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Factors affecting operative time in ureteroscopic stone removal: A cross-sectional study for prediction model construction

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Article

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Abstract

Objective:

To identify independent factors influencing operative time and develop a preoperative prediction model for patients achieving stone-free status after a single ureteroscopic stone removal procedure, supporting clinical decision-making and mitigating risks associated with prolonged surgery.

Methods:

In an observational cohort study, 495 patients undergoing ureteroscopic lithotripsy at Shandong Provincial Third Hospital (December 2023–December 2024) were included. Preoperative data included demographics, imaging features, and laboratory results. Variable selection used univariate analysis followed by LASSO regression. A Gamma regression model (Generalized Linear Model framework) served as the primary prediction tool, assessed via variance inflation factor (VIF) and residual analysis. Internal validation employed 1000 bootstrap samples; a nomogram was created for clinical use. A logistic regression model using dichotomized operative time was evaluated by ROC curve and Decision Curve Analysis (DCA).

Results:

Among 14 significant variables, three key predictors emerged: stone length and maximum stone density (risk factors), and simple ureteral stone (protective factor). The Gamma model showed no multicollinearity (VIFs < 2) and was robust on bootstrap validation (MSE: 20.2, RMSE: 26.9). Despite slight overestimation for very short procedures, predicted and observed operative times correlated significantly ($p < 0.05$). The logistic model demonstrated strong discrimination (AUC = 0.879) and favorable clinical utility on DCA.

Conclusion:

Stone length and density independently predict longer operative time, while simple ureteralstones shorten it. The Gamma and logistic regression models provide reliable, clinically applicable tools for preoperative planning, potentially improving resource allocation and patient safety.

Introduction

Urolithiasis (urinary stone disease) is among the most common conditions affecting the urinary system, with a global prevalence affecting approximately 10% of the population [1].The ureteroscope was first developed in 1912 when Hugh Hampton Young inadvertently used a pediatric cystoscope to examine a dilated ureter in an infant [2]. Subsequently, the flexible ureteroscope emerged, with the first clinical application reported by Marshall in 1964 [3]. Following significant refinements in optics, maneuverability, and the incorporation of working channels in the subsequent decades, the use of flexible ureteroscopy rapidly gained widespread adoption [4–6]. Due to its demonstrated efficacy and safety, the procedure has been incorporated into the European Association of Urology (EAU) guidelines as a standard minimally invasive approach for managing urinary tract stones [7].

However, patients remain at significant risk for various postoperative complications. These can be broadly categorized into procedure-related injuries, such as those occurring during access or manipulation, and device-

related issues, notably those associated with ureteral stents [8]. While the prediction of postoperative complications has been extensively studied, the forecasting of operative duration has been comparatively neglected [9–11]. This is a significant oversight, as operative time is a critical determinant of intraoperative safety and a crucial modifiable factor influencing patient prognosis.

While existing studies have attempted to predict operative time, they are often limited by a narrow focus on isolated variables [12]. There is a compelling need to develop a comprehensive and systematic predictive model for preoperative estimation. The crux of such prediction lies in the accurate identification of patient populations likely to undergo prolonged procedures.

This study retrospectively analyzed multi-dimensional patient data, including demographic characteristics, general examinations, complete blood and urine counts, and biochemical profiles, to identify independent determinants of operative time. Based on these factors, we developed a predictive model to preoperatively identify patients at high risk of prolonged procedures. The findings provide a scientific basis for optimizing individualized surgical planning and improving resource allocation in perioperative care.

Materials And Methods

Ethical Compliance

All methods were performed in accordance with the relevant guidelines and regulations.

Patient Data

A total of 495 patients with urinary calculus who underwent ureteroscopic stone removal at the Department of Urology, Shandong Provincial Third Hospital, between December 2023 and December 2024 were retrospectively enrolled. Clinical data collected included demographic characteristics (Age, Gender, Body mass index (BMI), History of present illness, History of past illness), general physical examinations (ASA score, Stone length, The maximum density of the calculus, Single urinary calculi, Simple kidney stones, Simple ureteral calculi, Renal and ureteral calculi), complete blood and urine tests (Alkaline urine, Urine glucose, Urinary nitrite, White Blood Cell (WBC), Urine White Blood Cell (UWBC), Urine Red Blood Cell (URBC)), and biochemical profiles (Serum creatinine, Blood uric acid, Blood calcium, Parathyroid hormone (PTH)).

