# The Prognostic Multivariate Models For Severe Complications After Heart Valve Surgery

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# Abstract

**Background:** To provide prognostic multivariate models for severe complications prediction after heart valvular surgery, such as low cardiac output syndrome (LOCS), acute kidney injury requiring hemodialysis (AKI-rH) and multiple organ dysfunction syndrome (MODS).

**Methods:** We developed multivariate logistic regression models to predict the severe complications after heart valvular surgery using 930 patients collected retrospectively from the first affiliated hospital of Sun Yat-Sen University from January 2014 to December 2015. The validation was conducted using a retrospective dataset of 713 patients from the same hospital from January 2016 to March 2017. We considered two kinds of prognostic models: the PRF models which were built by using the preoperative risk factors only, and the PIRF models which were built by using both of the preoperative and intraoperative risk factors. The Least absolute shrinkage selector operator was used for developing the models. We assessed and compared the discriminative abilities for both of the PRF and PIRF models via the receiver operating characteristic curve.

**Results:** Compared with the PRF models, the PIRF modes selected additional intraoperative factors, such as auxiliary cardiopulmonary bypass time and combined tricuspid valve replacement. The area under the curves (AUCs) of the PRF models for predicting LOCS, AKI-rH and MODS are 0.565 (0.466, 0.664), 0.688 (0.62, 0.757) and 0.657 (0.563, 0.751), respectively. As a comparison, the AUCs of the PIRF models for predicting LOCS, AKI-rH and MODS are 0.821 (0.747, 0.896), 0.78 (0.717, 0.843) and 0.774 (0.7, 0.847), respectively.

**Conclusions:** Adding the intraoperative factors can increase the predictive power of the prognostic models for severe complications prediction after heart valvular surgery.


# Background

Heart valve disease (HVD) is a common cardiosurgery disease, mainly includes rheumatic, degenerative, ischemic and myxoid valvular disease[1].The 30-day mortality after heart valve surgery is about 4~6%, nearly two-fold higher than coronary artery bypass graft (CABG)[2-4]. With the increase of aging population, the morbidity of HVD also increases[5, 6].

In the past 30 years, there are numerous conventional prognostic models to predict in-hospital mortality for patients who underwent cardiac surgery, such as the European system for cardiac operation risk evaluation (EuroSCORE), quality measurement and management initiative (QMMI), northern New England cardiovascular disease study group (NNECDSG), New York's cardiac surgery reporting system (NYCSRE), society of thoracic surgeons (STS) score[3, 7-12]. However, these prognostic models are mainly applied to CABG to predict mortality by preoperative factors, not to the valvular operation or concern on severe complications prediction.

As the clinical observations and researches show, the major causes of mortality were severe complications after cardiac valvular surgery, such as low cardiac output syndrome (LOCS), acute kidney injury requiring hemodialysis (AKI-rH) and multiple organ dysfunction syndrome (MODS)[13-15]. These complications not only prolong hospital stays but also increase the hospitalization expenses, and some important intraoperative factors, especially cardiaopulmonary bypass (CPB)-related factors significantly affect the complications morbidity[16, 17].

Therefore, this study aims to provide a method considering both preoperative and intraoperative factors to predict severe complications morbidity after heart valvular surgery within 30 days. Further, to provide a thought for these conventional prognostic models to more accurately predict mortality.

# Methods

### Patient selection:

This was a retrospective observational study of total 1643 adult patients who underwent heart valvular surgery from January 2014 to March 2017 in the first affiliated hospital of Sun Yat-sen University, Guangzhou, China. The 930 patients (445 males, 485 females) admitted from January 2014 to December 2015 were used for model development. The other 713 patients (370 males, 343 females) admitted from January 2016 to March 2017 were used for model validation.

The inclusion criteria for patient selection should be adult patients older than 18 years, without history of any mechanical assistant due to organ failure.

The investigation complied with the principles of the Declaration of Helsinki and was approved by the human ethics committee of the first affiliated hospital of Sun Yat-sen University. Written informed consent forms were obtained from all patients.

### Data collection

The preoperative clinical data were collected from patients' demographics, medical histories, results of essential laboratory tests and routine imaging examinations. The intraoperative clinical data were collected from surgical approaches, defibrillation frequency, aortic occlusion time (AOT) and auxiliary CPB time (ACPBT). The postoperative clinical data were collected from severe complications morbidty, mechanical assistant and discharge status.

