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ORIGINAL PAPER

Do the urolithiasis scoring systems predict the success of percutaneous nephrolithotomy in cases with anatomical abnormalities?

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Abstract The objective of this study is to assess the utility of the Guy, S.T.O.N.E., and CROES nephrolithometry scoring systems (SS), and compare the capability of each system to predict percutaneous nephrolithotomy (PNL) outcome in patients with anatomical abnormalities. We retrospectively collected medical records of patients with anatomical abnormalities who underwent PNL for the treatment of renal calculi by experienced surgical teams in four referral centers. All of the patients were graded by a single observer from each department based on preoperative computed tomography images using each SS. Patient demographics and outcomes were compared according to the complexity of the procedure as graded by each scoring system. A total of 137 cases with anatomical abnormalities [horseshoe kidney ($n = 46$), malrotation ($n = 33$), kypho and/or scoliosis ($n = 31$) and ectopic kidney ($n = 27$)] were assessed retrospectively. The mean stone burden, number, and density were 708.5 mm^2, 1.7, and 791.8 HU, respectively. The mean procedure, fluoroscopy, and hospitalization times were 75.2 ± 35.3 min, 133.4 ± 92.3 s, and 3.5 ± 2.1 days, respectively. Stone-free status was achieved in 106 cases (77.4 %). A total of 17 (13.6 %) complications occurred postoperatively. The mean scores were 2.7, 7.2, and 219.1, for the Guy, S.T.O.N.E., and CROES systems, respectively. CROES score was the independent predictor of PNL success in cases with anatomical abnormalities [*p*: 0.001, OR 1.01, (95 % CI 1005–1021)]. The CROES scoring system is well correlated with the success of PNL in cases with anatomical abnormalities; the S.T.O.N.E. and Guy scoring systems failed to predict the outcomes of PNL in this specific patient population.

Keywords Kidney stone · Anatomical abnormality · Percutaneous nephrolithotomy · Success · Nomogram

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Introduction

European and American urology guidelines recommend percutaneous nephrolithotomy (PNL) as the treatment modality to remove kidney stones >2 cm in size and staghorn calculi [1, 2]. PNL has been applied to cases ranging from those with normal kidneys to those with anatomical abnormalities. This procedure is considered more complex and challenging in cases with anatomical abnormalities such as abnormal renal and caliceal positioning, abnormal vascular structure, abnormal relationship with neighboring organs, and relative kidney immobility which prevents maneuverability of rigid endoscopes.

PNL outcomes are mainly associated with stone characteristics (size, location, and density), the condition of the patient (presence of anatomical abnormalities, history of previous treatment, comorbidities, and obesity) and procedural factors (tract size, number, location, and surgeon's experience) [3–6]. Scoring systems (SS) have recently been developed to grade the complexity and predict the outcome of PNL [7–11]. SS are useful in enhancing surgical planning and in providing patients with accurate predictive information about possible outcomes of the procedure. Today, the most popular SS are Guy's, S.T.O.N.E., and CROES nephrolithometry nomograms.

According to Guy's score, the complexity of the PNL procedure is upgraded in cases with anatomical abnormalities. In contrast, the effects of anatomical variations on outcome are not considered in S.T.O.N.E. and CROES nephrolithometry nomograms. This study assessed the utility of the Guy's, S.T.O.N.E., and CROES nephrolithometry SS, and examined the capability of each system to accurately predict PNL outcome in patients with anatomical abnormalities. To the best of our knowledge, this is the first study to utilize and compare nomograms in cases with anatomical abnormalities.

Patients and methods

After acquiring institutional review board approval, we retrospectively collected medical records of patients with anatomical abnormalities who had undergone PNL for the treatment of renal calculi by experienced surgical teams in four referral centers between 2010 and 2015. We excluded records from patients <18 years of age, and those who had not been preoperatively assessed with computed tomography (CT). Patient demographics included age, gender, body mass index (BMI), history of previous treatment, stone burden, location, type of anatomical abnormality, and perioperative parameters such as operation, fluoroscopy, hospitalization time, access site, location, and success and complication rates. Postoperative complications were classified using the Clavien grading system [12].

Measurements and patient grading

Patients were graded by four observers, one from each department (MT, TK, NKH, and EO). Assessment of the three scoring systems was based on preoperative CT images as described in the literature. For the Guy's SS, patients with anatomical abnormalities were categorized into grades 2, 3, or 4 depending on stone number, location, and staghorn status [7]. The S.T.O.N.E. nephrolithometry nomogram uses stone burden, tract length, obstruction, number of calculus calices, and stone density to grade complexity [9]. For the CROES system, previous treatment status and average case volume of the center are the other parameters used in addition to the stone parameters [8]. The case volume of the centers was documented as between 120 and 150 cases per year.

