Prediction of All-Cause Mortality Using an Echocardiography-Based Risk Score in Hemodialysis Patients

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Keywords

Echocardiography · Hemodialysis · Nomogram · Prognosis · Mortality

Abstract

Aim: To derive an echocardiography-based prognostic score for a 3-year risk of mortality in end-stage renal disease (ESRD) patients undergoing hemodialysis (HD). **Methods:** 173 ESRD patients hospitalized in the second affiliated hospital of Soochow University from January 1, 2010, to July 31, 2016, were enrolled and followed up for 3 years. All subjects began to receive HD from recruitment. Baseline clinical and echocardiographic parameters were collected and screened for risk factors using univariate and multivariate analysis. The prognostic value of echocardiographic indexes was determined by concordance indexes and reclassification assay. Restricted cubic spline models (RCS) and forest plots were employed to visualize the association between risk factors and all-cause mortality. A multivariate nomogram including the identified factors was developed to estimate the prognosis. **Results:** After multivariate adjustment for advanced age, hypertension, diabetes, and decreased hemoglobin (Hb), echocardiographic indexes including left atrial diameter index

(LADI), cardiac valvular calcification, and moderate to severe cardiac valve regurgitation were independently associated with the risk of 3-year mortality in HD patients. RCS showed that age, Hb, and LADI were positively associated with the risk of mortality. Adding multiple echocardiographic indexes to a basic model containing age, hypertension, diabetes, and Hb increased the concordance index and improved reclassification. A multivariate Cox model-derived nomogram showed the association between each factor and mortality by the end of follow-up. **Conclusions:** Echocardiographic indexes showed independent predictive power for mortality in ESRD patients and may constitute a promising prognostic tool in this population.

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Introduction

The mortality of end-stage renal disease (ESRD) patients remains high despite the evolving application of renal replacement therapies. Cardiovascular disease (CVD)

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is the most common complication in this population, contributing to nearly 50% of mortality [1]. It has been demonstrated that the proposed criteria for structural heart disease can in fact be systematically assessed by echocardiography and that most patients who begin dialysis have structural heart disease [2].

The Chinese guideline [3] suggests screening for conventional risk factors including age, hypertension, insulin resistance, and dyslipidemia, and chronic kidney disease (CKD)-specific risk factors including anemia, capacity overload, and mineral metabolism, etc. in ESRD patients. All patients were recommended to undergo CVD screening. Within 1–3 months since dialysis initiation, echocardiographic tests were advised after achieving dry body mass and followed up for every 3 years [4].

Echocardiography, the most common noninvasive imaging technique to evaluate cardiac function, provides an array of information on different aspects of the heart. The study of Hickson et al. [5] shows that structural heart disease was common in initiating hemodialysis (HD) patients, with a substantial majority of the patients having ≥ 1 baseline echocardiography abnormality and more than one half having ≥ 3 . However, the prognostic power of echocardiographic parameters remains unclear. We therefore designed this study to identify echocardiographic risk factors for mortality in HD patients. The prognostic power of combined echocardiographic indexes is estimated using a multivariate-based nomogram.

Materials and Methods

Patients and Basic Data Collection

Patients starting regular HD at the Second Affiliated Hospital of Soochow University from January 1, 2010, to July 31, 2016, were enrolled. We recruited patients above 18 years undergoing constant dialysis 3 times a week using an arteriovenous fistula. Exclusion criteria were acute kidney injury, acute exacerbation of CKD, and incomplete medical records.

We collected clinical and laboratory data from electronic medical records. Basic information included age, gender, body mass index, and history of hypertension, diabetes, coronary artery disease, and smoking. Laboratory data included hemoglobin (Hb), low-density lipoprotein, albumin, parathyroid hormone-releasing hormone, C-reactive protein, serum creatinine, and electrolytes including potassium (K), calcium (Ca), and phosphorus (P). When calculating the calcium phosphorus product ($\text{Ca} \times \text{P}$), an equation, validated in HD patients – adjusted calcium = measured calcium + $[0.0176 \times (34 - \text{serum albumin in g/dL})]$ –, was used to calculate an adjusted calcium [6]. These data were obtained on admission in the diagnostic laboratory of the Second Affiliated Hospital of Soochow University. All data were obtained within 1–3 months after the patient's regular HD reached dry body mass.