All patients had close 30-day follow-up after cardiac valvular surgery. The endpoints were the postoperative severe complications (LCOS, AKI-rH and MODS) within 30 days.

Treatment principles of patients with cardiac valve disease were in coincidence with international guidelines [18-21].

### The definition of severe complications

LCOS: (1) cardiac index (CI) <2min•m² and systolic blood pressure <90 mmHg, (2) mixed venous oxygen saturation ($SvO_2$) <50% and arterial oxygen saturation ($SaO_2$) minus $SvO_2$≥30%, (3) metabolic acidosis: the base excess indicate (B.E.) <-4, (4) signs of tissue hypoperfusion, (5) the results of Swan-Ganz catheterization, Pulse index Contour Cardiac Output (PiCCO), and echocardiography[13, 22-25].

MODS: It's a frequent complication of systemic inflammatory response syndrome, which presence of altered organ function in an acutely ill patients such that homeostasis cannot be maintained without intervention[26].

AKI-rH: (1) blood creatinine (BCr) ≥3 times baseline or BCr ≥354 mmol/l with the elevated level ≥44 mmol/l within 48 hours, (2) oliguria: urine output less than 0.3 ml/kg/h for ≥24 hours, (3) anuria for ≥12 hours[27-29].

### Statistical analysis

Analyses were performed in R version 3.5.1.

Two variable selection methods were respectively applied to build the prediction models: (1) preoperative variables were selected to build preoperative risk factors (PRF) models, (2) both preoperative and intraoperative variables were selected to build preoperative and intraoperative risk factors (PIRF) models (Figure 1).

After compared the two prediction models, we could conclude whether the predictive power improved when added intraoperative risk factors. Besides, considered a significant correlation might exist between preoperative and intraoperative risk factors in PIRF models, synchronous variable selection was performed among all related preoperative and intraoperative risk factors, rather than selecting separately. Using the least absolute shrinkage selector operator (LASSO) or stepwise regression analysis could effectively decrease the data dimensionality, further, the obligatory relationship between preoperative and intraoperative variables could also decrease, and enhanced the predictive effect of the PIRF model. A multiple logistic regression was established to compare the selected risk factors between these two models which were respectively applied to predict the three endpoints (LCOS, AKI-rH and MODS).

During the evaluation period, to estimate the accuracy, internal and external validation were separately processed in these prediction models. In the internal validation, bootstrap method with 1000 resampling was used to reduce the overfitting of the training dataset to obtain the internal evaluation results. In the external validation, the prediction models built by training dataset were applied for validation dataset to obtain the evaluation results. A multi-dimensional comparison included receiver operating characteristic curve (ROC) and the area under the ROC (AUC) of validation dataset was performed to estimate and compare the accuracy of PRF and PIRF model.

# Results

### Patients characteristics

The characteristics of training and validation datasets are listed in Table 1. Compared the two datasets, the morbidities of severe complications were LCOS (9.46% vs 5.33%, $P<0.05$), AKI-rH (4.48% vs 7.29%, $P<0.05$) and MODS (4.95% vs 4.49%, $P>0.05$).

