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Research Article

A Fitted Simplified Model of the CROES Nomogram to Predict Stone Free Status after Percutaneous Nephrolithotomy Using Logistic Regression Analysis -

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ABSTRACT

Aim: To predict the probability of stone free status calculated by CROES nomogram and to test the accuracy of our fitted regression model to predict outcomes of PCNL.

Methods: From July 2018 to May 2019, data of 100 patients underwent PCNL procedure for renal stones at Urology department at Menoufia University was collected and postoperative results were compared to the preoperative predicted stone free status. The CROES nomogram was applied to the data of all cases using its scale to calculate the total score and corresponding percent of stone free status after the procedure. We used binary logistic regression to test whether the six factors in the study can predict the PCNL outcome. We compared the calculated probabilities of stone free by our fitted regression model to the traditional method using the whole 6 parameters on the scale of nomogram.

Results: A total of 100 patients were included in the study. Mean patients' age was 41 ± 9.6 and mean stone burden was 564.59 ± 533.869 mm^2. Postoperative treatment success rate was 62%. CROES score was found to be independent predictor of treatment success. The estimated AUC was 0.96 and the model provided good calibration. The accuracy of our fitted logistic model was 78% when using it as a single method when compared to the probabilities of CROES Nomogram.

Conclusions: CROES nomogram is an efficient tool to predict outcomes of PCNL. Our model of noticeable accuracy in predicting PCNL outcomes using the most influent variables in the CROES nomogram.

Keywords: CROES; Nomogram; Percutaneous nephrolithotomy; Regression analysis; Reliability

ABBREVIATIONS

PCNL: Percutaneous Nephrolithotomy; CROES: Clinical Research Office of the Endourological Society; SFRs: Stone Free Rates; HU: Hounsfield Units; S-ReSC: Seoul National University Renal Stone Complexity Score; AUC: Area Under the Curve; ROC: Receiver Operating Characteristic.

INTRODUCTION

After urologists adopted Percutaneous Nephrolithotomy (PCNL) with a standardization of its practice, there has been a dramatic reduction in morbidity and mortality as a result of renal urolithiasis [1]. PCNL has now become the most preferred procedure used to treat large and complex kidney stones. Many large-scale studies have shown that PCNL is an effective procedure that offers a high postoperative stone-free rate [2].

The preoperative selection of the most suitable procedure is vital to decrease complications and increase the stone-free rate. Applying Computed Tomography (CT) in choosing the most appropriate line of treatment allowed us to move towards the right direction by giving detailed anatomical information [3].

Several scoring systems have been proposed by a number of authors for use in the percutaneous management of nephrolithiasis to allow appropriate counselling of patients, decrease adverse results, and provide a means for the standardized reporting of stone complexity and postoperative patient outcomes [4].

Smith, et al [5] developed the Clinical Research Office of the Endourological Society (CROES) nomogram using data from the CROES PCNL global study which included 2,086 patients from 96 centers worldwide [5].

Several preoperative variables were defined and compared to their Stone-Free Rates (SFRs), defined as an absence of >4 mm residual stones using KUB radiography and binary logistic regression for statistical analysis.

Multiple variants such as stone burden, case volume, previous stone treatment, presence of staghorn calculus, and stone location were found to be predictive of stone-free outcomes and overall procedure success.

The aim of this study is to assess the applicability of the CROES nomogram in predicting the treatment outcomes of percutaneous nephrolithotomy at Menoufia University Hospital.

PATIENTS AND METHODS

From July, 2018 to May, 2019, the data of 100 patients who underwent PCNL procedures for renal stones at the urology department of Menoufia University Hospital was collected.

The study included all adult patients with kidney stones who underwent PCNL with an initial, radio-opaque stone size of 20 mm or more and a radio-lucent stone size of 20 mm or more who failed medical treatment or Extra Corporeal Shock Wave Lithotripsy (ESWL). We excluded cases with severe coagulopathy, skeletal deformity, and patients who were generally unfit for surgery along with patients with anatomical abnormalities. A detailed history was compiled for each patient which included personal data such as name, age, and gender as well as a medical history to assess any recent complaints and any associated urinary symptoms.

The medical history was taken to reveal any contraindications to the procedure along with the patient's history of previous urological procedures and any trials of treatment for the recent stones. Ethical approval forms and written medical consent were obtained for all patients with thorough explanation of the procedure and follow-up plan. All patients submitted to preoperative Non-Contrast Computed Tomography (NCCT) and KUB.

The preoperative details from the NCCT were assessed alongside the retrograde pyelography, the intraoperative findings, and the most beneficial way to reach stone-free status. First-day, post-operative KUB was obtained along with NCCT if the procedure involved radiolucent stones. Patients were defined as stone free if there was no residual >4 mm.