Inclusion Criteria

Patients were included if they met the following criteria:

Adult age (≥18 years);

Availability of essentially complete clinical records;

Successful completion of ureteroscopic stone removal surgery;

Postoperative abdominal plain film confirmed complete stone clearance.

Exclusion Criteria

Individuals were excluded under the following conditions:

Minors (age <18 years);

Previous diagnosis of urothelial tumors;

History of chronic kidney disease.

Surgical Techniques

The ureteroscopic lithotripsy and stone extraction procedure was performed as follows. Initial access and preliminary maneuvers were accomplished using a rigid ureteroscope with available sizes of 6/7.5 Fr or 8/9.8 Fr. If the clinical situation warranted, such as for stones located in the proximal ureter or within the renal collecting system, the rigid scope was exchanged for a flexible ureteroscope to facilitate further access [13]. Intracorporeal lithotripsy, when required for stone fragmentation, was uniformly performed using a holmium:YAG laser [14]. In procedures where the flexible ureteroscope was deployed, a ureteral access sheath (UAS) was routinely employed. The use of a UAS offers several demonstrated advantages: it protects the ureteral wall from trauma during repeated scope passages, maintains lower intrarenal pressures by allowing for adequate irrigation outflow, and facilitates the efficient extraction of stone fragments [15]. To ensure procedural standardization and technical consistency across all cases in this study, the surgeries were performed by three attending urologists. All three surgeons had received centralized, structured training in this specific technique from the same senior endourology expert. This approach was taken to minimize inter-surgeon variability and ensure a uniformly high level of operative skill.

Statistical Analysis

All statistical analyses were performed using the R software environment (version 4.5.1, R Foundation for Statistical Computing). The analysis encompassed data preprocessing, descriptive statistics, model building, and internal validation.

Data Preprocessing and Descriptive Statistics

Missing data were handled using Multiple Imputation with the mice-package in R. Outliers were identified using box-plot visualization and addressed by applying the winsorization method (capping), where extreme values beyond the 90th percentile were set to the value at the 90th percentile to reduce their undue influence. Normality of continuous variables, including the dependent variable (operative time), was assessed using a combination of Q-Q plots, histograms, and normal density curves. Since operative time was confirmed to be right-skewed, all continuous variables are described accordingly: those conforming to a normal distribution are presented as mean ± standard deviation ($x \pm s$), while non-normally distributed variables are summarized as median with first and third quartiles (Md (Q1, Q3)). Categorical variables are expressed as frequency (n) and percentage (%). For univariate analysis involving continuous variables, the Spearman's rank correlation coefficient was employed. The Wilcoxon rank-sum test and the Kruskal-Wallis H test were used for comparing two or more groups of non-normally distributed continuous variables, respectively. P-value < 0.05 was defined as the threshold for statistical significance for all tests.

Model Development and Internal Validation

Model building was conducted in a multi-step process. Initially, a quantile regression model was constructed to model the median or other quantiles of operative time. Subsequently, the dependent variable was log-transformed to address its skewness. Key predictors were then selected using the Least Absolute Shrinkage and Selection Operator (LASSO) regression, with a significance level of $P < 0.05$ for retention. The relative importance of these selected

factors was visualized using a bar plot. These key factors were incorporated into a Gamma regression model within the Generalized Linear Models (GLM) framework, chosen for its suitability for modeling positive, right-skewed continuous data. The model's adequacy was rigorously checked: Variance Inflation Factors (VIF) were calculated to assess multicollinearity, and a plot of residuals versus fitted values was examined to verify the randomness of residuals and homogeneity of variance. A sensitivity analysis was performed by comparing the original model with a model fitted after removing identified outliers. Internal validation of the final model was carried out using Bootstrap resampling with 1000 repetitions to estimate the model's optimism and true predictive performance on new data. A nomogram was constructed based on the final model to facilitate clinical application by providing individualized risk predictions.

