Development and Validation of a Model to Predict Ureteral Stent Placement Following Ureteroscopy: Results From a Statewide Collaborative

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OBJECTIVE To develop and validate a model to predict whether patients undergoing ureteroscopy (URS) will receive a stent.

METHODS Using registry data obtained from the Michigan Urological Surgery Improvement Collaborative Reducing Operative Complications from Kidney Stones initiative, we identified patients undergoing URS from 2016 to 2020. We used patients' age, sex, body mass index, size and location of the largest stone, current stent in place, history of any kidney stone procedure, procedure type, and acuity to fit a multivariable logistic regression model to a derivation cohort consisting of a random two-thirds of episodes. Model discrimination and calibration were evaluated in the validation cohort. A sensitivity analysis examined urologist variation using generalized mixed-effect models.

RESULTS We identified 15,048 URS procedures, of which 11,471 (76%) had ureteral stents placed. Older age, male sex, larger stone size, the largest stone being in the ureteropelvic junction, no prior stone surgery, no stent in place, a planned procedure type of laser lithotripsy, and urgent procedure were associated with a higher risk of stent placement. The model achieved an area under the receiver operating characteristic curve of 0.69 (95% CI 0.67, 0.71). Incorporating urologist-level variation improved the area under the receiver operating characteristic curve to 0.83 (95% CI 0.82, 0.84).

CONCLUSION Using a large clinical registry, we developed a multivariable regression model to predict ureteral stent placement following URS. Though well-calibrated, the model had modest discrimination due to heterogeneity in practice patterns in stent placement across urologists. UROLOGY 177: 34–40, 2023. © 2023 Elsevier Inc. All rights reserved.

The incidence and prevalence of urolithiasis has been rising across the world,[1,2] and its effects are compounded by a recurrence rate of up to 50% within the 5 years following an initial kidney stone episode.[3] Patients with kidney stones experience pain and decreased physical function that is worse with more stone episodes,[4] are more likely to develop anxiety and depression regardless of their baseline comorbidities,[5] and have worse health-related quality of life.[6] Ureteroscopy (URS) is one of the most common interventional methods to remove kidney stones. Ureteral stents, often placed in the ureter following URS, maintain patency in the event of ureteral edema. However, ureteral stents may cause discomfort and complications in patients.[7,8] Uncertainty around the need for a stent further contributes to patient anxiety during counseling for a URS particularly in patients who have previously had an episode requiring a stent.[9,10]

Knowing the likelihood of stent placement may alleviate some of this anxiety, particularly in patients who can be reassured by a predictive model that they are unlikely to require a stent. Communicating this risk to patients is

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important as a part of pre-URS counseling. While several models already exist to counsel patients with urolithiasis, prior work has focused on developing models to predict the occurrence[11] or recurrence[12] of kidney stones, postoperative infections,[13] and spontaneous passage of ureteral stones.[14] While these models are useful in guiding the prevention of recurrent stones, or in deciding whether a procedure may be required to clear a stone, there is a need for risk stratification tools around the need for a stent among patients requiring URS.

In this context, we developed and validated a model to predict patients' likelihood of getting a ureteral stent following URS, using data from a large clinical registry maintained by the Michigan Urological Surgery Improvement Collaborative (MUSIC). The objective of this study was to develop a simple and accurate model that estimates the probability of stenting using preoperative patient and clinical information as a quick tool for risk communication.

METHODS

Data Source

Established in 2011, MUSIC is a physician-led quality improvement collaborative across the state of Michigan funded by Blue Cross Blue Shield of Michigan. MUSIC comprises 46 diverse community and academic urology practices representing approximately 90% of the urologists in the state. Reducing Operative Complications from Kidney Stones (ROCKS) is an initiative designed to improve the quality of care for kidney stone patients, particularly decreasing modifiable emergency department visits following surgery, specifically after URS and shockwave lithotripsy (SWL). This all-payer registry captures detailed clinical and operative data for patients undergoing URS and SWL in the state of Michigan. Each MUSIC practice obtained an exemption or approval for collaborative participation from a local institutional review board.

Study Cohort

The cohort of this study included adult patients who had kidney and/or ureteral stone(s) and underwent URS between June 2016 and June 2020. We excluded patients with unknown height or weight. Furthermore, we excluded patients with missing ureteral stent placement status (ie, where it was unknown whether a stent was placed). Patient comorbidity information was included if collected before URS or in the 90 days after URS. The patient cohort was divided into derivation and validation cohorts using 2:1 random sampling at the patient level to ensure that patients with repeated encounters had all their encounters in either the derivation or validation cohort.