**Table 1.** Patient characteristics

| Characteristics | Training dataset (n=930) | Validation dataset (n=713) | P |
|---|---|---|---|
| **Demographics** | | | |
| Age (y) | 47.91±13.83 | 49.68±15.00 | 0.001 |
| Gender (female, No. %) | 485(52.15%) | 343(48.11%) | 0.115 |
| Height (cm) | 160.73±8.18 | 160.49±10.69 | 0.939 |
| Weight (kg) | 54.66±10.39 | 56.96±11.95 | <0.01 |
| BMI | 21.08±3.29 | 21.97±3.62 | <0.01 |
| BSA ($m^2$) | 6.87±1.29 | 7.15±1.49 | <0.01 |
| Smoke (No. %) | 166 (17.85%) | 95(13.32%) | 0.016 |
| **Medical histories** | | | |
| CF (<4 weeks, No. %) | 601(64.62%) | 421(59.05%) | 0.024 |
| Endocarditis (No. %) | 88(9.46%) | 120(16.83%) | <0.01 |
| Diabetes (No. %) | 48(5.16%) | 49(6.87%) | 0.176 |
| Hypertension (No. %) | 122(13.12%) | 129(18.09%) | 0.007 |
| Hepatitis (No. %) | 78(8.39%) | 23(3.23%) | <0.01 |
| Pulmonary disease (No. %) | 78(8.39%) | 30(4.21%) | 0.001 |
| Dialysis (No. %) | 0(0.00%) | 0(0.00%) | <0.01 |
| PVD (No. %) | 0(0.00%) | 0(0.00%) | <0.01 |
| Re-operation (No. %) | 58(6.24%) | 52(7.29%) | 0.453 |
| **Laboratory values** | | | |
| WBC ($\times10^9$/l) | 7.04±2.46 | 7.22±2.38 | 0.076 |
| PLT ($\times10^{12}$/l) | 213.26±66.44 | 217.74±82.53 | 0.789 |
| RBC ($\times10^9$/l) | 4.68±0.70 | 4.58±0.76 | 0.003 |
| RBC-DW | 0.14±0.02 | 0.14±0.03 | <0.001 |
| <0.12 | 3(0.32%) | 1(0.14%) | |
| 0.12-0.15 | 772(83.01%) | 560(78.54%) | |
| >0.15 | 148(15.91%) | 151(21.18%) | |
| Hb (g/l) | 133.78±19.63 | 130.54±21.53 | 0.001 |

| | | | |
|---|---|---|---|
| ALT (u/l) | 25.79±33.6 | 26.94±29.51 | 0.998 |
| ALB (g/l) | 42.29±18.01 | 39.36±4.92 | <0.01 |
| TBil (mmol/l) | 15.88±10.39 | 16.52±9.76 | 0.001 |
| BUA (mg/l) | 374.78±122.51 | 423.22±140.87 | <0.01 |
| BUN (mmol/l) | 6.12±2.51 | 6.15±2.93 | 0.249 |
| <2.9 | 24(2.58%) | 22(3.09%) | |
| 2.9-8.6 | 802(86.24%) | 606(84.99%) | |
| >8.6 | 95(10.22%) | 84(11.78%) | |
| BCr (umol/l) | 77.19±27.07 | 86.11±68.24 | 0.01 |
| <50 | 56(6.02%) | 43(6.03%) | |
| 50-115 | 808(86.88%) | 609(85.41%) | |
| 116-200 | 55(5.91%) | 51(7.15%) | |
| >200 | 3(0.32%) | 9(1.26%) | |
| BUN/BCr | 0.08±0.04 | 0.08±0.03 | <0.01 |
| <0.055 (No. %) | 127(13.66%) | 143(20.06%) | |
| 0.055-0.075 (No. %) | 308(33.12%) | 250(35.06%) | |
| >0.075 (No. %) | 486(52.26%) | 319(44.74%) | |
| CCr (ml/min/1.73m$^2$, No.) | 79.62±34.28 | 76.17±26.37 | 0.046 |
| <50 (No. %) | 116(12.47%) | 98(13.74%) | |
| 50-80 (No. %) | 396(42.58%) | 338(47.41%) | |
| >80 (No. %) | 404(43.44%) | 275(38.57%) | |
| APTT (secs.) | 29.3±5.72 | 31.74±6.75 | <0.01 |
| Fbg (g/l) | 3.08±1.16 | 3.08±1.20 | 0.419 |
| ESR (mm) | 23.49±20.45 | 26.16±23.34 | 0.192 |
| **ECG measurements** | | | |
| Atrial fibrillation (No. %) | 389(41.83%) | 235(32.96%) | <0.01 |
| **UCG measurements** | | | |
| LVD (mm) | 54.51±11.10 | 53.65±10.97 | 0.220 |
| EF (%) | 62.71±10.14 | 63.95±9.93 | 0.005 |