Model Evaluation

Model performance was evaluated across multiple dimensions. A calibration scatter plot was used to assess the agreement (calibration) between predicted and observed values. A scatter plot of residuals versus predicted values was drawn to detect any systematic patterns of fit error. To further evaluate the clinical utility of the model, the continuous operative time variable was dichotomized based on a clinically meaningful cut-off value ("≤90 minutes" vs. ">90 minutes").[7] A logistic regression model was then constructed using the key predictors identified earlier. The discriminative ability of this binary classification model was quantified by calculating the area under the receiver operating characteristic (ROC) curve (AUC). Finally, decision curve analysis (DCA) was applied to evaluate the net clinical benefit of the model across different decision thresholds, thereby clarifying its clinical applicability .

This comprehensive statistical analysis strategy ensures the robustness and clinical utility of the study findings in identifying factors influencing operative time and developing a reliable prediction model.

Results

This study retrospectively analyzed a cohort of 495 patients who underwent ureteroscopic lithotripsy. In all cases, stone-free status (SFR Grade A) was confirmed by a plain abdominal X-ray (KUB) performed prior to the removal of the ureteral stent following the procedure.

For continuous variables, potential outliers were first identified using box plots, followed by an assessment of normality distribution through Q-Q plots, histograms, and normal density curves. The baseline characteristics of the study population, including both continuous and categorical variables, are summarized in Table 1.The results of the univariate analysis are summarized in Table 2. Among the 29 preoperative variables assessed, 14 factors—including simple ureteral stone, stone length and maximum stone density—were found to be statistically significant ($P < 0.05$).

Table 1
Baseline characteristics of patients

Characteristic	N = 495 Median(Q1,Q3); Mean(SD); n(%)	Characteristic	N = 495 Median(Q1,Q3); Mean(SD); n(%)
Operation time	53.00(32.00,87.00)	Gender	
Age	49.96(13.62)	Female	165(33%)
BMI	26.11 (3.71)	Male	330(67%)
WBC	6.90(5.46,8.98)	Second stage operation	
UWBC	26.20(9.20,75.50)	No	445(90%)
URBC	53.80(8.50,331.80)	Yes	50(10%)
Serum.creatinine	79.00(66.00,96.00)	Without.Symptom	
Blood.uric.acid	341.97(88.89)	No	430(87%)
Blood.calcium	2.30(0.11)	Yes	65(13%)
PTH	42.87(33.04,53.04)	High.blood.pressure	
Stone.length	0.90(0.60,1.20)	No	367(74%)
The.maximum.density. of.the.calculus	846.18(377.75)	Yes	128(26%)
History.of.calculi		Diabetes	
No	351(71%)	No	432(87%)
Yes	144(29%)	Yes	63(13%)
ESWL		Cardiovascular.and.cerebrovascular.diseases	
No	446(90%)	No	430(87%)
Yes	49(10%)	Yes	65(13%)
Bilateral.calculi		Anatomic.Abnormality	
No	442(89%)	No	482(97%)
Yes	53(11%)	Yes	13(3%)
Simple.ureteral. calculi		Urine.glucose	
No	237(48%)	No	455(92%)
Yes	258(52%)	Yes	40(8%)

Characteristic	**N = 495 Median(Q1,Q3); Mean(SD); n(%)**	**Characteristic**	**N = 495 Median(Q1,Q3); Mean(SD); n(%)**
Characteristic	**N = 495** Median(Q1,Q3); Mean(SD); n(%)	**Characteristic**	**N = 495** Median(Q1,Q3); Mean(SD); n(%)
Renal.and.ureteral. calculi		Urinary.nitrite	
No	353(71%)	No	474(96%)
Yes	142(29%)	Yes	21(4%)
Single.urinary.calculi		Alkaline.urine	
No	176(36%)	No	468(95%)
Yes	319(64%)	Yes	27(5%)
ASA.score		Simple.kidney.stones	
1	17(3%)	No	399(81%)
2	453(92%)	Yes	96(19%)
3	25(5%)		