Model Development

All variables in the kidney stone data set were screened and a list of candidate predictors were selected by urologists. Using age, body mass index (BMI), size of the largest stone as numeric predictors; female sex, history of any kidney stone procedure, current stent in place, location of the largest stone, procedure type (ie, laser lithotripsy or basket stone extraction), and procedure acuity, we fitted a multivariable logistic regression model to predict the probability of having a stent placed during URS.

Model Validation

The logistic regression model trained from the derivation cohort was evaluated on the validation cohort. The model discrimination was evaluated using the area under the receiver operating characteristic curve (AUC). Sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) were also used to evaluate the model discrimination at different thresholds. Model calibration was evaluated using a calibration plot, comparing the deciles of the predicted probabilities with the observed risk.

Missing Data

Missing data were imputed via bagged trees, a nonparametric imputation method.[15] For each variable requiring imputation, a bagged tree was fit using the variable of interest as the outcome and the rest of the variables were used as predictors. The bagged tree models were fit using the derivation cohort only, and then applied to both the derivation and validation cohorts.

Sensitivity Analysis

To examine the variability across urologists in the placement of a ureteral stent, we fit two generalized linear mixed models in which we used the same modeling strategy, except that the intercept was allowed to vary by urologist. In our first model, we fit a null model on the derivation cohort using *only* the random intercept and no covariates. In the second model, fit a random intercept model that *also* included patient characteristics as covariates. AUC was measured in the validation cohort and compared with the primary model.

Software

All analyses were done using R 3.6.0.[16] The cohort preparation, missing data imputation and multivariable logistic regression modeling were implemented using *tidyverse* (version 1.3.2),[17] *tidymodels* (version 1.0.0),[18] and *h2o* (version 3.38.0.1).[19] The generalized linear mixed model was fit using *lme4* (version 1.1-31).[20,21]

Table 1. Patient characteristics of the study cohort by stent placement.

Characteristic	*N*	Overall[1] (*N* = 15,048, 13,958 Patients)	Outcome: Stent Placement Yes* (*N* = 11,471, 10,777 Patients)	No* (*N* = 3577, 3465 Patients)	*P*-value†
Age, y	15,048	55.9 (15.9)	56.5 (15.7)	53.9 (16.2)	**< 0.001**
Female	15,048	7656 (51%)	5729 (50%)	1927 (54%)	**< 0.001**
Race	13,178				0.064
African American		932 (7.1%)	722 (7.3%)	210 (6.4%)	
Caucasian		11,755 (89%)	8827 (89%)	2928 (89%)	
Other		491 (3.7%)	353 (3.6%)	138 (4.2%)	
Unknown		1870	1569	301	
BMI, kg/m^2	15,048	31.1 (7.7)	31.2 (7.8)	30.7 (7.5)	**< 0.001**
Ureteral stent in place	14,699	5724 (39%)	3966 (36%)	1758 (49%)	**< 0.001**
Missing		349	340	9	
History of prior kidney stone surgery	11,406	5597 (49%)	4177 (48%)	1420 (52%)	**0.002**
Missing		3642	2814	828	
Size of the largest stone, mm	13,504	7.8 (4.5)	8.2 (4.7)	6.4 (3.2)	**< 0.001**
Unknown		1544	1239	305	
Location of the largest stone	13,041				**< 0.001**
Upper/Proximal pole calyx		574 (4.4%)	442 (4.5%)	132 (4.2%)	
IP calyx		552 (4.2%)	412 (4.2%)	140 (4.4%)	
Lower/Distal pole calyx		1636 (13%)	1247 (13%)	389 (12%)	
RP		1060 (8.1%)	893 (9.0%)	167 (5.3%)	
UMU		3866 (30%)	2993 (30%)	873 (28%)	
LDU		2954 (23%)	2080 (21%)	874 (28%)	
UPJ		1212 (9.3%)	1016 (10%)	196 (6.2%)	
UVJ		1187 (9.1%)	791 (8.0%)	396 (13%)	
Missing		2007	1597	410	
Procedure type	15,048				**< 0.001**
Laser lithotripsy		11,713 (78%)	9476 (83%)	2237 (63%)	
Basket stone extraction		3335 (22%)	1995 (17%)	1340 (37%)	
Procedure acuity	14,402				**< 0.001**
Elective		12,093 (84%)	9073 (83%)	3020 (86%)	
Urgent/Emergent		2309 (16%)	1834 (17%)	475 (14%)	
Missing		646	564	82	

BMI, body mass index; IP, interpolar; LDU, lower/distal ureter; RP, renal pelvis; UMU, upper/proximal/mid ureter; UPJ, ureteropelvic junction; UVJ, ureterovesical junction. Bold is for p<0.05.