| | | | |
|---|---|---|---|
| >50 | 777(83.55%) | 612(85.83%) | |
| 30-50 | 93(10%) | 72(10.1%) | |
| <30 | 4(0.43%) | 1(0.14%) | |
| PASP (mmHg) | 21.86±27.54 | 45.59±17.4 | <0.01 |
| >60 | 80(8.6%) | 86(12.06%) | |
| 30-60 | 310(33.33%) | 380(53.3%) | |
| <30 | 540(58.06%) | 57(7.99%) | |
| **Intraoperative variables** | | | |
| AOT (min) | 80.23±34.70 | 90.0±46.70 | 0.001 |
| ACPBT (min) | 37.7±22.50 | 58.4±40.20 | <0.01 |
| Defibrillation (freq.) | | | 0.351 |
| <1 | 773(83.12%) | 605(84.85%) | |
| ≥1 | 157(16.88%) | 108(14.79%) | |
| Surgical approaches | | | |
| AVR (No. %) | 378(40.65%) | 293(41.09%) | 0.894 |
| MVR (No. %) | 684(73.55%) | 432(60.59%) | <0.01 |
| TVR (No. %) | 33(3.55%) | 31(4.35%) | 0.483 |
| MVP (No. %) | 57(6.13%) | 84(11.78%) | <0.001 |
| TVP (No. %) | 298(32.04%) | 303(42.5%) | <0.001 |
| CABG (No. %) | 28(3.01%) | 32(4.49%) | 0.147 |
| RFA (No. %) | 27(2.9%) | 33(4.63%) | 0.086 |
| other cardiac surgery (No. %) | 60(6.45%) | 210(29.45%) | <0.001 |
| non-cardiac surgery (No. %) | 4(0.43%) | 0(0.00%) | 0.138 |
| **Severe complications** | | | |
| LCOS (No. %) | 88(9.46%) | 38(5.33%) | 0.002 |
| AKI-rH (No. %) | 45(4.84%) | 52(7.29%) | 0.047 |
| MODS (No. %) | 46(4.95%) | 32(4.49%) | 0.752 |
| **Mechanical assistant** | | | |
| IABP /ECMO (No. %) | 33(3.55%) | 29(4.07%) | 0.677 |

| Discharge status | | | |
|---|---|---|---|
| Death (No. %) | 61(6.56%) | 47(6.59%) | 1.000 |

The age in training dataset is younger than validation dataset (47.91±13.83 vs 49.68±15 years, P<0.05), cardiac failure (CF) was also shorter (64.62% vs 59.05%, P<0.05). However, the morbidities of preoperative pulmonary disease (PD) and hepatitis of training dataset were higher than that of validation dataset (PD: 8.39% vs 4.21%, P<0.05; hepatitis: 8.39% vs 3.23%, P<0.05).

More patients had history of endocarditis in validation dataset than training dataset (16.83% vs 9.46%, P<0.05), important organs, such as liver and kidney suffer more damages. In addition, according to the result of echocardiography, the validation dataset has higher pulmonary artery systolic pressure (PASP) than training dataset (45.59±17.4 mmHg vs 21.86±27.54 mmHg, P<0.05).

Furthermore, the AOT and ACPBT of training dataset are both shorter than validation dataset (AOT: 80.23±34.7 mins vs 90.0±46.7 mins, P<0.01; ACPBT: 37.7±22.5 mins vs 58.4±40.2 mins, P<0.01).

### Prediction model for LCOS

The PRF model for LCOS includes BCr (OR 1.85; 95%CI 0.95-3.59), creatinine clearance rate (CCr)(OR 0.46; 95%CI 0.32-0.67 ), hemoglobin (Hb)(OR 0.73; 95%CI 0.58-0.91), PAH (OR 1.34; 95%CI 0.96-1.86), and hypertension (OR 1.70; 95%CI 0.94-3.05) (Table 2). As a comparison, the PIRF model only includes CCr (OR 0.38; 95%CI 0.27-0.53) and ACPBT (OR 1.80; 95%CI 1.52-2.12).We applied both models to the validation dataset. The AUC of the PIRF model is 0.821 (0.747, 0.896), which is statistically higher (P<0.01) than that 0.565 obtained in the PRF model (Figure 2, Table 5).