Echocardiography

To avoid the effect of volume load, all echocardiographic data were collected on dialysis days when the HD was done. All echocardiographic measurements were acquired using Model GE Vivid E9 and Vivid 7 platforms. We recorded the left atrial diameter (LAD), left ventricular internal diameter at end-diastole (LVIDD), interventricular septal thickness (IVST), left ventricular posterior wall thickness (LVPWT), right atrial diameter (length and transverse diameter), and right ventricular diameter (basement and midlevel). The LAD index (LADI, LAD/body surface area) and LVIDD index (LVIDD/body surface area) were obtained by adjusting to the body surface area. We used chamber diameter and wall thickness (LVPWT and IVST) to calculate the left ventricular (LV) mass according to the equation [7]: $\text{LV mass (g)} = 0.8 \times 1.04 \times [(LVIDD + LVPWT + IVST)^3 - LVIDD^3] + 0.6$. The LV mass index was defined as the LV mass/height^{2.7} as suggested by the 2013 European Society of Hypertension/European Society of Cardiology guidelines [8]. LV ejection fraction was calculated using the modified Simpson method from the apical 4- and 2-chamber views. Cardiac valve calcification (CVC) is defined as bright echoes of more than 1 mm on 1 or more cusps of the aortic valve, mitral valve, or mitral annulus [9]. Accordingly, patients were divided into including noncalcification, valve sclerosis, and valve calcification groups. Valvular stenosis or regurgitation was recorded. The peak early diastolic velocity (E) of the mitral orifice was measured by pulsed Doppler sonography from the apical 4-chamber view. The peak velocity of the early diastolic wave (e') was measured by pulsed-wave tissue Doppler sonography, with the sample volume close to the mitral valve annulus in the apical 4-chamber view in the lateral wall. The peak velocity of tricuspid regurgitation (TR) was obtained in the apical 4-chamber view with continuous-wave Doppler sonography. We calculated the E/e' and defined $E/e' > 13$ as one of the indices of LV diastolic dysfunction according to the recommendation from the American Society of Echocardiography [10]. In general, a diameter > 41 mm at the base and > 35 mm at the midlevel in the right ventricle-focused view indicate right ventricular dilatation. Right atrium length > 53 mm and transverse diameter > 44 mm indicate right atrial dilatation. All echocardiographic measurements were performed by experienced echocardiographic technicians who were blinded to the clinical conditions.

Statistical Analysis

Statistical analyses were performed using the SPSS software (version 25.0) and R software (version 3.6.1). Continuous variates with normal distribution were presented as mean $\pm$ SD and compared using Student's *t* test. Variates without normal distribution data were presented as median with interquartile ranges and compared using the Mann-Whitney U test. Categorical data were presented as the number of cases and percentages and compared using the χ^2 test. Univariate survival analyses of the grouping variates were performed using Kaplan-Meier curve with log-rank test. Restricted cubic spline models were used to describe the relationships between continuous variables and mortality. Multivariate-adjusted hazard ratios were estimated using the Cox model and visualized using a forest plot.

The independent prognostic value of echocardiographic indexes was determined by improvement in area under the curve using Harrell's test. The increase in concordance index after incorporating LADI, CVC, and cardiac valve regurgitation (CVR) to a basic model including age, diabetes, hypertension, and Hb were calcu-

Table 1. The comparison of clinical characteristics in patients

Characteristics	Without events (<i>n</i> = 130)	With events (<i>n</i> = 43)	<i>p</i> value
Age, years	53 (38, 65)	69 (58, 77)	<0.001
Male gender, <i>n</i> (%)	92 (70.8%)	29 (67.4%)	0.680
BMI	20.92 (19.85, 22.66)	20.47 (18.74, 22.32)	0.115
Diabetes, <i>n</i> (%)	27 (20.8%)	21 (48.8%)	<0.001
Hypertension, <i>n</i> (%)	93 (71.5%)	40 (93.0%)	0.003
Smoking, <i>n</i> (%)	18 (13.8%)	11 (25.6%)	0.074
CAD, <i>n</i> (%)	4 (3.1%)	3 (7.0%)	0.497
Hb, g/L	88.01±21.30	80.35±15.56	0.013
P, mmol/L	1.71 (1.28, 2.18)	1.48 (1.31, 1.87)	0.144
Mg, mmol/L	0.98 (0.81, 1.00)	0.90 (0.79, 1.01)	0.958
Ca, mmol/L	2.05±0.28	2.01±0.19	0.314
Ca × P, mg ² /dL ²	43.08 (33.80, 54.41)	39.24 (32.83, 48.41)	0.125
Scr, μmol/L	790.00 (537.50, 1,149.75)	552 (383, 906)	0.008
LDL, mmol/L	2.27 (1.84, 2.94)	2.36(1.89,3.63)	0.248
Alb, g/L	33.14±6.65	32.48±5.43	0.517
CRP, mg/L	7.00 (6.30, 12.93)	7.0 (6.4,49.8)	0.239
PTH, pg/mL	228.80 (120.93, 426.55)	182.55 (104.4, 332.9)	0.324