* Statistics presented: mean (SD); n (%).

† Statistical tests performed: Wilcoxon rank sum test; chi-square test of independence.

RESULTS

Cohort Characteristics

Our MUSIC ROCKS database consisted of 25,422 adult patients (including both SWL and URS cases). After excluding those without basic demographics information ($n = 1929$), those underwent SWL or no procedure was done ($n = 8370$), and those with missing stent placement status ($n = 75$), we identified 15,048 URS procedures (13,958 patients) which met the inclusion and exclusion criteria (Supplementary Fig. 1). The final cohort consisted of 51% female and 89% white patients with a mean age of 55.9 years. Of this final cohort, 11,471 (76.2%) procedures led to ureteral stent placement. After the random split, the derivation and validation cohorts contained 10,022 procedures (9305 patients) and 5026 procedures (4653 patients), respectively.

Supplementary Table 1 displays the patient characteristics of those in the derivation cohort and those in the validation cohort. No characteristic was statistically different between the two cohorts. Table 1 demonstrates the patient characteristics of those with and without ureteral stent placement. Compared with the no stent placement group, those who had stent placement were more likely to be older (mean age, 56.5 vs 53.9; $P < .001$), male (50% vs 46%; $P < .001$), have higher BMI (mean, 31.2 vs 30.7; $P < .001$), have no stent in place (64% vs 51%; $P < .001$), have no prior kidney stone procedure (52% vs 48%), and have a larger stone (mean, 8.2 mm vs 6.4 mm; $P < .001$). Their location of

Table 2. Multivariable logistic regression results.

Variable	Odds Ratio (95% CI)	*P*-value
Age	1.01 (1.01, 1.01)	**< 0.001**
Female	0.90 (0.81, 0.99)	**0.034**
BMI	1.01 (1.00, 1.01)	0.051
Diameter of the largest stone (mm)	1.12 (1.10, 1.14)	**< 0.001**
Location of the largest stone (reference: UMU)		
Upper/Proximal pole calyx	0.68 (0.53, 0.88)	**0.004**
IP calyx	0.60 (0.47, 0.78)	**< 0.001**
Lower/Distal pole calyx	0.74 (0.63, 0.88)	**< 0.001**
RP	0.81 (0.64, 1.02)	0.071
LDU	0.72 (0.63, 0.82)	**< 0.001**
UPJ	1.23 (1.00, 1.52)	**0.050**
UVJ	0.61 (0.51, 0.73)	**< 0.001**
Prior stone surgery (reference: No)		
Yes	0.86 (0.78, 0.96)	**0.005**
Ureteral stent in place		
Yes	0.52 (0.47, 0.58)	**< 0.001**
Procedure type (reference: Laser lithotripsy)		
Basket stone extraction	0.51 (0.46, 0.57)	**< 0.001**
Procedure acuity (reference: Elective)		
Urgent/Emergency	1.30 (1.12, 1.50)	**< 0.001**
Intercept	1.29 (0.95, 1.75)	0.099

Bold is for p<0.05.

the largest stone, procedure type, and procedure acuity were also statistically different between the two groups.

Model Characteristics

The results of the multivariable logistic regression model are shown in Table 2. All predictors, except BMI and having the largest stone in the renal pelvis, were significantly associated with ureteral stent placement. Among these predictors, being older, male, having a larger stone, with the largest stone in the ureteropelvic junction (compared to in the upper/proximal/mid ureter), having a history of stone surgery, not pre-stented, undergoing a laser lithotripsy, urgent procedure, increased the odds of having ureteral stent placement significantly at the level of .05.

Model Discrimination and Calibration

The model achieved an AUC of 0.69 (95% CI 0.67, 0.71) in the validation cohort. Parallel comparison of the model performance (sensitivity, specificity, PPV, and NPV) at different thresholds is shown in Figure 1. Approximately 76% of episodes in our cohort had stent placement and the rest 24% did not. For patients with a predicted probability below a threshold of 0.50, the model had a NPV of 61% while identifying 11% of patients who would not require stenting (ie, specificity). Above this threshold, the PPV was 77% and the sensitivity was 98%. The model was well-calibrated in the validation cohort (Fig. 2).

Sensitivity Analysis

Using generalized linear mixed modeling, the null model (random intercept only) had an AUC of 0.76 (95% CI 0.74, 0.77) in the validation cohort. The model containing patient covariates and random intercepts achieved an AUC of 0.83 (95% CI 0.82, 0.84) in the validation cohort. In this model, age, size of the largest stone, certain location of the largest stone, history of stone surgery, in-place stent, procedure type, and procedure acuity remained statistically significant (Supplementary Table 2).

