External validation of the S.T.O.N.E. nephrolithometry scoring system

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Abstract

Introduction: We perform external validation of the S.T.O.N.E. nephrolithometry scoring system for the preoperative assessment of percutaneous nephrolithotomy (PCNL) outcomes.
Methods: After obtaining institutional review board approval, all PCNLs performed from 2009 to 2013 at a tertiary referral centre were reviewed. The S.T.O.N.E. score was calculated and correlated with stone-free status, estimated blood loss (EBL), operative time, length of hospital stay (LOS), and postoperative complications.
Results: A total of 155 PCNLs were included, with 100 (64.5%) males and 55 (35.5%) females. The mean age was 54.9 ± 1.2 years (range: 17–85), with a mean body mass index of 26.9 ± 0.5 kg/m^2 (range: 17.2–51). The mean S.T.O.N.E. score was 7.67 ± 0.1 (range: 5–12), with a mean stone size of 609.8 ± 48.4 mm^2 (range: 250–4030), a mean Hounsfield unit of 887.7 ± 25.3 (range: 222–1766), a mean tract length of 97.3 ± 1.9 mm (range: 53–175), a mean operative time of 100.1 ± 2.8 min (range: 60–240), and a mean LOS of 4.2 ± 0.3 days (range: 1–18). The overall stone-free rate after the primary procedure was 71.6%. The S.T.O.N.E. score significantly affected stone-free status ($p = 0.001$) and EBL ($p = 0.003$). There was significant correlation between the S.T.O.N.E. score and operative time ($r = 0.4$; $p < 0.001$) and LOS ($r = 0.3$; $p = 0.001$). Therefore, the higher the S.T.O.N.E. score, the longer the operative time, the higher the EBL, the longer the LOS, and the lower the chance of being stone-free. The overall complication rate after the primary procedure was 15.5%, which did not correlate with the S.T.O.N.E. score ($p = 0.9$).
Conclusion: Although this study externally validates the S.T.O.N.E. scoring system, its accuracy is comparable to stone size and number of involved calyces in predicting stone-free status post-PCNL.

Introduction

According to the American Urological Association (AUA) guidelines, percutaneous nephrolithotomy (PCNL) is the gold standard for managing renal calculi, including staghorn stone.[1] With rising incidence of stone disease in North America, PCNL is being performed more often.[2,3] However, there are no widely-accepted standardized preoperative assessment tools to determine post-PCNL outcomes. These preoperative assessment tools are important for preoperative patient counselling and for comparing outcomes among different institutions.

Several assessment tools have been described. In 2011, Thomas and colleagues devised the Guy's scoring system based on preoperative non-contrast computed tomography (NCCT) parameters and patient medical history, such as spina bifida.[4] Recently, the S.T.O.N.E. nephrolithometry scoring system was introduced by the Smith Institute for Urology.[5] This scoring system is based solely on 5 parameters obtained from preoperative NCCT. These parameters include **S**tone size (mm^2), **T**ract length (mm), hydronephrosis or **O**bstruction, **N**umber of involved calyces, and stone density or **E**ssence (Hounsfield units, HU). The total S.T.O.N.E. nephrolithometry score ranges from 5 to 13, with 13 representing the most complex PCNL and 5 representing the simplest PCNL.[5] The S.T.O.N.E. score successfully predicts post-PCNL stone-free status ($p = 0.001$). In addition, it showed significant positive correlation with operative time ($p = 0.001$), estimated blood loss (EBL) ($p = 0.005$), and length of hospital stay (LOS) ($p = 0.001$).[5] However, there was no impact of this scoring system on the incidence of post-PCNL complications ($p = 0.09$).[5,6] The Guy's scoring system has been externally validated.[7,8] However, the S.T.O.N.E. nephrolithometry scoring system has not been externally validated. Therefore, the objective of this study was to perform external validation of S.T.O.N.E. nephrolithometry scoring system for the preoperative assessment of

PCNL outcomes. We hypothesize that the S.T.O.N.E. nephrolithometry scoring system will predict operative time, EBL, LOS, and postoperative stone-free status and complications.

Methods

Study design

After obtaining approvals from the Institutional Review Board (No. 14-050-GEN) and the Director of Professional Services of McGill University Health Centre, electronic charts and PCNL datasheets of all patients undergoing PCNL between 2009 and 2013 were retrospectively reviewed. All PCNLs, except one, were performed in the prone position under general anesthesia as described previously.[9] At the end of the procedure, antegrade indwelling double-pigtail 6F ureteral stents together with 20F council-tip nephrostomy tubes were inserted. For tubeless cases, the skin was closed with 4-0 absorbable suture. All PCNLs were performed by a single fellowship-trained endourologist (SA), who filled out the PCNL datasheets immediately postoperatively. These PCNL datasheets contained intra-operative procedural details regarding the number of punctures, number of tracts, operative and fluoroscopy times, in addition to EBL and intra-operative stone-free status. Moreover, the assistance and level of postgraduate trainees were recorded. A puncture was defined as a needle pass to the kidney to obtain percutaneous renal access (PCA). A tract was defined as a successful puncture over which dilatation was performed.