The CROES nomogram was applied to the data of all cases using its scale model to calculate preoperatively the total score and corresponding percentage of stone-free patients after the procedure. Postoperative results were compared to the preoperative predicted percentage of stone-free status.

Our Fitted Logistic Model:

$$\hat{p} = \frac{1}{1+e^{-(1.151-0.088*\mathbf{SB}-1.799*\mathbf{PCNL}+3.923*\mathbf{NS})}}$$

$\hat{p}$ is the estimated probability of Stone-free status, e is a constant = 2.73, SB is the score of Stone Burden (mm^2), PCNL is the score of prior treatment, and NS is the score Number of Stones. All of the three predictors were calculated from CROES nomogram scoring scale [5].

We used Binary logistic regression to test whether the six factors in the study can predict the PCNL outcome. The accuracy of the logistic regression model was tested using the Receiver Operating Characteristic curve (ROC) and Area Under the Curve (AUC) to determine by what percentage the used model predicted the outcome. By using a Microsoft Excel sheet, the results of our equation can be calculated in no time.

The stone-free probabilities calculated by our model are compared to those predicted by the CROES nomogram.

Data was analyzed using Statistical Package of Social Sciences (SPSS) version 24 with statistical significance considered at 0.05. *P*-values below 0.05 indicate significant tests.

RESULTS

The study included 100 patients with a mean age of 41 ± 9.6. The average radiodensity measured in Hounsfield Units (H.U.) was 1,030.20 ± 334.821 H.U. and the mean stone burden was 564.59 ± 533.869 mm^2. Regarding the location of stones, the largest proportion of stones were in multiple calyces, representing 55% of the sample. In 27% of the sample, stones were pelvic and in 10%, they were in the lower calyx.

Data of all patients was plotted on the CROES nomogram. The mean calculated score was 185.37 ± 55.025. The participating sample reported a mean stone-free rate of 84.59% ± 14.344%.

Postoperative follow-up showed that when patients' outcome was arranged in two groups, the stone-free group of patients was 62 (62%) and the non-stone free group was 38 (38%) (Table 1).

A multivariate and univariate logistic regression analysis was conducted for 100 patients. The multivariate logistic regression analysis included a full model using all 6 CROES parameters (stone burden, location of stones, prior treatment, presence of staghorn stone, number of stones, and case volume), and a reduced model using only parameters which showed statistical significance (stone burden, prior treatment, and number of stones) (Table 2).

The stone-free probabilities calculated by our model was compared to those predicted by the CROES nomogram and the accuracy of the fitted logistic model was 78 % when using it as a single method.

AUC and ROC

The area under the curve is 0.959 with a 95% confidence interval (0.915, 1.000). Also, the area under the curve is significantly different from 0.5 since p-value is 0.000 meaning that the logistic regression classifies the group significantly better than random (Figure 1).

DISCUSSION

With a worldwide increase in renal stone disease, optimization in choosing suitable procedures has become mandatory. Many authors

Table 1: Descriptive statistics of patients and stones.

	Overall	Stone Free	Non-Stone Free
Number of Patients	100	62	38
Age (Mean ± SD)	40.57 ± 9.600	41.77 ± 9.196	38.61 ± 10.039
Pre-operative KUB	Number (%)	(%)	(%)
Lucent	22.00	20.97	23.68
Opaque	78.00	79.03	76.32
H.U. (Mean ± SD)	1,030.20 ± 334.821	1,022.77 ± 333.582	1,042.32 ± 340.964
Stone Burden in mm^2 (Mean ± SD)	564.59 ± 533.869	330.09 ± 274.872	947.20 ± 628.929
Location of Stones	Number (%)	(%)	(%)
Multiple Calyces	55.00	35.48	86.84
Upper Calyx	2.00	3.23	-
Lower Calyx	10.00	12.90	5.26
Pelvic	27.00	38.71	7.89
Middle Calyx	6.00	9.68	-
Prior Treatment	Number (%)	(%)	(%)
PCNL	7.00	1.61	15.79
ESWL	21.00	30.65	5.26
Non	72.00	67.74	78.95
Staghorn Stone	Number (%)	(%)	(%)
	8.00	-	21.05
Number of Stones	Number (%)	(%)	(%)
Single	54.00	74.19	21.05
Multiple	46.00	25.81	78.95
Total calculated score (Mean ± SD)	185.37 ± 55.025	215.84 ± 40.935	135.65 ± 35.267
Percent of Stone Free (%) (Mean ± SD)	84.59 ± 14.344	86.80 ± 13.144	80.97 ± 15.622
Post-operative Follow Up	Number (%)	(%)	(%)
CT	22.00	20.97	23.68
KUB	78.00	79.03	76.32