Table 2
Univariate analysis of variables

Variable	P	Variable	P
Age	0.005587	Renal.and.ureteral.calculi	< 0.001
WBC	< 0.001	ASA.score	0.01731
UWBC	< 0.001	BMI	0.3023
Stone.length	< 0.001	URBC	0.3634
The.maximum.density. of.the.calculus	< 0.001	Serum.creatinine	0.3289
Second.stage.operation	0.01252	Blood.uric.acid	0.8284
Without.Symptom	< 0.001	Blood.calcium	0.6087
History.of.calculi	< 0.001	PTH	0.286
Bilateral.calculi	< 0.001	Gender	0.08882
Urine.glucose	0.2349	Alkaline.urine	0.5379
Urinary.nitrite	0.1527	High.blood.pressure	0.1207
ESWL	0.1473	Diabetes	0.07979
Single.urinary.calculi	< 0.001	Cardiovascular.and. cerebrovascular.diseases	0.08377
Simple.kidney.stones	< 0.001	Anatomic.Abnormality	0.2494
Simple.ureteral.calculi	< 0.001		

An initial predictive model was developed using quantile regression. However, this model was found to be affected by significant multicollinearity. To address this, the operative time was log-transformed, and a Least Absolute Shrinkage and Selection Operator (LASSO) regression was applied. We performed cross-validation following the LASSO fit and compared the models built using the min rule versus the 1se rule. The model constructed with the minimum criterion (min) rule (MSE = 0.1857) required the inclusion of 8 variables. In contrast, the model built using the one standard error (1se) rule (MSE = 0.1951) incorporated only 3 variables. This resulted in a substantially simplified model at the cost of only a 5% increase in error. The relative influence of the three variables incorporated under the 1se rule on operative time was evaluated. It was found that the variation in operative time was attributed to the presence of a simple ureteral stone (-26.62%), stone length (57.85%), and maximum stone density (0.03%).

Subsequently, a Gamma regression model was constructed. A sensitivity analysis comparing the initial Gamma model (Null deviance = 193.6, Residual deviance = 91.0,AIC = 4512.2) with a model refitted after removing influential data points (Null deviance = 195.1, Residual deviance = 89.3, AIC = 4494.7) revealed that the coefficients for key predictors (e.g., stone length and presence of simple ureteral stones) changed by less than 1%, indicating robust parameter estimates. The variance inflation factor (VIF) for each predictor in the final Gamma model was below 2, confirming the absence of multicollinearity concerns. The model's goodness-of-fit was further assessed by examining the plot of residuals versus fitted values, which showed a random distribution of points and stable variance, supporting the model's assumptions. Internal validation was performed using Bootstrap resampling with

1000 repetitions. The bootstrap-derived confidence intervals indicated that stone length (95% CI: 0.4387 to 0.5951) and the presence of simple ureteral stones (95% CI: -0.4791 to -0.2880) were statistically significant predictors. While maximum stone density reached statistical significance, its effect size was minimal(95% CI: 0.0003–0.0005). The sampling distribution of the coefficients from the bootstrap analysis was approximately normal, satisfying statistical assumptions and demonstrating precise model estimates, which validates the obtained confidence intervals.

A nomogram was developed based on the final model to provide a practical tool for individualized preoperative prediction of operative time (Fig. 1). Subsequently, the calibration scatter plot demonstrated a significant positive correlation trend between the model's predicted values and the actual observed values. However, the smoothed calibration curve lay below the line of perfect calibration, indicating a slight systematic overestimation by the model (MAE = 20.2, RMSE = 26.9). This observation was further supported by the scatter plot of residuals versus predicted values. Although a few instances with strongly negative residuals were severely overestimated by the model, no significant heteroscedasticity (funnel effect) was detected overall.

To further evaluate the clinical utility of the model, operative time was dichotomized (e.g., “≤90minutes” vs. “>90minutes”), and a logistic regression model was developed. The discriminative ability of this model was excellent, with an area under the receiver operating characteristic (ROC) curve (AUC) of 0.879 (Fig. 2). Decision Curve Analysis (DCA) showed that the logistic regression model provided a higher net clinical benefit within a medium probability threshold range (0.1 ~ 0.5), demonstrating its potential clinical value(Fig. 3).