To be congruent with the original study by Okhunov and colleagues, second-look PCNL procedures were excluded, while including the first PCNL procedures for patients who underwent second-look PCNL later on.[5] Therefore, the exclusion criteria were second-look PCNLs, and PCNLs where the percutaneous renal access was obtained by interventional radiology. S.T.O.N.E. nephrolithometry scores were calculated using preoperative NCCT scans, according to what has been previously described by Okhunov and colleagues.[5,6] The tract length recorded in millimeters represented the distance from the centre of the stone to the skin at an angle of 45° on preoperative NCCT scans. The S.T.O.N.E. nephrolithometry score was then correlated with stone-free status (stone-free vs. non-stone-free), EBL (<250 cc vs. ≥250 cc), operative time (minutes), LOS (days), and postoperative complications using the modified Clavien classification system.[10] Stone-free status was confirmed by postoperative KUB (kidney, ureter, bladder) and/or NCCT scan. Patients with residual stones ≥4 mm were considered as non-stone-free after the primary PCNL procedure.

Statistical analysis

Descriptive variables were presented as means and standard errors of mean or numbers and percentages. Associations between continuous variables were compared using the Mann-Whitney *U*-test and Kruskal-Wallis test or independent sample (*t*) test and one-way ANOVA test, whenever appropriate. Correlations between continuous variables were assessed using the Spearman rank correlation coefficient. Categorical variables were compared using Fisher's exact test or Chi-square test. Statistical significance was considered when two tailed p value was <0.05. Logistic regression analysis was performed to determine predictors of stone-free status. Linear regression analysis was performed to assess the effect size of S.T.O.N.E. nephrolithometry score on both the operative time and LOS. Receiver operator characteristic (ROC) curve was performed to assess the accuracy of preoperative predictors of stone-free status. The statistical analysis was conducted using the Statistical Package of Social Sciences for Windows (SPSS, Chicago, IL) version 20. The areas under the curves of the stone size and the number of involved calyces were compared with the area under the curve of the S.T.O.N.E. nephrolithometry score using the online calculator of significance of difference between areas under two independent ROC curves.[11]

Results

A total of 155 cases were included after the exclusion of 15 second-look PCNLs and 15 PCNLs, where the access was obtained by the interventional radiologist. The mean age was 54.9 ± 1.2 years (range: 17–85) with mean BMI of 26.9 ± 0.5 kg/m^2 (range: 17.2–51). There were 100 (64.5%) males and 55 (35.5%) females. The mean S.T.O.N.E. score was 7.67 ± 0.1 (range: 5–12). However, there were no cases meeting the criteria for S.T.O.N.E. score of 13 (Table 1).

The overall stone-free rate after the primary PCNL procedure was 71.6%. The S.T.O.N.E. score had a significant effect on the stone-free status; the higher the S.T.O.N.E. score the lower the chance of being stone-free ($p = 0.001$) (Fig. 1).

Similarly, the S.T.O.N.E. score had a significant effect on the EBL, where PCNLs with EBL ≥250 cc had significantly higher mean S.T.O.N.E. score when compared with PCNLs with EBL <250 cc (8.3 ± 0.1 vs. 7.4 ± 0.3; $p = 0.003$). There was significant correlation between the S.T.O.N.E. score and operative time ($r = 0.4$; $p < 0.001$). Similarly, there was significant correlation between the S.T.O.N.E. score and LOS ($r = 0.3$; $p = 0.001$). Therefore, the higher the S.T.O.N.E. score, the longer the operative time, the higher the EBL, the longer the LOS, and the lower the chance of being stone-free. The overall complication rate after the primary procedure was 15.5%. Patients with post-PCNL complications did not have significantly different S.T.O.N.E. score when compared with patients without complications (7.66 vs. 7.67; $p = 0.98$) (Table 1).

On logistic regression analysis, there was significant inverse association between stone-free status and stone size ($p = 0.001$), number of involved calyces ($p = 0.001$), number of tracts ($p = 0.01$), operative time ($p = 0.001$), and the S.T.O.N.E. score ($p = 0.002$) (Table 2).