**Table 2.** Prognostic models for LCOS in development dataset

| Variables | PRF model (n=930) | | | PIRF model (n=930) | | |
|---|---|---|---|---|---|---|
| | β | OR (95% CI) | P | β | OR (95% CI) | P |
| Intercept | -2.4909 | 0.08 | 0.015 | -0.3645 | 0.69 | 0.311 |
| BCr | 0.6152 | 1.85 (0.95-3.59) | 0.068 | | | |
| CCr | -0.7756 | 0.46 (0.32-0.67) | <0.01 | -0.9801 | 0.38 (0.27-0.53) | <0.01 |
| Hb | -0.3191 | 0.73 (0.58-0.91) | 0.006 | | | |
| PASP | 0.2929 | 1.34 (0.96-1.86) | 0.082 | | | |
| Hypertension | 0.5281 | 1.70 (0.94-3.05) | 0.079 | | | |
| ACPBT | | | | 0.5855 | 1.80 (1.52-2.12) | <0.01 |

### Prediction model for AKI-rH

The PRF model for AKI-rH includes CCr (OR 0.33; 95%CI 0.21-0.52), red blood cell distribution width (RBC-DW)(OR 2.59; 95%CI 1.31-5.13) and total bilirubin (TBil) (OR 1.51; 95%CI 1.20-1.90)(Table 3). As a comparison, the PIRF model includes CCr (OR 0.36; 95%CI 0.22-0.57), RBC-DW(OR 2.19; 95%CI 1.08-4.43), TBil (OR 1.52; 95%CI 1.21-1.92) and ACPBT (OR 1.50; 95%CI 1.23-1.82). We applied both models to the validation dataset. The AUC of the PIRF model is 0.78 (0.717, 0.843), which is statistically higher (P<0.01) than that 0.688 obtained in the PRF model (Figure 2, Table 5).

**Table 3.** Prognostic models for AKI-rH in development dataset

| Variables | PRF model (n=930) | | | PIRF model (n=930) | | |
|---|---|---|---|---|---|---|
| | β | OR (95%CI) | P | β | OR (95% CI) | P |
| Intercept | -2.9392 | 0.05 | 0.002 | -2.8605 | 0.06 | 0.004 |
| CCr | -1.1041 | 0.33 (0.21-0.52) | <0.01 | -1.0247 | 0.36 (0.22-0.57) | <0.01 |
| RBC-DW | 0.9530 | 2.59 (1.31-5.13) | 0.006 | 0.7835 | 2.19 (1.08-4.43) | 0.030 |
| TBil | 0.4093 | 1.51 (1.20-1.90) | 0.001 | 0.4206 | 1.52 (1.21-1.92) | <0.01 |
| ACPBT | | | | 0.4042 | 1.50 (1.23-1.82) | <0.01 |

### Prediction model for MODS

The PRF model for MODS includes CCr (OR 0.28; 95%CI 0.18-0.45), BUN/BCr (OR 1.81; 95%CI 1.11-2.95), Hb (OR 0.74; 95%CI 0.55-1.01), heart failure history (OR 1.84; 95%CI 0.82-4.16) and PD (OR 3.33; 95%CI 1.55-7.16) (Table 4). As a comparison, the PIRF model includes CCr (OR 0.29; 95%CI 0.17-0.48), BUN/BCr (OR 1.86; 95%CI 1.1-3.14), CF (<4 weeks) (OR 1.95; 95%CI 0.83-4.58), PD (OR 4.69; 95%CI 2.10-10.47), ACPBT (OR 1.71; 95%CI 1.41-2.09) and combined with tricuspid valve replacement (cTVR) (OR 3.69; 95%CI 1.16-11.47). We applied both models to the validation dataset. The AUC of the PIRF model is 0.774 (0.70, 0.847), which is statistically higher (P<0.01) than that 0.657 obtained in the PRF model (Figure 2, Table 5).