Table 2: *Univariate and multivariate logistic regression analysis of predictors of PCNL success using ROC AUC.*

	Uni-variate Odds Ratio (95% CI)	Multivariate Odds Ratio (95% CI)	
		Full Model	Reduced Model
Stone Burden in mm^2	0.95 (0.95 - 0.97)*	0.91 (0.86 - 0.96)*	0.92 (0.87 - 0.96)*
Location of Stones	0.96 (0.94 - 0.98)*	0.99 (0.95 - 1.03)	----
Prior Treatment			
Prior Treatment PCNL (1)	Prior TTT (1)	0.22 (0.05 - 1.03)	0.12 (0.02 -0.80)*
Prior Treatment (2)	Prior TTT (2)	11.39 (2.58 - 50.16)*	6.05 (0.17 - 217.17)
Presence of Staghorn Stone (1)	3,338,648,009.00	1,472,342,166.00	----
Number of Stones (1)	10.78 (4.11 - 38.31)*	53.84 (4.42 - 656.04)*	50.56 (5.86 - 435.93)*
Percent of Stone Free	.97 (.94 - 1.00)	1.03 (.96 - 1.10)	----

*. *Significant at α = 0.05*

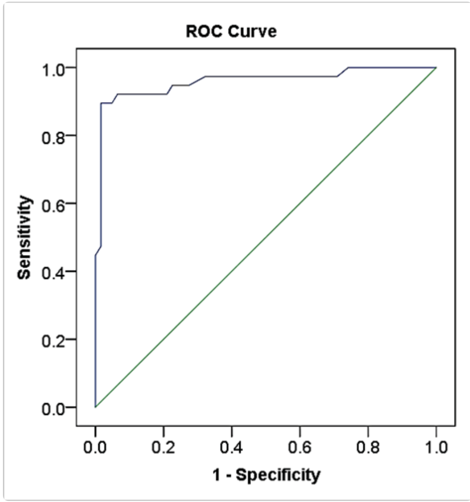

Figure 1: ROC Curve demonstrating the sensitivity and specificity of CROES nomogram.

revealed that PCNL is an efficient procedure that offers a high rate of postoperative stone-free patients [2].

Large renal stones are a common problem affecting all population groups around the world and, if untreated, may cause serious complications. The management of renal stones has progressed significantly over the past few years with the beginning of the minimally invasive era. This has led to shorter hospital stays, reduced postoperative pain, and faster recovery compared to the previous usual open surgery option. PCNL continues to be the gold-standard option for the treatment of complex renal stones and large-sized stones. Modifications in techniques, improvements in equipment, and increasing clinical experience have led to improved stone-free rates being achieved with decreased patient morbidity [6].

Guy's stone score, the S.T.O.N.E. score, the CROES nomogram, and the Seoul National University Renal Stone Complexity Score (S-ReSC) are modern scoring systems introduced to provide a standardized grading of stone complexity and percutaneous stone surgery outcomes [7].

Our study plotted the six parameters' data on the CROES nomogram and treatment success was defined as the absence of any fragment greater than 4 mm as in the original study by Smith et al. recently suggested [5,8].

Our mean age was 40.57 ± 9.600 which is comparable to that reported by Smith et al. in the original study which reported a mean age of 49.2 ± 14.7 years and to that reported by Sfoungaristos et al. which was 55.2 ± 13.9 years [9].

Our study showed a male to female ratio of 64 (64%) male and 36 (36%) female cases while Smith et al. reported a male to female ratio of 59.8% male and 40.2% female. Sfoungaristos et al. reported a ratio of 67% males and 33% females.

With the pre-operative data of the studied cases collected by both KUB and NCCT, 78 cases had radiopaque stones and 22 cases had radiolucent stones with an overall mean H.U. of 1,030.20 ± 334.821. Sfoungaristos et al. also used preoperative KUB and NCCT to include radiolucent stones within their study while Kumar et al. used only KUB as a preoperative tool [5,9,10].

Smith et al. included only the radiopaque stones and considered KUB only as a postoperative indicator for stone-free status. They excluded all patients who were evaluated postoperatively by NCCT scan or ultrasound. This raised doubts concerning the correct evaluation of patients with radiolucent stones or with clinical features, like severe obesity, that may decrease the sensitivity of KUB. Our inclusion criteria overcome these problems as the treatment success outcomes were assessed by NCCT.

Our study included 54 cases (54%) with a single renal stone while multiple stones were found in 46 cases (46%). This was similar to Smith et al. who reported 54.7% of cases with a single stone and 45.3 % with multiple stones.