Figures in parentheses are ranges or percentages as indicated. BMI, body mass index; CAD, coronary artery disease; Hb, hemoglobin; P, phosphorus; Mg, magnesium; Ca, calcium; Ca × P, calcium phosphorus product; Scr, serum creatinine; LDL, low-density lipoprotein; Alb, albumin; CRP, C-reactive protein; PTH, parathyroid hormone.

lated. The prognostic value was validated using calibration curve and time-dependent receiver-operating characteristic curve. Re-classification assay, including net weight subindex and integrated differentiation index, was used to evaluate the discrimination ability of echocardiographic indexes. The validated multivariate model was visualized using a nomogram to quantify the risk of mortality. A *p* value <0.05 was considered statistically significant.

Results

Baseline Characteristics

A total of 173 patients were enrolled in the study. The baseline characteristics of the studying population were summarized in Table 1. The average age was 58 (41.5, 69.5) years. Of the cohort, 69.9% were male (121/173). There were 48 diabetic patients and 133 hypertensive patients. The pathogenesis of ESRD included glomerulonephritis (73/173), diabetic nephropathy (48/173), polycystic kidney disease (8/173), urinary tract infection (4/173), gouty nephropathy (4/173), urine tract obstruction (4/173), IgA nephropathy (3/173), tumor-related nephropathy(2/173), renal tuberculosis(2/173), congenital renal atrophy (2/173), and with unidentified causes in 23 patients. 43 people died by the end of the follow-up.

Independent Predictors of All-Cause Mortality in Maintenance HD Patients

Patients with mortality end points had elder age (*p* < 0.001), higher serum creatinine (*p* = 0.008), increased incidence of hypertension (*p* = 0.003), diabetes (*p* < 0.001), and severe anemia (*p* = 0.013) compared with surviving patients (Table 1). Table 2 showed the differences between surviving patients and deceased patients in echocardiographic parameters; the data with differences include LAD (*p* < 0.001), LADI (*p* < 0.001), LVIDD index (*p* = 0.041), *e'* (*p* = 0.009), TR (*p* = 0.002), *E/e'* (*p* = 0.011), CVC (*p* < 0.001), and CVR (*p* = 0.006).

As shown in Figure 1, univariate analyses showed that age, hypertension, diabetes, Hb, LADI, TR, CVC, CVR and right atrial dilatation were associated with the risk of overall mortality. Restricted cubic spline models in Figure 2 presented the relationships between age, Hb, LADI and TR, and mortality. All these factors were included in multivariate COX analysis to screen for risk factors of mortality. Table 3 shows that age, hypertension, diabetes, LADI, CVC, and CVR were independently associated with overall mortality. And a final model was fitted using identified factors and clinically relevant Hb [11]. The forest plot (Fig. 3) shows the hazard ratio of each covariate with overall mortality.

Improvement of Basic Model by Echocardiography

As shown in Figure 4, the echocardiography-fortified model showed an increased area under the curve compared to the baseline model (0.788 vs. 0.691), with a lower Brier index (0.089 vs. 0.099), indicating an improved predictive value for mortality. Moreover, the time-dependent AUC supported a better prognostic power of the echocardiography-fortified model throughout the 3-year observation. The echocardiography-fortified model also displayed higher discriminating capacity in patients at different risk levels (net weight subindex = 0.532, integrated differentiation index = 0.0762) (Table 4).

Construction of the Predictive Nomogram for Death in Patients with Maintenance HD

Based on the multivariate model, we generated a nomogram as shown in Figure 5. The contribution of each variate was quantified and visualized. By summing the scores, we can find a point on the line that represents the total score. The value at this point represents the predicted risk of mortality. A higher score indicated that a patient was more likely to die in 3 years.