Discussion

Transurethral ureteroscopic surgery has become a widely adopted clinical intervention for the management of urinary tract stones. The duration of the procedure is a critical factor significantly influencing both intraoperative safety and postoperative patient outcomes. Evidence consistently demonstrates that prolonged operative time is associated with an increased risk of complications. Studies by Tan S and Karakan T, among others, have indicated that extended surgical duration elevates the likelihood of intraoperative ureteral injury and subsequent stricture formation, which can have long-term consequences for patients [16, 17]. Furthermore, research by Yuan H et al. has shown that longer operations are correlated with delayed patient discharge, impacting healthcare efficiency [18]. Southern JB and colleagues have reported that excessive operative time increases the risk of postoperative fever (POF) and even systemic inflammatory response syndrome (SIRS) [19].

Conversely, work by Chugh S and Bhojani N suggests that shorter procedure times can effectively reduce the incidence of postoperative urinary tract infections and urosepsis [20, 21]. In patients with compromised renal reserve, such as those with an isolated kidney, minimizing operative duration is a critical surgical objective. The work by Pan Y et al. underscores this principle, demonstrating that reducing operative timein this vulnerable population is instrumental in preserving renal function and mitigating the risk of postoperative renal deterioration [22].

Recognizing the clinical significance of operative time, several studies have attempted to develop predictive models. For instance, the research by Kuroda S et al. resulted in a prediction model incorporating variables such as stone volume, maximum Hounsfield Units (HUs), operator experience, sex, preoperative stenting, and ureteral sheath diameter [12]. The present study aims to construct a more concise predictive model for operative time in ureteroscopic lithotripsy. By integrating a wider array of preoperatively available patient-specific, stone-related, and technical variables, we seek to enhance predictive accuracy. This model is intended to provide a simple but reliable

tool for preoperative planning, potentially aiding in resource allocation, patient counseling, and strategic clinical decision-making to optimize outcomes.

The correlation between stone burden and operative time is a well-recognized principle in endourology. This is confirmed by Tobe T et al., who established stone size as an independent factor for prolonging surgery, a finding that aligns with clinical experience [23]. This relationship carries significant implications for patient outcomes. As noted in the review by Bhanot R et al., longer procedures, often necessitated by larger stones, are not merely an issue of operating room efficiency. They are associated with a higher incidence of major complications, most notably sepsis, which can prove fatal [24]. Therefore, the pursuit of a powerful preoperative predictive model is not just an academic exercise but a fundamental component of patient safety.

Lower stone density, as measured in Hounsfield units (HU), is significantly associated with improved surgical outcomes. Aksoy et al. demonstrated that patients with lower-density stones had significantly shorter operative times and higher stone-free rates compared to those with high-density stones, underscoring the role of density as a key predictor of procedural efficacy [25]. This aligns with broader evidence indicating that stone density inversely correlates with fragmentation efficiency and clearance .

Furthermore, our findings are consistent with existing literature. Specifically, Bozzini et al.demonstrated that patients with simple ureteral stones have a significantly shorter operative time compared to those with renal stones, which aligns with the protective effect of simple ureteral stones identified in our models [26]. This finding is consistent with clinical observations: compared to patients with renal stones, those with pure ureteral stones often present with a smaller stone burden. In some cases, stone extraction can be completed without the need for flexible ureteroscopy, thereby resulting in a shorter operative time.

In our study, three independent predictors were identified: stone length, maximum stone density, and the presence of a simple ureteral stone. A Gamma regression model incorporating these factors was developed for the preoperative prediction of continuous operative time. Subsequently, according to EAU guidelines, a logistic regression model was constructed to identify patients at risk for prolonged operative time exceeding 90 minutes [7]. Both models consistently indicated that greater stone length and higher stone density were significant risk factors for increased operative time, while the presence of a simple ureteral stone served as a protective factor.

These predictive models can assist surgeons in accurately identifying high-risk patients, enabling improved preoperative planning. For patients presenting with longer stones, higher density stones, or concurrent renal stones, a thorough preoperative assessment of surgical risk is warranted. This includes optimizing preoperative preparations and establishing a detailed surgical strategy to mitigate the risk of serious postoperative complications associated with prolonged operative times.

Despite these insights, our study has several limitations. Its single-center, cross-sectional design and regional restrictions may limit the generalizability of the findings. Furthermore, the spectrum of predictive factors analyzed could be expanded. Future research should aim to incorporate multi-center data, larger sample sizes, and a broader range of potential predictors to enhance the model's robustness and external validity.