Since stone size, number of involved calyces, and S.T.O.N.E. score are the only preoperative predictors of stone-free status, ROC curves were drawn to compare their accuracies in predicting stone-free status (Fig. 2).

All three had comparable accuracies with the area under curve (AUC) of 0.64 (95% confidence interval [CI] 0.54–74; $p = 0.005$), 0.66 (95% CI 0.57–76; $p = 0.001$), and 0.63 (95% CI 0.53–0.73; $p = 0.01$) for stone size, number of involved calyces and S.T.O.N.E. nephrolithometry scoring system, respectively. There was no significant difference between the AUC of the S.T.O.N.E. scoring system and the AUC of the stone size (0.63 vs. 0.64; $p = 0.88$) and between the AUC of the S.T.O.N.E. scoring system and the AUC of the number of involved calyces (0.63 vs. 0.66; $p = 0.66$).

Regression analysis was performed to assess the effect size of the S.T.O.N.E. score on stone-free status, EBL, operative time, and LOS (Table 3). Stone-free status had an odds ratio of 0.7 (range: 0.6–0.9) and EBL (≥250 cc) had an odds ratio of 1.4 (range: 1.1–1.7). Furthermore, each unit increase in the S.T.O.N.E. nephrolithometry score led to an increase in the operative time of 7.7 minutes (range: 4.6–10.9) and an increase in the LOS of 0.6 days (range: 0.2–0.9) (Table 3).

Table 1. Baseline demographic and perioperative characteristics

Variable		Mean ± SE	Range
Patient age (years)		54.9±1.2	17–85
Gender (male/female) (n, %)		100 (64.5%) / 55 (35.5%)	N/A
BMI (kg/m²)		26.9 ± 0.5	17.2–51
S.T.O.N.E. nephrolithometry score		7.67 ± 0.1	5–12
Stone size (mm²)		609.8 ± 48.4	250–4030
Stone HU		887.7 ± 25.3	222–1766
Radiolucent stone		19 (12.3%)	N/A
Left-sided stone		90 (58.1%)	N/A
Pelvis involvement		107 (69%)	N/A
Presence of hydronephrosis		62 (40%)	N/A
Preoperative indwelling ureteral stent		87 (56.1%)	N/A
No. punctures		2.1 ± 0.1	1-6
No. tracts		1.2 ± 0.03	1-3
Tract length (mm)		97.3 ± 1.9	53–175
Postoperative nephrostomy tube		81 (52.6%)	N/A
Operative time (min)		100.1 ± 2.8	60–240
Postoperative complications according to the modified Clavien Classification	Grade 1	7 (4.5%)	N/A
	Grade 2	5 (3.2%)	N/A
	Grade 3a	2 (1.3%)	N/A
	Grade 3b	9 (5.8%)	N/A
	Grade 4a	0 (0%)	N/A
	Grade 4b	1 (0.6%)	N/A
	Grade 5	0 (0%)	N/A
Length of hospital stay (days)		4.2 ± 0.3	1–18

SE: standard error; BMI: body mass index; HU: hounsfield units.

Table 2. Logistic regression analysis of parameters predicting stone-free status

Variable	Logistic regression analysis			
	Wald Chi-square	OR	(95% CI of OR)	*p* value
Patient age (10 years)	0.05	1	0.9–1.1	0.8
Male gender	0.02	1	0.5–2.2	0.9
BMI	0.5	1	0.9–1.1	0.5
Radiolucent stone	1.9	2.5	0.7–8.9	0.2
Left-sided stone	0.3	0.8	0.4–1.7	0.6
Stone size (100 mm²)	10.3	0.99	0.99–1	0.001
Tract length	0.002	1	0.9–1.1	0.9
Presence of hydronephrosis	0.8	0.7	0.4–1.5	0.4
No. calices involved	11.3	0.5	0.3–0.7	0.001
Stone HU (100 HU)	3.8	0.99	0.99–1	0.05
S.T.O.N.E. nephrolithometry score	10	0.7	0.6–0.8	0.002
No. punctures	1.3	0.8	0.6–1.1	0.1
No. tracts	6.7	0.4	0.2–0.8	0.01
Operative time (10 min)	11	0.98	0.97–0.98	0.001
EBL ≥250 mL	3.3	1.9	0.9–4	0.06

OR: odds ratio; BMI: body mass index; HU: hounsfield units; EBL : estimated blood loss.