Table 2. The comparison of echocardiography characteristics in patients

Characteristics	Without events (<i>n</i> = 130)	With events (<i>n</i> = 43)	<i>p</i> value
LAD, mm	41 (36, 46)	46.0 (43.0, 48.9)	<0.001
LADI, mm/m ²	24.69 (21.78, 28.54)	29.36 (26.13, 32.93)	<0.001
LVIDD, mm	52.49±6.82	52.98±6.74	0.683
LVIDDI, mm/m ²	32.38±4.04	33.89±4.55	0.041
LVEF, %	62.95 (56.75, 67.64)	61.10 (54.07, 67.18)	0.356
LVEF <45%, <i>n</i> (%)	12 (9.2%)	5 (11.6%)	0.871
IVST, mm	10.65 (9.88, 12.55)	12 (10,13)	0.212
LVPWT, mm	10.10 (9.48, 12.03)	11.3 (9.9, 13.0)	0.302
LV mass, g	217.76 (169.92, 284.36)	233.53 (176.04, 314.56)	0.277
LVMI, g/m ^{2.7}	54.08 (45.17, 66.43)	59.18 (49.02, 79.53)	0.087
e', cm/s	9.00 (8.00, 11.13)	8 (6, 10)	0.009
TR, m/s	2.39 (2.13, 2.68)	2.65 (2.27, 3.04)	0.002
E/e'	9.10 (7.00, 12.41)	11.8 (8.0, 15.0)	0.011
CVC, <i>n</i> (%)			<0.001
1	77 (59.2%)	19 (44.2%)	
2	20 (15.4%)	23 (53.5%)	
CVS, <i>n</i> (%)	3 (2.3%)	4 (9.3%)	0.065
CVR, <i>n</i> (%)	18 (13.8%)	14 (32.6%)	0.006
CE, <i>n</i> (%)	54 (41.5%)	23 (53.5%)	0.172
RA dilatation, <i>n</i> (%)	18 (13.8%)	11 (25.6%)	0.074
RV dilatation, <i>n</i> (%)	12 (9.2%)	6 (14.0%)	0.554

Figures in parentheses are ranges or percentages as indicated. LAD, left atrial diameter; LADI, left atrial diameter index; LVIDD, left ventricular internal diameter at end-diastole; LVIDDI, LVIDD/body surface area (mm/m²); LVEF, left ventricular ejection fraction; IVST, interventricular septal thickness; LVPWT, left ventricular posterior wall thickness; LV mass, left ventricular mass; LVMI, left ventricular mass index; E, peak early diastolic velocity (by pulsed Doppler sonography); e', peak velocity of the early diastolic wave (by pulsed-wave tissue Doppler sonography); TR, peak velocity of tricuspid regurgitation; CVC, cardiac valvular calcification (1, valve sclerosis; 2, valve calcification); CVS, cardiac valve stenosis; CVR, cardiac valve regurgitation; CE, pericardial effusion; RA dilatation, right atrium dilatation; RV dilatation, right ventricle dilatation.

Fig. 1. a–i Kaplan-Meier survival analysis of 173 hemodialysis patients. DM, diabetes; HTN, hypertension; Hb, hemoglobin; LADI, left atrial diameter index; TR, peak velocity of tricuspid regurgitation; CVR, cardiac valve regurgitation; RA dilatation, right atrium dilatation. (For figure see next page.)

Fig. 2. a–d Restricted cubic spline models to evaluate the association between continuous variables and mortality. Hb, hemoglobin; LADI, left atrial diameter index; TR, peak velocity of tricuspid regurgitation.

Fig. 3. Forest plot of multivariate-adjusted hazard ratio (HR) of each risk factor. HTN, hypertension; DM, diabetes; Hb, hemoglobin; LADI, left atrial diameter index; CVC, cardiac valvular calcification; CVR, cardiac valve regurgitation. LADI/5[#]: for every 5 mm/m² increase in LADI, HR increases to 1.5.

Fig. 4. a–c Receiver-operating characteristic (ROC) curves and calibration curves and time-dependent ROC curves for the basic model and the updated model containing echocardiography factors. AUC, area under the curve; HTN, hypertension; DM, diabetes; Hb, hemoglobin; LADI, left atrial diameter index; CVC, cardiac valvular calcification; CVR, cardiac valve regurgitation; m1, model 1, based on basic data, including age, HTN, DM, and Hb; m2, model 2, based on m1 + LADI, CVC, and CVR.

