = 0.338$) and 1,122.12 ± 915.03/1,128.6 ± 1,096.08 ($p = 0.218$), respectively (Table 3). As for the SFR, the SFRs for PL and HLL were 48.15% ($n = 39/81$) and 59.09% ($n = 13/22$) ($p = 0.363$), respectively.

Seventeen patients in the PL group experienced postoperative complications (complication rate of 20.99%), while only 2 patients in the HLL group had postoperative complications (complication rate of 9.09%) ($p = 0.351$). Three patients in the PL group needed blood transfusion and 1 underwent angioembolization because of renal hemorrhage, while 1 patient in the HLL group also underwent angioembolization due to the postoperative hemorrhage. They have been presented according to the modified Clavien system in Table 4.

Discussion

Urinary stone disease is very common and brings a significant healthcare burden in many countries [1, 6]. Currently, the kidney stone-adjusted prevalence rate was 5.8% in China (about 6.5% in men and 5.1% in women); when adjusted to the 1.1 billion adult population of China, there are about 61.2 million people currently suffering from renal stones [2]. Staghorn calculus is one type of complex renal stones. They are large and branching stones that fill part or all of the pelvicalyceal system and often linked to urease-producing bacterial infections which may cause the formation of struvite infection stones [19]. Many factors may be blamed for staghorn stone formation, including urinary tract infections, urinary tract abnormalities or obstruction, previous surgical history of urinary diversion, long-term use of urethral catheter, and neurogenic bladder pathology [10, 20]. All these factors will increase the difficulty of staghorn stone

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Table 4. Postoperative complications

Modified Clavien system	PL	HLL	*p* value
Complication rate, % (*n*)	20.99 (17/81)	9.09 (2/22)	0.351
Grade 1, *n*			
Fever (>38°C)	12	1	
Grade 2, *n*			
Blood transfusion	3	–	
Grade 3a, *n*			
Renal hemorrhage requiring angioembolization	1	1	
Grade 3b, *n*	–	–	
Grade 4a, *n*			
Neighboring organ injury	1	–	
Grade 4b, *n*	–	–	
Grade 5, *n*	–	–	

PL, pneumatic lithotripsy; HLL, holmium laser lithotripsy.

treatment compared to other kinds of renal stones. Furthermore, patients with staghorn stones were more difficult to achieve a satisfying SFR, and the stone recurrence rate for patients with staghorn stone was 31.2% [21, 22]. As we have mentioned before, different SS have been developed for predicting the success rates of PCNL before the operation. Guy's SS remains a simple and easily applicable way for describing the complicacy of PCNL when pre-estimating the SFR. Patients who have staghorn calculus or any stone in a patient with spina bifida or spinal injury were classified as Guy's Grade IV [10, 13, 14]. Grade IV patients are more challenging to surgeons when they perform the PCNL procedure. About 23.41% renal stone patients included in our study were classified as Grade IV, and further study on this specific patient group would be meaningful and worthy to clinical procedure.

PCNL has been one of the best choices of minimally invasive operation for the treatment of staghorn calculi and complex renal stones since its introduction more than 30 years ago. PCNL numbers were rising in recent years [23]. The most commonly used instruments for fragmentation in PCNLs are pneumatic and Ho:YAG laser lithotripters. Both of them are promising therapeutic methods for stone fragmentation [24]. Nevertheless, further investigations into a comparison of both lithotripsy methods in PCNL in the treatment of patients with staghorn stones, especially comparisons of efficacy, safety, and reliability in Guy's SS Grade IV patients, have not been reported in the literature.