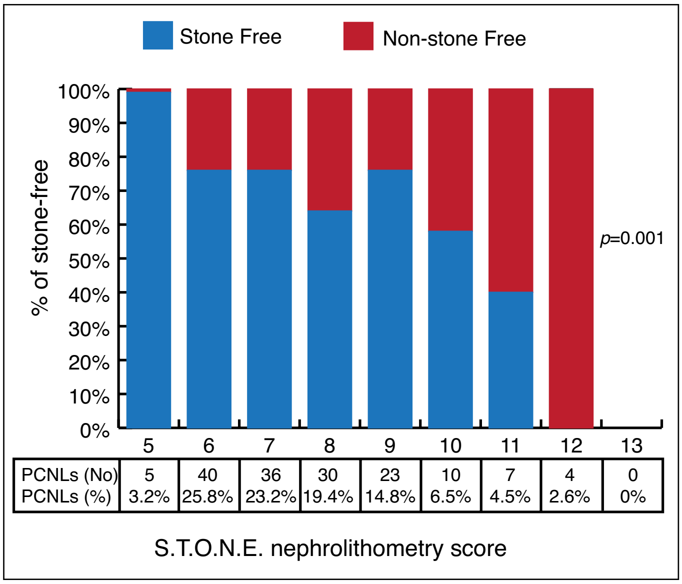

Fig. 1. Demonstrates the effect of S.T.O.N.E. nephrolithometry score on the stone-free status.

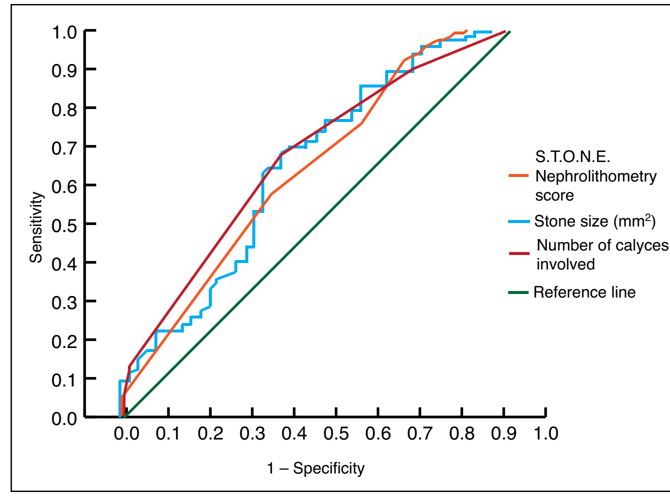

Fig. 2. Receiver operator characteristic curve demonstrating accuracy of the S.T.O.N.E nephrolithometry score, stone size, and number of involved calyces on preoperative prediction of stone-free status.

Discussion

Standardization of a universal scoring system that assesses PCNL complexity and predicts PCNL outcomes will not only aid urologists in preoperative patient counselling, but it will also help in comparing PCNL outcomes among different surgeons and institutions. The current study assessed the external validation of the S.T.O.N.E. nephrolithometry scoring system and helped to determine significant predictors of stone-free status post-PCNL. Despite the lack of correlation between the S.T.O.N.E. score and postoperative complications ($p = 0.9$), the S.T.O.N.E. score significantly affected the stone-free status ($p = 0.001$), operative time ($p < 0.001$), EBL ($p = 0.003$), and LOS ($p = 0.001$). These are consistent with the results of the Okhunov study.[5] The mean S.T.O.N.E. score in this study was 7.67, which is comparable to the mean S.T.O.N.E. score of 7.7 in the Okhunov study.[5]

Although one may expect stones with renal pelvic involvement would be associated with higher stone-free status, we found that renal pelvic involvement had no effect on the stone-free status ($p = 0.8$). This is unlike the original S.T.O.N.E. nephrolithometry scoring system study, where renal pelvic involvement was associated with significantly higher probability of having postoperative residual stones ($p = 0.007$).[5] This difference could be due to different definitions used for renal pelvic involvement. While in the original study, there was no clear definition of renal pelvic involvement, in the present study renal pelvic involvement was considered when the bulk of the renal stone occupied the renal pelvis. In addition, stones with renal pelvic involvement may be larger than those without renal pelvic involvement. Therefore, stone size is a confounder, which was not accounted for in the Okhunov study.[5]

The stone-free rate in the present study was 71.6%, with 15.5% postoperative complications. This is comparable to the 80% stone-free rate and the 21% postoperative complication rate of the Okhunov study.[5] In addition, these results are in line with the stone-free rate and postoperative complication rates reported by the Clinical Research Office of the Endourological Society (CROES) study, which included 5803 patients in 96 centres.[12] They reported a stone-free rate of 75.7% and a complication rate of 21.5%.[12]