Table 3. Multivariate Cox regression analysis of variables predicting mortality

Variables		β -coefficient	SE	Wald	<i>p</i> value	OR	95% CI
Step 1	Age	0.6	0.341	3.102	0.078	1.822	0.935–3.552
	DM	0.656	0.327	4.022	0.045	1.928	1.015–3.662
	HTN	0.982	0.618	2.528	0.112	2.670	0.796–8.958
	CVC	0.703	0.317	4.913	0.027	2.021	1.085–3.764
	CVR	0.746	0.394	3.588	0.058	2.110	0.974–4.567
	TR	−0.066	0.361	0.033	0.856	0.936	0.461–1.902
	Hb	0.258	0.383	0.454	0.501	1.294	0.611–2.743
	LADI	0.077	0.038	4.198	0.040	1.080	1.003–1.163
Step 3	Age	0.610	0.339	3.247	0.072	1.841	0.948–3.574
	DM	0.618	0.314	3.858	0.050	1.854	1.001–3.434
	HTN	1.052	0.609	2.984	0.084	2.864	0.868–9.452
	CVC	0.702	0.306	5.261	0.022	2.019	1.108–3.679
	CVR	0.804	0.351	5.255	0.022	2.234	1.124–4.442
	LADI	0.078	0.037	4.576	0.032	1.081	1.007–1.162

SE, standard error; OR, odds ratio; CI, confidence interval; DM, diabetes; HTN, hypertension; CVC, cardiac valvular calcification; CVR, cardiac valve regurgitation; TR, peak velocity of tricuspid regurgitation; Hb, hemoglobin; LADI, left atrial diameter index.

Table 4. Reclassification assay between the basic model and the updated model containing echocardiography factors

		Updated mode			% reclassified				
Risk level		low	medium	high					
Basic model	Low	46	7	1	15				
	Medium	34	47	11	49				
	High	0	8	19	30				
Model		Concordance <i>p</i> value index		NRI categorical, %	<i>p</i> value	NRI continuous, %	<i>p</i> value	IDI, %	<i>p</i> value
Basic		69.1 (56.6–81.5)		ref. (1.00)		ref. (1.00)		ref. (1.00)	
Updated		78.8 (69.3–88.4)	0.045	30.07 (10.65–49.49)	0.002	53.20 (19.66–86.74)	0.002	7.62 (2.90–12.33)	0.002

Basic model: based on basic data, including age, HTN, DM, Hb; updated model: based on basic data + LADI, CVC, CVR. NRI, net weight subindex; IDI, integrated differentiation index; HTN, hypertension; DM, diabetes; Hb, hemoglobin; LADI, left atrial diameter index; CVC, cardiac valvular calcification; CVR, cardiac valve regurgitation.

Discussion

CKD patients are at high risk of CVD. Decreased glomerular filtration rate and increased serum creatinine raised the risk of CVD. CVD is one of the most important prognostic factors in CKD, contributing to the majority of deaths in this population [12]. Several guidelines mentioned the use of echocardiography to assess cardiac function in patients with CKD, and many studies have confirmed that cardiac ultrasonography has a good predictive function for the death of CKD patients [13]. Most of these studies evaluated one or more indicators with CKD death. We designed a predictive nomogram of the risk of death in the HD patients based on echocardiography, combined with basic clinical and laboratory data.

We incorporated independent predictors including age, hypertension, diabetes, LADI, CVC, and CVR into the model. Hb is also considered together because of its clinical significance. Consistently with previous studies, our study shows that advanced age, diabetes, anemia, and high blood pressure increase the risk of death. In addition, in our study, we found that LADI, CVC, and CVR are the echocardiographic data most closely related to death risk.

In our study, LADI is an independent predictor of mortality risk in HD patients. We found that LADI increased for every 5 mm/m²; the hazard ratio increased to 1.5 accordingly. Left atrial (LA) dilatation is common in

patients with CKD due to stress and volume overload [14]. It has been suggested that LA enlargement is a marker of adverse cardiovascular outcomes in patients with CKD [15, 16]. Our previous studies showed that peritoneal dialysis patients developed early LV diastolic dysfunction, and cardiac diastolic function declines over time with long-term peritoneal dialysis [1, 17]. While in this study, just as other studies previously reported [18], we suggested that LV diastolic function indicators, TR and LA size, which were recommended by the LV diastolic guidelines [10], have a significant prognostic value of HD patients. However, the LA volume index, recommended by the guideline, is not a routine measurement in the clinic, and we only have the LADI to evaluate the LA size. There may be too many factors affecting the measurement, and we have not found the predictive value in *e'* and *E/e'*, although some articles have pointed out that they also have the same significance [13]. In addition, we found that TR >2.8 m/s was associated with the risk of overall mortality in our study. Just as the European Association of Cardiovascular Imaging recommended, when TR >2.8 m/s, the probability of pulmonary hypertension may then be judged as high, which suggested that pulmonary hypertension may be associated with the death in HD patients, consistent with the study of Reque et al. [19].