Surgical technique

After insertion of a ureteral catheter, the procedure was performed with the patient in the prone position under general anesthesia. Access to the collecting system was performed with either fluoroscopy or combined fluoroscopy and ultrasonography (US) guidance. In cases with a pelvic ectopic kidney, renal puncture was performed with the aid of laparoscopy in the supine position. Tract dilation was performed up to 30 Fr using Amplatz dilators. Stone disintegration and removal was done with a pneumatic lithotripter or Ho:YAG laser via rigid or flexible nephroscopes. An additional tract was created when required. The procedures were terminated with placement of a nephrostomy tube. The operative time was defined as the period starting from access puncture until placement of the nephrostomy tube. Stone-free status was assessed with CT during a control visit in the fourth week. Success was defined as the lack of residual fragments, or the presence of fragments <4 mm.

Statistical analysis

Data were collected using IBM SPSS version 20.0. Continuous variables were compared using the independent sample (t) and one-way ANOVA tests, and the results are presented as means and standard errors of means. Categorical parameters were compared using Fisher's exact or Chi-square tests, and the results are presented as numbers with percentages. Correlation analyses were evaluated using the Pearson correlation coefficient (r). Two-tailed p values <0.05 were considered statistically significant. Receiver operating characteristic (ROC) curves were generated for each scoring system. The AUC and asymptotic 95 % CI were calculated for each ROC curve. ROC curves were drawn to assess the accuracies of all of the scoring systems for preoperative prediction of success rate.

Results

Demographic values

A total of 137 cases were assessed retrospectively. Their anatomical abnormalities included horseshoe kidney ($n = 46$), malrotation ($n = 33$), kypho and/or scoliosis ($n = 31$), and ectopic kidney ($n = 27$). The mean patient age was 44.2 ± 14.9 (18–73) years and the mean BMI was 26.6 ± 4.3 (16–40) kg/m^2. The mean tract length, stone burden, number, and density were 83.6 mm, 708.5 mm^2, 1.7, and 791.8 HU, respectively. Staghorn stones were observed in 21 cases. Among the 137 cases, 43 (31.4 %) had the history of renal procedure including SWL, PNL or f-URS. Of the patients 64 (46.7 %) had isolated pelvic or

Table 1 Demographics and postoperative parameters

	Total	Stone free	Not stone free	*p*
N	137	106 (77.4)	31 (22.6)	
Mean age (years)	44.2 ± 14.9	44.3 ± 14.8	43.9 ± 15.4	0.892
Sex (male/female)	79/58	65/41	14/17	0.082
BMI (kg/m^2)	26.6 ± 4.3	26.7 ± 4.3	26.3 ± 4.1	0.737
Stone laterality (right/left)	64/73	51/55	13/18	0.345
Stone burden (mm^2)	708.5 ± 550.2	674.9 ± 540.9	827.7 ± 575.6	0.187
Stone number	1.7 ± 0.9	1.6 ± 0.9	2.2 ± 0.8	**0.003**
Stone density (HU)	791.8 ± 294.5	790.4 ± 289.2	796.2 ± 317.1	0.923
Staghorn stones (*n*)	21 (15.3)	14 (13.2)	7 (22.6)	0.160
Anatomical abnormality				0.950
Pelvic kidney	27 (19.7)	22 (81.5)	5 (18.5)	
Horseshoe kidney	46 (33.6)	35 (76.1)	11 (23.9)	
Malrotation	33 (24.1)	25 (75.8)	8 (24.2)	
Kypho and/or scoliosis	31 (22.6)	24 (77.4)	7 (22.6)	
Operation time (min)	75.2 ± 35.3	70.7 ± 34.5	90.8 ± 33.9	**0.005**
Fluoroscopy time (s)	133.4 ± 92.3	128.6 ± 83.3	149.7 ± 118.4	0.265
Hematocrit drop (%)	4.2 ± 2.8	4.2 ± 2.9	4.4 ± 2.7	0.695
Hospitalization time (days)	3.5 ± 2.1	3.3 ± 1.8	4.4 ± 2.7	**0.006**
Access number	1.1 ± 0.3	1.1 ± 0.3	1.2 ± 0.5	0.134
N of complications	17 (12.4)	11 (10.4)	6 (19.3)	0.153
GUY's	2.7 ± 0.7	2.6 ± 0.7	3.1 ± 0.5	**0.001**
STONE	7.2 ± 1.8	7.1 ± 1.8	7.6 ± 1.9	0.168
CROES	219.1 ± 65.0	230.9 ± 62.4	178.5 ± 57.9	**0.000**

Bold values are statistically significant

caliceal stones, 52 (38 %) had multiple caliceal stones, and 21 (15.3 %) had staghorn stones.