In the present study, the S.T.O.N.E. nephrolithometry scoring system had accuracy or AUC of 0.63 (range: 0.53–0.73) in predicting stone-free status post-PCNL (Fig. 2). Labadie and colleagues recently compared three nephrolithometry scoring systems (S.T.O.N.E., Guy's and CROES nomogram) and found that all three were comparable in

Table 3. Effect size of S.T.O.N.E. score on stone-free status, EBL (≥250 cc), operative time, and LOS on regression analysis

Variable	ß-coefficient	OR	95% CI		p value
			Lower	Upper	
Stone-free	NA	0.7	0.6*	0.9*	0.002
EBL (≥250 cc)	NA	1.4	1.1*	1.7*	0.002
Operative time	7.7	NA	4.6**	10.9**	<0.001
LOS	0.6	NA	0.2**	0.9**	0.001

*95% CI of OR for stone-free and EBL. **95% CI of ß-coefficient for LOS and operative time. EBL: estimated blood loss; LOS: length of hospital stay; OR: odds ratio; CI: confidence interval.

predicting stone-free status.[13] They reported AUC of 0.67 (range: 0.60–0.73) for the S.T.O.N.E. nephrolithometry scoring system.[13] Out of the 5 elements of the S.T.O.N.E. nephrolithometry scoring system, only 2 were significant predictors of stone-free status in the present study. Whereas stone size and number of involved calyces were significant predictors of stone-free status, tract length, obstruction/hydronephrosis and stone essence were not (Table 2). In addition, the AUCs for stone size and number of involved calyces were not significantly different than that for the S.T.O.N.E. scoring system, with AUCs of 0.64, 0.66, and 0.63, respectively ($p > 0.05$) (Fig. 2). Therefore, the stone size and number of involved calyces are as good as the S.T.O.N.E. nephrolithometry scoring system in predicting stone-free status post PCNL. In addition, tract length, obstruction/hydronephrosis and stone essence may not contribute to predicting stone-free status post-PCNL. This could be due to the way each of these elements is scored within S.T.O.N.E. nephrolithometry scoring system. For example, the absence of hydronephrosis is scored as 0, mild hydronephrosis as 1, and moderate/severe hydronephrosis as 2. However, from personal experience, a patient with a staghorn stone without any hydronephrosis is much more complex than a patient with a staghorn stone with moderate or severe hydronephrosis. According to the S.T.O.N.E. nephrolithometry scoring system, the first patient would be scored 12, whereas the second patient would be scored 13. Interestingly, there were no patients in the current series with a S.T.O.N.E. score of 13 (Fig. 1). The other insignificant predictor of stone-free status was tract length, which is used as a surrogate for obesity. Similar to the present study, previous studies have shown that obesity did not affect PCNL outcomes.[14,15] The last insignificant predictor was stone essence or HU. Since fluoroscopy is used intra-operatively to locate stones, radiolucent stones may be easily missed. Therefore, radiolucent stones would be expected to be associated with lower stone-free status. However, this was not seen in the present series, perhaps due to small number of PCNLs with radiolucent stones (only 19 PCNLs making up 12.3%) (Table 1). In addition, the lack of association of stone HU with stone-free status may also be due to the availability of different modes of intra-corporeal lithotripters, such as pneumatic, ultrasonic and Holmium:YAG laser, which are capable of fragmenting stones with various densities.

In the current series, 56% of cases had preoperative indwelling ureteral stent. This is because our centre is a tertiary referral centre for management of complex stone disease. Often the referring community urologist inserts ureteral stents and then transfers the patient to our centre for definitive management of stones. As expected, there was higher mean number of punctures (2.1) when compared with the mean number of tracts (1.2), since each tract may have required more than one puncture to obtain the correct PCA. In addition, postgraduate trainees assisting PCNLs often attempt the first one or two punctures. If these are not appropriate for dilation, then the attending endourologist obtains the PCA.

The limitations of this study include its retrospective nature. In addition, all preoperative NCCTs were studied and S.T.O.N.E. scores were calculated by a single reviewer. Therefore, inter-rater concordance could not be performed. However, the S.T.O.N.E. scoring system had a good inter-rater reliability on a previous study.[6] In addition, the single reviewer adds consistency in evaluating charts. Nonetheless, the present study is the first study to externally validate the S.T.O.N.E. nephrolithometry scoring system.

Conclusion

Although this study externally validates the S.T.O.N.E. scoring system, its accuracy is comparable to stone size and number of involved calyces in predicting stone-free status post-PCNL. In addition, the S.T.O.N.E. score failed to predict postoperative complications, which may be related to other factors not included in the scoring system. Factors, such as surgeon experience and assistance of postgraduate trainees, may need to be incorporated in future nephrolithometry scoring systems.

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