The incidence of CVC in patients with ESRD is 5–10 times higher than that of patients without renal dysfunction.

Fig. 5. Nomogram model for predicting all-cause mortality in patients starting hemodialysis for end-stage renal disease. HTN, hypertension; DM, diabetes; Hb, hemoglobin; LADI, left atrial diameter index; CVC, cardiac valvular calcification; CVR, cardiac valve regurgitation. CVC*: 0, noncalcification; 1, valve sclerosis; 2, valve calcification.

tion [20]. Previous studies showed that CVC is associated with atherosclerosis, arterial calcification, LV hypertrophy, and other CVDs in patients with CKD [21–23]. Samad et al. [24] reported that the high incidence of valvular heart disease in patients with ESRD may contribute to a high mortality rate. Both CVC and valvular heart disease may be attributed to metabolic disorders associated with ESRD. The prevalence of CVC is correlated with increased calcium (Ca), phosphorus (P), blood lipids, parathyroid hormone, and increased release of chronic inflammatory mediators [21, 25–27]. While CVC has been extensively studied in the ESRD population, data on CVR are still limited. Multiple factors despite ESRD, including cardiac enlargement and functional regurgitation, may predispose to CVR. Although mild CVR usually has no special clinical significance, moderate and severe CVR may disturb cardiac hemodynamics. Chronic CVR may even cause dilatation of the cardiac chambers and diastolic/systolic dysfunction. In our study, secondary mitral regurgitation (MR) cases account for the majority of CVR, but how much of CVR was due to CVC was difficult to ascertain. Severity of MR may increase over time because of the associated progressive LV systolic dysfunction and dysfunction due to adverse remodeling of the left

ventricle [28]. Severe MR can cause pulmonary hypertension and atrial fibrillation, heart failure, and even death. The incidence of all-cause death, cardiogenic death, and cardiovascular events within 5 years in asymptomatic severe MR patients was 22 ± 3 , 14 ± 3 , and $33 \pm 3\%$ [29].

Previous studies [5] have found that LV systolic dysfunction (ejection fraction $<45\%$) is an important predictor of death in ESRD patients. But in the population in our study, LV ejection fraction did not show statistical significance, and in our study, patients with low LV ejection fraction ($<45\%$) only account for 9.8% (17/173) in initiating HD. Most of these patients have preserved LV systolic function. This score may apply to patients with preserved LV systolic function more than patients with reduced systolic function. At the same time, although the enlargement of the right atrium has some predictive value for mortality, its independent predictive value has not been obtained.

There have been several articles on the relationship between echocardiography and the prognosis of dialysis patients, and some independent predictors have been identified. But few people have developed an integration system like us to combine these data with clinical factors. And with the addition of echocardiography data, our no-

mogram has a better discriminating power in predicting the risk of death in patients with HD. Besides, when it comes to identifying people with different risk stratifications, our model is more advantageous.

Our research also has some limitations. Firstly, because our research is a retrospective study, the lack of some indicators prevents us from conducting more in-depth research on right heart functions, LV systolic dysfunction using 3-dimensional echocardiography or strain analysis. Secondly, due to the size of the study, we have a small sample size. Although we use the bootstrap method to carry out the internal verification, which is in line with statistical needs, we lack more cases for further external validation. Thirdly, the study is a single-center study, and the nomogram needs to be validated at other centers to test its generalizability.

Conclusion

We showed that age, hypertension, diabetes, anemia, LADI, CVC, and CVR are independently associated with the risk of overall mortality in ESRD patients undergoing HD. A multivariate model based on these risk factors may assist the clinician in the risk stratification of ESRD patients.

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Statement of Ethics

This study was approved by the Ethics Committee of the Second Affiliated Hospital of Soochow University and registered in the Chinese Clinical Trial Registry (No. ChiCTR1900024999). Informed consent was obtained from all participants. The study protocol conformed to the Declaration of Helsinki.

Disclosure Statement

There are no conflicts of interest to disclose.

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