Software

A web app implementing the model from the primary analysis is accessible at (https://ml4lhs.shinyapps.io/askmusic_rocks_stent/).

DISCUSSION

We developed a logistic regression model to predict the probability of having a ureteral stent placed following URS based on common demographic and clinicopathologic factors. The model exhibited modest discrimination (ie, AUC) and good calibration in the validation cohort. Below a threshold of 0.50, the model was able to identify a small proportion (11%) of patients who did not receive a stent with a NPV of 61%, which is more than double the probability of avoiding a stent among the entire cohort (24%, 3577/15,048). Thus, while our model has the potential to inform preprocedure discussions with patients, only a small fraction of patients can be reassured that their chance of avoiding a stent is double the overall cohort—even in this cohort, over a third will ultimately require a stent.

We found that much of the variation in stent placement was attributable to urologists, with both mixed effects models outperforming the primary model (AUCs of 0.76 and 0.83 for the mixed effects models vs 0.69 for the primary model). The decision to place a stent appears to be driven more by which urologist is evaluating a

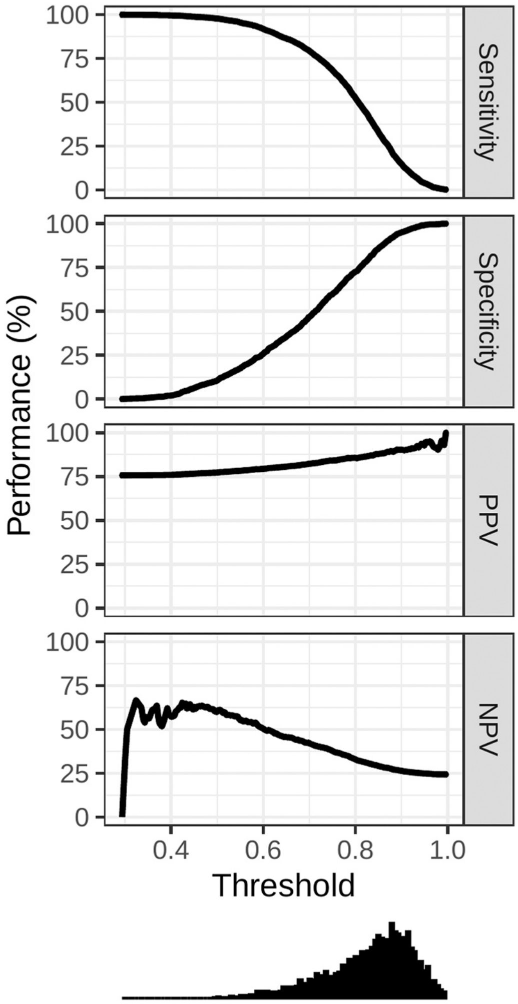

Figure 1. Model performance at different thresholds. Model discrimination on the validation cohort at different thresholds. Metrics presented for parallel comparison include sensitivity, specificity, positive predictive value, and negative predictive value. The histogram on the bottom shows the distribution of predicted probabilities.

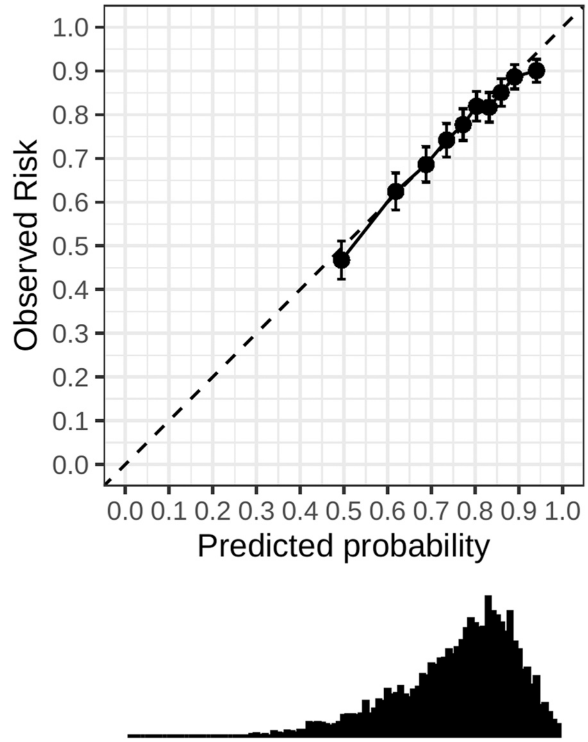

Figure 2. Model calibration plot. Model calibration on the validation cohort. The predicted probabilities (deciles) are plotted against the observed probabilities with 95% confidence intervals. The diagonal line demonstrates the ideal calibration. The histogram on the bottom shows the distribution of predicted probabilities.

patient than clinical factors pertinent to their case. Recent efforts within MUSIC to standardize criteria for stent placement are aimed to reduce this heterogeneity.[22] Our intent is not to facilitate comparison shopping for patients based on stenting rates, so our web app for predicting stent placement only draws from the primary model and not the mixed effects models.