**Table 4.** Prognostic models for MODS in development dataset

| Variables | PRF model (n=930) | | | PIRF model (n=930) | | |
|---|---|---|---|---|---|---|
| | β | OR (95% CI) | P | β | OR (95% CI) | P |
| | -2.5690 | 0.08 | 0.002 | -3.0533 | 0.05 | 0.001 |
| CCr | -1.2645 | 0.28 (0.18-0.45) | <0.01 | -1.2457 | 0.29 (0.17-0.48) | <0.01 |
| BUN/BCr | 0.5907 | 1.81 (1.11-2.95) | 0.018 | 0.6219 | 1.86 (1.10-3.14) | 0.020 |
| Hb | -0.296 | 0.74 (0.55-1.01) | 0.057 | | | |
| CF | 0.6110 | 1.84 (0.82-4.16) | 0.141 | 0.6660 | 1.95 (0.83-4.58) | 0.127 |
| PD | 1.2038 | 3.33 (1.55-7.16) | 0.002 | 1.5459 | 4.69 (2.10-10.47) | <0.01 |
| ACPBT | | | | 0.5381 | 1.71 (1.41-2.09) | <0.01 |
| cTVR | | | | 1.3049 | 3.69 (1.16-11.47) | 0.027 |

**Table 5.** Comparisons of PRF and PIRF models for three complications in validation dataset

| Complications | AUC | | |
|---|---|---|---|
| | PRF model (n=713) | PIRF model (n=713) | P |
| LCOS | 0.565 (0.466, 0.664) | 0.821 (0.747, 0.896) | <0.01 |
| AKI-rH | 0.688 (0.62, 0.757) | 0.78 (0.717, 0.843) | <0.01 |
| MODS | 0.657 (0.563, 0.751) | 0.774 (0.7, 0.847) | 0.003 |

# Discussion

The postoperative mortality of cardiac surgery obviously declines to 1%~2%, but the morbidity of postoperative severe complications (LOCS, AKI-rH and MODS) still remains high, caused by surgical trauma, CPB-related injury, ischemia-reperfusion, endotoxemia, and blood transfusion repeatedly[24, 30]. These complications will prolong hospital stays and rise hospitalization costs[31].

Postoperative LCOS is one of the most serious complications and major cause to high mortality[13]. Around 70% postoperative cardiac surgery patients have signs of ventricular systolic and diastolic dysfunction. The pathophysiology is systemic hypoperfusion leading to metabolic acidosis[22, 32]. Brain, liver, and kidney failure are common consequences of LOCS, leading to MODS eventually.

Postoperative AKI-rH is another cause to high mortality. More than 35% preoperative cardiac surgery patients have previous history of chronic kidney disease, it is also a significant independent predictor of

postoperative short and long term mortality[14, 33]. Approximately 40%~50% postoperative cardiac surgery patients have acute kidney injury (AKI) attributed to ischemia-reperfusion injury during the surgery, especially for the elder, diabetic and coronary artery disease (CAD) patients[33, 34]. The incidence of AKI-rH is nearly 1%~3%, it is rising due to increasing surgery complexity, and AKI-rH tends to cause end-stage renal disease (ESRD)[4, 29, 35].

Postoperative MODS is a common final cause of death among critically ill patients, the mortality is approximately 54%[15, 31, 36, 37]. In most cases, patients with MODS in supported continuous vasoactive agents or mechanism assistances, to maintain vital signs[38]. The nature of MODS is focusing on the crosstalk among different organs, damage from one organ could induce secondary injury for another organ, finally active a vicious circle[39]. Higher than 5% postoperative patients will develop to MODS, especially LOCS and AKI-rH are combined[40].

Nowadays, there are two classical prognostic models to predict in-hospital morality after heart valve surgery, the  Society for Thoracic Surgeons 2008 Cardiac Surgery Risk Models (STS) score and European System for Cardiac Operative Risk Evaluation (EuroSCORE) II [41, 42]. The limitations for these models are (1) focus on endpoint of mortality; (2) predictive accuracy only relies on preoperative factors; (3) model-based design of patients underwent CABG, instead of cardiac valvular surgery.

Based on clinical observations and recent research results, important intraoperative factors can influence the prognosis of patients, mortality due to severe surgical complications increases. In this study, we provide a method that consider both preoperative and intraoperative factors to predict severe complications morbidities after heart valvular surgery.

The differences of independent factors between PRF model and PIRF model were showed (Figure 2, Table 2-4). The result presented PIRF model is more accurate and reliable compared with PRF model.

Therefore, based on above results, we can alternate treatment plan in time, and provide a thought for conventional model to more accurately predict mortality.

As a retrospective study, it also has some limitations. The sample size is limited by a single-center research and only focus on postoperative complications within 30 days. Therefore, it is necessary to validate the prognostic multivariate model by using a larger sample size from multiple centers and focus on long-term prognosis in the future.