Our results showed a mean stone burden of 564.59 ± 533.869 mm^2 with 670.24 ± 609.804 mm^2 in the post-PCNL stone-free group and 384.71 ± 300.967 mm^2 in the non-free group. In comparison to the original study results, stone burden was 463.9 ± 310.0 mm^2 and 433.5 ± 292.8 mm^2 in patients with postoperative stone-free status and 602.2 ± 346.6 mm^2 in the non-free group [5].

These numbers identify the important fact that stone burden comes first among all the predictors of PCNL success and its effect on the results appeared clearly on a statistical base with a *P* value of < 0.001 which also was reported by Smith et al. and Labadie et al. and Kumar et al. [11].

Our results showed that the more calyces occupied by stones, the less stone-free status we reach. Upon multivariate analysis, 55% of our cases had multiple calyceal stones with a success rate of 35.48%. This is parallel to that reported by Smith et al. (39.8%), as also observed by S foungaristos et al. and Kumar et al.

To overcome this problem, Smith et al. suggested combining techniques and Sfoungaristos et al. tried this by incorporating the use of a flexible nephroscope as a standard step after stone fragmentation, inspecting the collecting system and proximal ureter, removing any residual fragment which could not be approached by the rigid nephroscope [5,9,10].

We had only 8 (8%) cases with staghorn stones and all of them had a residual stone upon postoperative follow up radiology. This goes along with the results of the global CROES PCNL study, which stated that the presence of staghorn stones decreases the stone-free rate [12].

Our mean CROES-calculated total score was 185.37 ± 55.025. Our results revealed that, with increasing the total score, the chance of a stone-free result increased as the mean total score of the stone-free group was 215.84 ± 40.935 while the non-free was 135.65 ± 35.267. Subsequently, the corresponding percentage of stone-free rate increases. Choi et al. reported an overall mean total score of 202.1 ± 66.4, 218.8 ± 58.0 in the stone-free group and 140.3 ± 59.1 in the non-free group [13].

Our study showed a stone-free rate of 62 cases (62%) and residual stones > 4 mm in 38 cases (38%). Our stone-free rate is less than the original study by Smith et al. due to many factors.

According to Opondo et al. the stone-free rate increases by increasing the case volume of the center with a peak at 120 case per year but, even with the very high case volumes, the stone-free rate appears to decrease due to a variety of reasons: centers with high case volumes have surgeons with a different level of surgical experience, may have a teaching program for junior surgeons, or also may be a main referral center for the surrounding city or region [14].

Kumar et al. reported a mean stone-free rate of 76% but this may be due to the larger sample (313 patients) and their use of KUB only to detect residual stones [10].

We developed a new model using a logistic regression analysis based on the most significant factors among the predictors of the CROES nomogram and compared the calculated probabilities of a stone-free outcome produced by our model to the traditional method using all six parameters of the nomogram.

We suppose that a main cause of difference in stone-free rates is that we included in our study radiolucent stones with postoperative NCCT while Smith A, et al. for statistical purposes, excluded all patients evaluated postoperatively by CT or ultrasound.

Also, our results might be affected by the early nature of the postoperative follow ups since there are residual fragments that may pass through the urinary tract spontaneously. Our study's data base relied on the single-center experiences of one-hundred patients with a relatively short inclusion period of one year.

Our results show that the CROES nomogram provided high predictive accuracy regardless of the follow-up imaging technique. The AUC was 0.959 with a 95% confidence interval. The ROC AUC for predictions based on this nomogram by Tepeler et al. was 0.729 [4].

They also reported that the nomogram is clinically applicable if urologists use a 60% or greater stone-free rate as the threshold to decide whether to perform PCNL or modify the treatment strategy [15].

The accuracy of our fitted logistic model was 78% when using it as a single method when compared to the probabilities of CROES nomogram. The reason for this is that this is a new, primitive trial to make the nomogram easier to use in daily practice. Also, the data was based on a narrow scale.

CONCLUSION

The CROES nomogram represents a significant tool to evaluate the complexity of renal stones and provide a high-accuracy prediction to estimate postoperative treatment success, expressing its ability to translate well to the clinical setting.

Applying multivariate logistic regression analysis. The scoring system was found to be valid and a significant independent predictor of postoperative efficacy outcomes. Our data shows that stone burden, number of stones, and prior treatment are the most influential parameters in predicting PCNL success.

Our fitted logistic model would be a good start in the way of reaching a simple standardized method of predicting stone-free status after PCNL which would make it easier in daily practice. This, however, is just the precursor to the building of a project with a wider scale and larger number of cases to create an even better, more refined and standardized model.

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