The greatest disadvantage of PL is the physical damage to the mucosa caused by impact of stones during fragmentation. Sometimes it may even cause perforation of the collecting system, and increases the risk of complications like hemorrhage [25, 26]. However, the Ho:YAG laser can develop fragmentation through a photothermal mechanism, which may penetrate the soft tissue only at a 0.5-mm depth [27]. According to our research, patients in the PL group showed a higher rate of complications than those in the HLL group. This was in accordance with Atar et al. [27]. They also found that laser lithotripsy has a lower complication rate in the treatment of pediatric ureteral stones. Hemorrhage is still a common and severe postoperative complication in PCNL. Although most cases of postoperative hemorrhage can be treated conservatively, severe blood loss may require renal arteriography and selective embolization (~0.8%) [9, 28]. According to our study, the decline in postoperative hemoglobin and hematocrit in the HLL group was significantly lower than that in the PL group. Therefore, HLL seems to be safer than PL in dealing with Grade IV patients in PCNL.

Increasingly, healthcare cost is a source of concern to patients, governments, health economists, and the medical profession worldwide [29]. Patients will pay more attention to their hospitalized expense, hospital stays, and human care cost. Although the total hospitalized expense between HLL and PL does not show statistical difference, the postoperative hospitalization days for the HLL group were statistically significantly fewer than those in the PL group. Based on cost-conscious concern, fewer hospitalization days can reduce human care cost, and it would be more welcomed by patients in China.

SFR is very vital in evaluating the PCNL procedure. However, it was still a big challenge for urology surgeons to achieve high SFR in PCNL for patients with high stone

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burden. When Thomas et al. [10] first introduced Guy's Stone Score systems in their research, the SFR for Grade IV patients was only 29%. In an endourological society PCNL global study, PCNL for staghorn stones revealed SFR of 56.9% [21]. El-Nahas et al. [30] had reported the SFRs of PCNL for staghorn stones were 57% for ultrasonic lithotripsy and 60% for HLL. In our study, the SFRs for the PL and HLL groups were 48.15 and 59.09%, respectively. Although the SFR of PCNL for general renal stones can reach more than 90% [8], we still could not achieve a satisfying SFR for Grade IV renal stone patients in our study. It may be related to the following factors. Considering that multiple punctures may cause more bleeding for Grade IV patients, especially for those with severe hydronephrosis and renal insufficiency, or those with positive urine culture before procedure, we applied the single-tract approach to our patient cohort [9]. What is more, the nephroscope we used in PCNL was the traditional hard nephroscope but not the flexible one, so the blind area of the pelvis could hardly be reached during surgery.

There are some limitations to our study. First, we could not get the data on stone composition because we lacked a stone analyzer. It has been reported that the stone composition may affect the fragmentation and operative time for different lithotripsy methods [31, 32]. Second, the short follow-up duration did not allow adequate evaluation of recurrence of stone disease. Last, not enough Grade IV patients were enrolled due to our single-center study. Establishing a better follow-up system, enrolling more patients from multiple centers, and designing a prospective study could be the possible measures to improve our future related study.

Conclusion

In conclusion, comparing the efficacy and reliability of HLL and PL in PCNL in the treatment of patients with Grade IV kidney stones based on Guy's Stone Score, HLL showed comparable advantages of not only decreased postoperative hemoglobin and hematocrit but also fewer postoperative hospitalization days. Based on the results of our retrospective study, for those Grade IV kidney stone patients who have a risk of bleeding before PCNL operation, for example, anemia, severe infection, and hemorrhagic tendency, HLL can be a considerable treatment option. Besides, in consideration of reducing the human care cost, HLL, which showed fewer hospitalization days, would be more welcomed by patients.

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Statement of Ethics

All patients gave their written informed consent, and the study protocol was approved by the Ethics Committee of The Second Affiliated Hospital of Shantou University Medical College.

Conflict of Interest Statement

All authors read and approved the final version of this paper and have no conflicts of interest to declare.

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Author Contributions

Y.H.: concept, design, data collection and processing, writing, and analysis. Q.Y., G.H., and D.Z.: concept and surgical and medical practices. X.C.: analysis or interpretation. H.L. and J.Z.: concept, design, review, and full study suggestion.

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