Our study adds to the growing body of literature on prediction models that support the care of patients with urolithiasis.[11-14,23] Whereas existing models focus on issues related to the subacute management of stones, including prediction of occurrence, recurrence, spontaneous passage, and complications, our model's intended use is during the acute presentation of urolithiasis requiring ureteroscopic management. We also identified factors in our multivariable model associated with stent placement, including older age, male sex, larger stone size, not prestented, history of stone surgery, stone location, laser lithotripsy, and urgency of the procedure. As our study was not designed to test a hypothesis, these associations should be considered hypothesis-generating only.

Our study is limited by a modest discriminative performance, with an AUC of 0.69 in our primary analysis. This appears to be due to heterogeneity in practice patterns across urologists based on our finding that the mixed effects models outperformed the primary model. Given the observed differences in stent rates across urologists in our cohort, similar differences outside of our cohort may limit the generalizability of our findings without knowing and accounting for these differences.

Despite these limitations, our work has important implications for clinical practice and research. Recent work has suggested that ureteral stent placement following URS increases ED visits,[24] and the degree of patient discomfort during URS is linked to both the presence of and type of stent.[25] This suggests a need for preoperative counseling about the need for and type of stent. Our study, drawing from a large and diverse multicenter cohort that includes academic and community practice settings, provides the first evaluation of a model developed to aid in the communication of information around need for a ureteral stent that may help to reassure a small proportion of low-risk patients among an otherwise high-risk population in whom over three-quarters of patients received a stent. By putting kidney stone registry data back into the hands of patients in the form of a patient-facing tool, this work empowers patients to have a more informed conversation with their urologist about their need for ureteral stenting.

Take Home Message

We have developed and tested a model that predicts the risk of ureteral stent placement following URS for the treatment of kidney stones. Use of the model to communicate this risk has the potential to alleviate uncertainty around the need for a stent.

AUTHOR CONTRIBUTIONS

Karandeep Singh had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis. *Study concept and design*: Cao, Inadomi, Hiller, Ghani, Singh. *Acquisition of data:* Cao, Inadomi, Singh. *Analysis and interpretation of data:* All of the authors. *Drafting of the manuscript:* Cao. *Critical revision of the manuscript for important intellectual content:* All of the authors. *Statistical analysis:* Cao, Inadomi, Singh. *Obtaining funding:* Ghani. *Administrative, technical, or material support:* None. *Supervision:* Singh. *Other:* None.

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APPENDIX A. SUPPORTING INFORMATION

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.urology.2023.01.059.

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EDITORIAL COMMENT

Urologists today practice in a clinical environment that is awash in electronic health data. Sadly, much of these data are locked in the electronic medical record, unable to provide meaningful information for guiding patient care. Real-world evidence, such as data from the electronic medical record, can inform comparative effectiveness studies, pragmatic trials, and clinical prediction models, among other uses

In this study,[1] investigators use data collected within the Michigan Urological Surgery Improvement Collaborative Reducing Operative Complications from Kidney Stones initiative to derive a model predicting the probability that a patient undergoing ureteroscopy for stone treatment would have a ureteral stent placed. Incorporating data from over 15,000 ureteroscopic stone removals, and incorporating variation among urologists within the collaborative, the investigators achieved a model with an area under the receiver operating characteristic curve of 0.83 (0.82, 0.84),[1] which shows good predictive ability. Urologists who use this model can potentially provide more precise guidance for patients regarding whether a ureteral stent is likely postoperatively, which may help in treatment selection as well as preparing patients for postoperative recovery. As the authors note, generalizability of the model to states other than Michigan should be assessed in future studies

Nevertheless, development of this predictive model is a seminal demonstration of applying real-world evidence to guide care and counseling for patients with stone disease. This type of innovation should impel formation of additional interdisciplinary collaborations of informaticists, statisticians, endourologists, and patient advocates, leveraging the promise of data science and EHR to mitigate the burden of stone disease for our patients.

DECLARATION OF COMPETING INTEREST

No conflict.

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