Conclusion

Greater stone length and higher maximum stone density were identified as independent risk factors for prolonged operative time in ureteroscopic stone removal, while the presence of a simple ureteral stone (without concurrent renal stones) served as an independent protective factor .

The Gamma regression model developed in this study demonstrated good preoperative predictive value for estimating operative time. Furthermore, the logistic regression model exhibited excellent discriminative ability (as indicated by a high AUC value) and clinical utility, confirming its value for clinical decision-making. These models show promise for the preoperative estimation of expected operative time, thereby providing a scientific basis for developing more appropriate and individualized surgical plans.

Declarations

Author contributions

Study design: Zhiwei Zhang,Mingjie Li

Data Collection: Xiangtao Wang,Jianchao Zhang,Qiang Wei,Shangzhen Geng

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Manuscript drafting: Zhiwei Zhang,Mingjie Li

Manuscript revision: Deqi Jiang,Shuhui Li

Conflicts of Interest

The authors declare no competing interests.

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Ethical Approval

The Institutional Review Board (IRB) :

The Medical Ethics Committee of Shandong Provincial Third Hospital.

The component of this study involving human participants was reviewed and approved by the Medical Ethics Committee of Shandong Provincial Third Hospital (Approval No. KYLL-2025099). As the research utilizes historical, anonymized data, the committee granted a waiver of informed consent.

Data Availability Statement

The datasets generated and analyzed during the current study are not publicly available due to patient privacy but are available from the corresponding author on reasonable request. Requests for data access will be reviewed by the Medical Ethics Committee of Shandong Provincial Third Hospital to determine whether the data can be shared under a data transfer agreement.