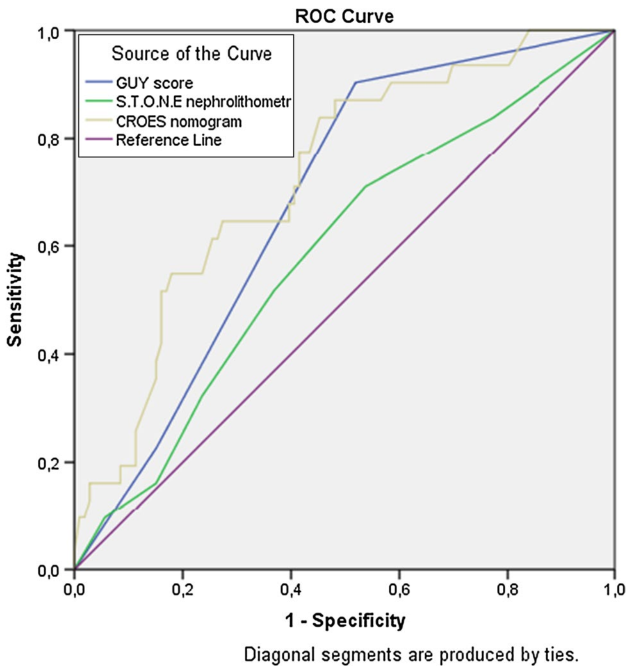
Surgical outcomes

The mean procedure, fluoroscopy, and hospitalization times were 75.2 ± 35.3 min, 133.4 ± 92.3 s, and 3.5 ± 2.1 days, respectively. The mean hematocrit drop was calculated as 4.2 ± 2.8 %. The mean tract number was calculated as 1.1 (1–3). PNL was performed with the guidance of laparoscopy while the patient was in the supine position in the 11 cases with pelvic ectopic kidney. Stone-free status was achieved in 106 cases (77.4 %) after the procedure. A total of 17 (13.6 %) complications occurred postoperatively, including fever ($n = 3$, Clavien grade 1), urinary tract infection ($n = 6$, Clavien grade 2), bleeding requiring blood transfusion ($n = 4$, Clavien grade 2), urine leakage requiring stent insertion ($n = 3$, Clavien grade 3b), and colon injury requiring open conversion ($n = 1$, Clavien grade 3b).

The mean scores for the Guy's, S.T.O.N.E., and CROES systems were 2.7, 7.2, and 219.1, respectively (Table 1). Comparing groups that were stone free with those who had stones, statistical differences were found in the Stone SS number (*p*: 0.003), Guy's SS (*p*: 0.001) and CROES score (*p*: 0.000), as well as in operation (*p*: 0.005) and hospitalization times (*p* 0.006). The CROES SS had the highest accuracy for predicting the success of PNL in patients with anatomical abnormalities. On multivariate logistic regression analysis disclosed that the CROES score was an independent predictor of PNL success in cases with anatomical abnormalities [*p*: 0.001, OR 1.01 (95 % CI 1005–1021)]. Figure 1 presents the AUC and ROC curves.

Discussion

Despite the widespread use of PNL in referral centers, this procedure is considered complex and may lead to complications. Many factors related to different characteristics



Area Under the Curve

Test Result Variable(s)	Area	Asymptotic 95% Confidence Interval	
		Lower Bound	Upper Bound
CROES nomogram	**,729**	,633	,825
S.T.O.N.E nephrolithometry	,586	,473	,698
GUY score	,683	,587	,778

Fig. 1 ROC curves of scoring systems

of stones, kidneys, and patients have been investigated to assess the complexity and outcome of the procedure [3–6]. Recently, researchers have proposed SS to predict the outcome of PNL based on data obtained from preoperative imaging methods or perioperative parameters [7–11]. A predictive and accurate SS is necessary for improved patient counseling, planning of the procedure, assessment of the postoperative course, and standardized outcome reporting.