# Conclusions

In this study, we consider both preoperative and intraoperative factors to predict severe complications morbidities after heart valvular surgery, to further provide a thought for conventional prognostic model. After re-selected and re-determined relative risk variables, the PIRF model was more accurate and reliable by adding the intraoperative factors, which will help us alternate treatment in time to decrease mortality.

# Abbreviations

ACPBT: auxiliary cardiopulmonary bypass time; AKI: acute kidney injury; AKI-rH: acute kidney injury requiring hemodialysis; ALB: albumin; ALT: alanine transaminase; AOT: aortic occlusion time; APTT: activated partial thromboplastin time; AUC: the area under the receiver-operator characteristic (ROC) curve; AVR: aortic valve replacement; BCr: blood creatinine; B.E.: base excess indicate; BMI: body mass index; BSA: body surface area; BUA: blood uric acid; BUN: blood urea nitrogen; BUN/BCr: blood urea nitrogen/blood creatinine; CABG: coronary artery bypass graft surgery; CAD: coronary artery disease; CAG: coronary angiography; CCr: creatinine clearance; CI: cardiac index; CPB: cardiaopulmonary bypass; CPBT: CPB time; cTVR: combined tricuspid valve replacement; ECG: electrocardiogram; ECMO: extracorporeal membrane oxygenation; EF: ejection fraction; ESR: erythrocyte sedimentation rate; ESRD: end-stage renal disease; EuroSCORE: European system for cardiac operation risk evaluation; Fbg: fibrinogen; GFR: glomerular filtration rate; Hb: hemoglobin; CF: cardiac failure; HVD: heart valve disease; IABP: intra-aortic balloon pump; ICU: Intensive Care Unit; LASSO: least absolute shrinkage selector operator; LCOS: low cardiac output syndrome; LVD: left ventricular dimension; MODS: multiple organ dysfunction syndrome; MVP: mitral valvuloplasty; MVR: mitral valve replacement; NNECDSG: northern New England cardiovascular disease study group; NYCSRE: New York's cardiac surgery reporting system; PASP: pulmonary artery systolic pressure; PiCCO: Pulse index Contour Cardiac Output; PLT: platelet; PIRF: preoperative and intraoperative risk factors; PRF: preoperative risk factors; PVD: peripheral vascular disease; QMMI: quality measurement and management initiative; RFA: radiofrequency ablation. RBC: red blood cell; RBC-DW: red blood cell distribution width; ROC: receiver operating characteristic curve; $SaO_2$: arterial oxygen saturation; STS: society of thoracic surgeons; $SvO_2$: mixed venous oxygen saturation; TBil: total bilirubin; TVP: tricuspid valvuloplasty; TVR: tricuspid valve replacement; UCG: ultrasound cardiography; WBC: white blood cell.

# Declarations

### Ethics approval and consent to participate

All the protocols in this study were approved by the clinical research of the First Affiliated Hospital of Sun Yat-sen University and performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and its later amendments. Written informed consent forms were obtained from all patients.

### Consent for publication

Not applicable.

### Availability of data and material

All data generated or analyzed during this study are included in this published article

### Conflict of interests

The authors declare that they have no conflict of interests.

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### Authors' Contributions

Yunqi Liu designed this retrospective research and interpreted patient's clinical data; Jiefei Xiao and Xiaoying Duan wrote the manuscript; Xingwei Lu performed statistical analysis of the data set; Xin Gong verified the data set; Jiantao Chen collected and recorded the patient's clinical data; Mai Xiong amended the manuscript; Zhongkai Wu, Shengli Yin performed the surgical treatment; Xiaobo Guo was responsible for the design and quality control of the statistical program; Zhongkai Wu supervised the research and was responsible for the overall research quality control.