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Figures

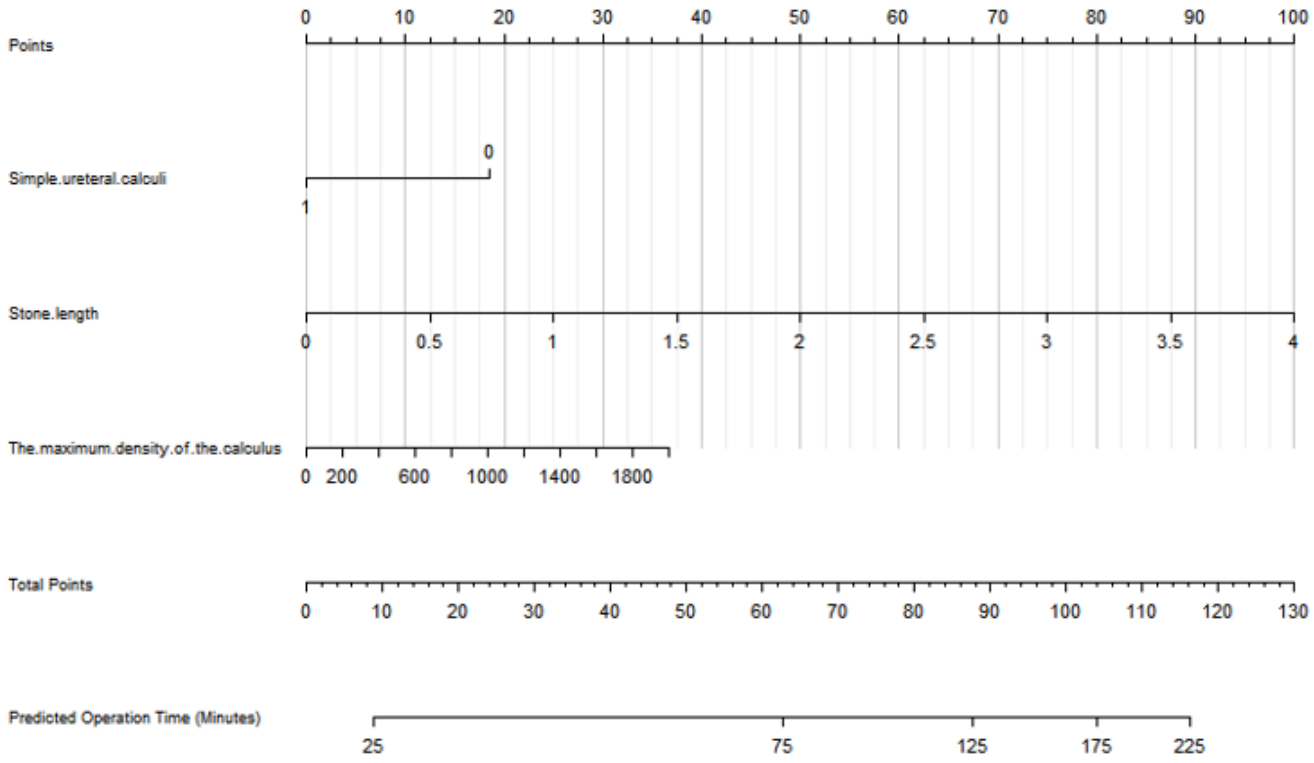


Figure 1

Nomogram of Gamma Regression Model