Initially, Thomas et al. introduced a simple, quick, and reproducible grading system using preoperative abdominal X-ray—namely the Guy's SS—which correlated with the success of the PNL procedure [7]. This system was primarily based on four grades according to the stone location and burden within the kidney. Patients with abnormal anatomy and solitary or multiple stones were classified as grade 2 and grade 3, respectively. In a series that included 100 PNL procedures, 20 procedures were performed in cases with anatomical abnormalities ($n = 15$) and abnormal skeletal anatomy ($n = 5$). However, detailed data were unavailable for this group of cases.

The S.T.O.N.E. nephrolithometry introduced by Okhunov et al. was primarily based on five parameters (stone size, tract length, obstruction, number of calices, and stone density) derived from preoperative CT images [9]. Based on the scores, the risks of the procedures were graded as low (4 and 5), moderate (6, 7, and 8), and high (9, 10, and 11). Stone-free status was negatively correlated with this SS, with higher scores significantly associated with more complex procedures and lower stone-free rates. Smith et al. described a nomogram to predict the success of PNL using clinical and radiological parameters from the CROES global PNL database [8]. In this scoring system, the main determinants of the stone-free rate were considered to be preoperative characteristics, including case volume per year, prior treatment (ureteroscopy, shockwave lithotripsy, open surgery, or PNL), location, number and sizes of the stones, and staghorn status.

After the introduction of the Guy's SS, external validation studies confirmed that it is an important tool for predicting success rates and complications after PNL [13–15]. Similarly, the S.T.O.N.E. nephrolithometry system was externally validated in a multicenter study [16]. This study emphasized that the success and complication rates, blood loss, and operation and hospitalization time were associated with S.T.O.N.E. scores [16]. CROES nephrolithometry was externally validated in a recent study that showed high predictive accuracy for estimation of the success rate [17]. In one study comparing Guy's and S.T.O.N.E. nephrolithometry SS, the authors found that operation and hospitalization time as well as blood loss were associated with both SS [18], beside their being similarly accurate in predicting success rate. A recently published study compared Guy's, S.T.O.N.E., and CROES SS and showed that all three SS had similar capabilities to predict PNL outcome [19].

Despite variation in the developmental concepts of the three main scoring systems, stone-related factors (size, location, density, number, and staghorn status) are the main determinants of stone-free status. The authors in a recently published study applied nomograms for staghorn stones and compared predictive capability [20]. According to their results, STONE nephrolithometry SS was the most accurate in predicting success rate. In studies that have explored factors affecting PNL outcome in patients with horseshoe kidneys, the significant determinants were stone burden, staghorn status, and stone number [21, 22].

In addition to stone-related parameters, inherent variation among cases with anatomical abnormalities may affect the procedure technique and its outcome. To achieve high stone-free rates in these challenging cases, various technical approaches have been recommended, including CT to delineate vascular and pelvicaliceal anatomical variations, laparoscopy assistance, upper pole access, flexible nephroscopy, multiple puncture, and second-look nephroscopy [23, 24]. We believe that in cases with anatomical abnormalities, the treatment plan and surgical technique should be modified and individualized. For example, in the present study laparoscopy-guided access was performed in 11 cases with pelvic ectopic kidney.

To develop a universally accepted and highly accurate SS, external validation in different patient groups and series is crucial. From this perspective, the current study is the first to assess the utility of three popular SS and compare their predictive value and accuracy for PNL in patients with anatomical abnormalities. The Guy's SS is a reproducible and easily implemented tool for clinical practice, whereas the S.T.O.N.E. and CROES systems are more comprehensive but difficult to apply. However, while the Guy's SS considers anatomical abnormalities, the latter two systems do not. Our data indicate that the CROES SS is an important tool for predicting the success rate in cases with anatomical abnormalities. The CROES system had the highest accuracy for predicting the success rate of PNL.

The main limitation of this study may be its retrospective and multi-centric design. In addition, the patient population displayed heterogeneity. The lack of the information about the access site may be regarded as the other limitation. However, this is the first study to evaluate the scoring systems for predicting the success of PNL in patients who have anatomical abnormalities. Further prospective studies with large case numbers are warranted to further evaluate the scoring systems in this unique group of patients.

Conclusion

For the prediction of outcomes in cases with anatomical abnormalities, the CROES scoring system was correlated with the success of PNL, whereas the S.T.O.N.E. and Guy's systems were not. A comprehensive scoring system that includes detailed individual data is needed for this group of patients.

Compliance with ethical standard

Conflict of interest The authors declare that they have no conflict of interest.

Ethical standard The study was performed in accordance with the Declaration of Helsinki and its amendments. All patients provided written informed consent.

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