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# Figures

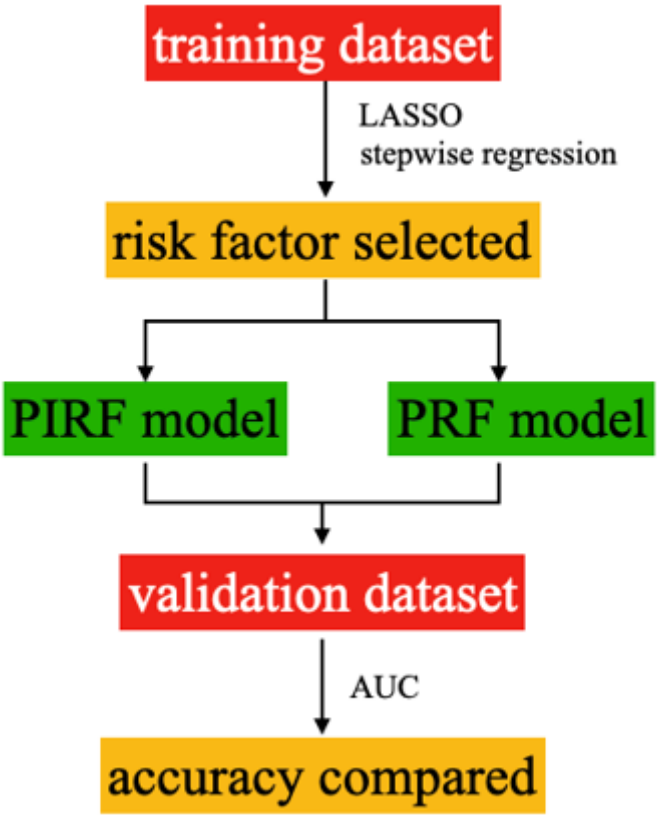


**Figure 1**

Establishment and validation of PRF and PIRF model

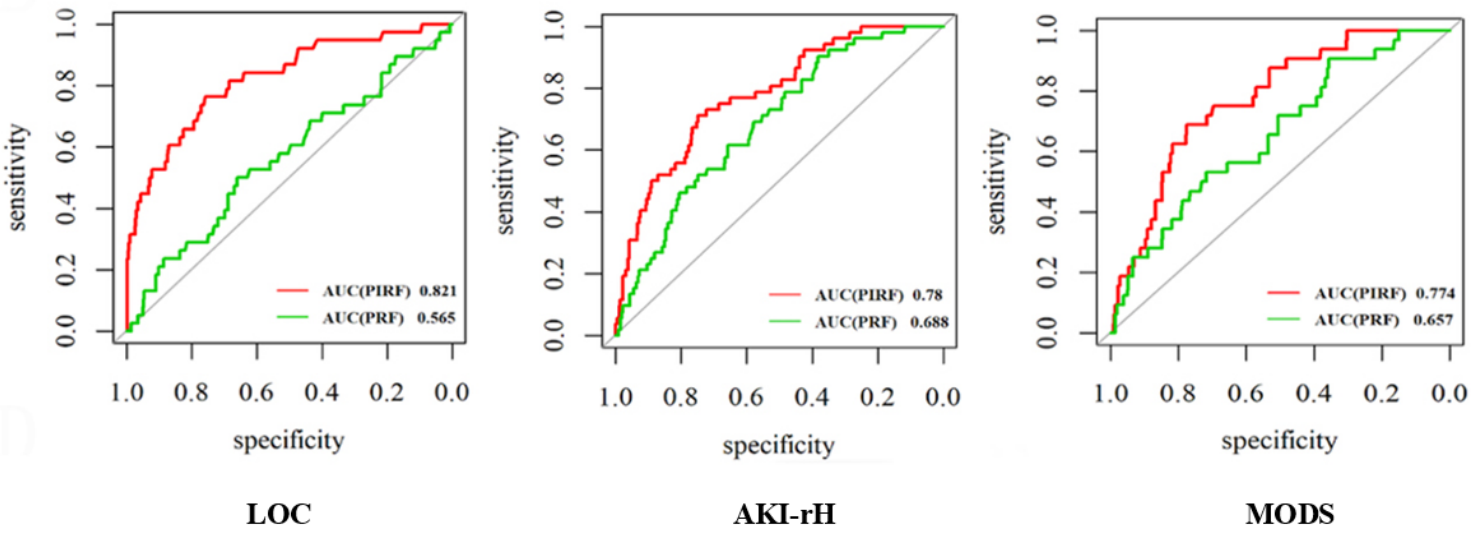


**Figure 2**

Validation cohort ROC curve of different complications.