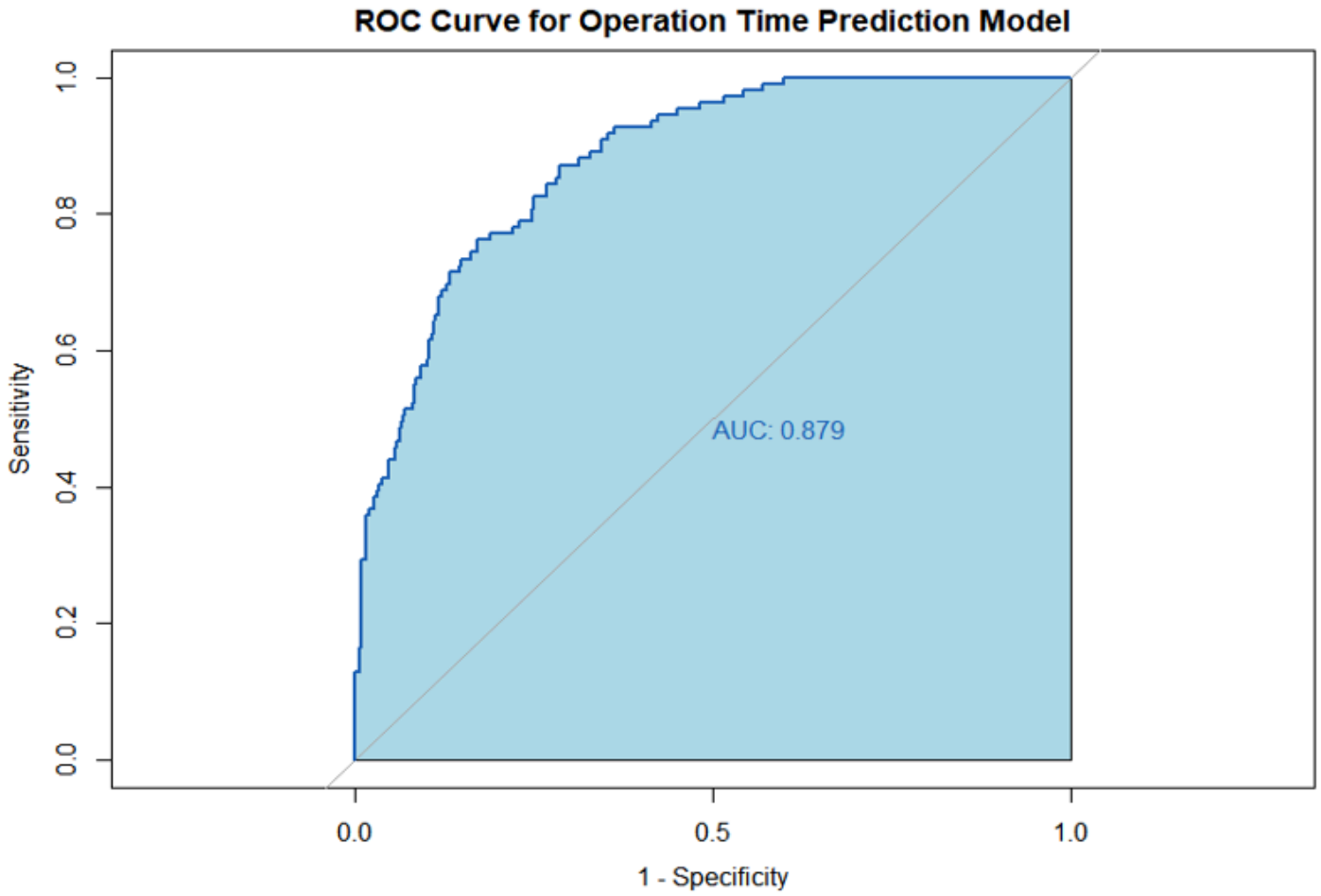


Figure 2

ROC Curve of Logistic Regression Model

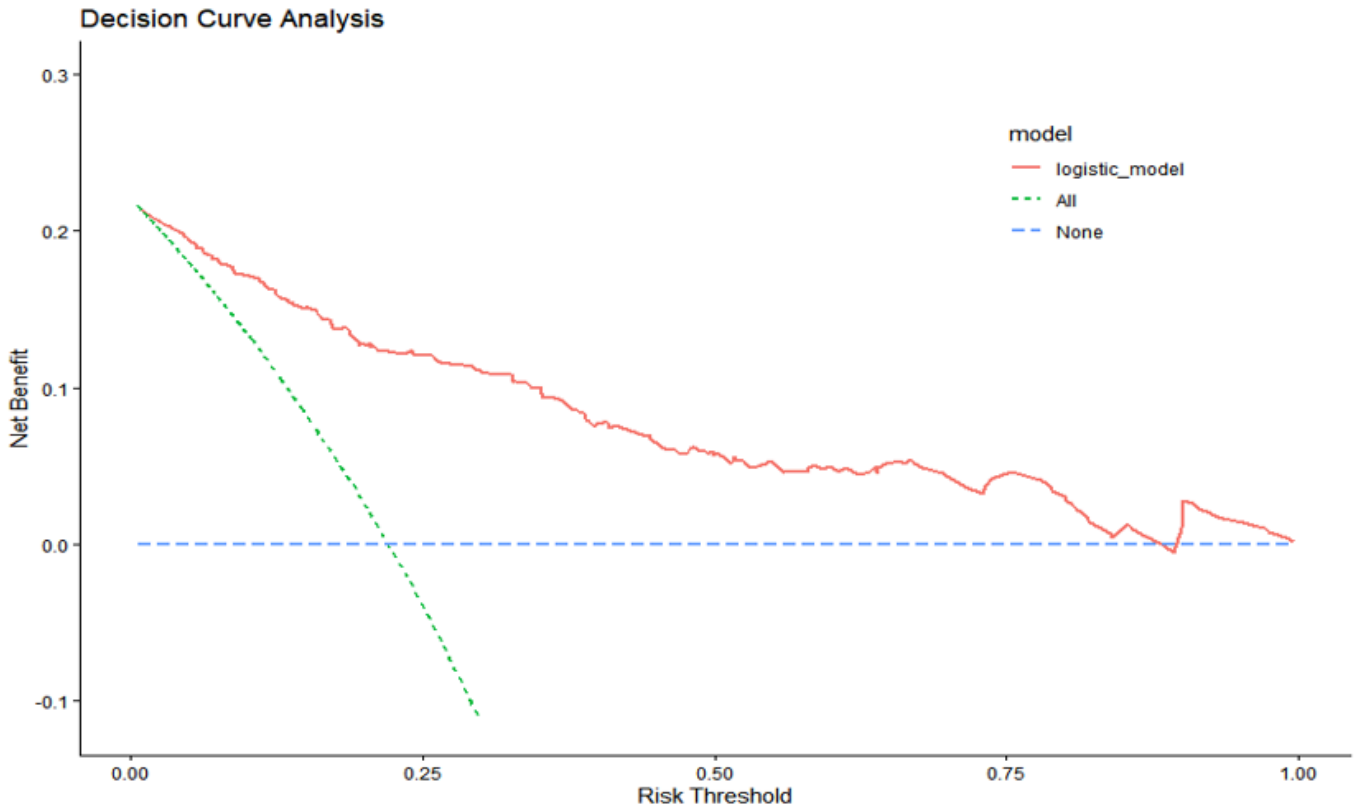


Figure 3

DCA of Logistic Regression Model