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Prognostic value of lung ultrasound (B-Line) in pre-discharge as a predictor of 90 days rehospitalization in patient with reduced ejection fraction

Yogi Andrew Taruk Padang, Akhtar Fajar Muzakkir, Peter Kabo, Ali Aspar Mappahya

Department of Cardiology, Faculty of Medicine, Hasanuddin University, Makassar, South Sulawesi, Indonesia

ABSTRACT

Objectives. This study aimed to evaluate the prognostic value of pre-discharge lung ultrasound B-line quantification in predicting 90-day rehospitalization among patients with heart failure with reduced ejection fraction (HFrEF).

Materials and methods. A retrospective cohort study was conducted at the Integrated Heart Center of Wahidin Sudirohusodo Hospital, including 120 patients with HFrEF hospitalized between March and July 2023. Adult patients (≥18 years) with left ventricular ejection fraction <50% were included, while those undergoing cardiac interventions or with pericardial disease were excluded. Pre-discharge B-lines were quantified across eight lung zones using a Philips Lumify ultrasound device. The primary endpoint was heart failure–related rehospitalization within 90 days. Statistical analyses included receiver operating characteristic curve analysis using the Youden index to determine optimal B-line cutoffs and multivariate logistic regression for risk stratification.

Outcomes. Of the 120 patients (mean age 58.6 ± 12.3 years, 73.3% male), 42.5% experienced rehospitalization. Rehospitalized patients had significantly higher B-line counts (26.2 ± 8.1 vs. 19.0 ± 8.5; $p < 0.0001$). A B-line cutoff of ≥20 predicted rehospitalization with 78.4% sensitivity and 68.1% specificity (AUC 72.2%), conferring a 7.2-fold increased risk (OR 7.216, 95% CI 3.091–16.846). Additional predictors included estimated glomerular filtration rate <63 mL/min/1.73 m², serum creatinine ≥1.26 mg/dL, and left ventricular ejection fraction <32%. Chronic kidney disease was six-fold more prevalent in rehospitalized patients (25.5% vs. 4.4%; $p < 0.001$).

Conclusions. Pre-discharge B-line quantification is a robust bedside predictor of 90-day rehospitalization in patients with HFrEF. A threshold of ≥20 B-lines identifies patients at high risk who may benefit from intensified decongestion strategies and closer post-discharge monitoring. Integration of lung ultrasound with renal and echocardiographic parameters improves risk stratification and supports the incorporation of lung ultrasound into routine discharge assessment to reduce readmissions.

Keywords: congestive heart failure, rehospitalization, lung ultrasound, B-line

INTRODUCTION

Heart failure (HF) remains one of the most significant cardiovascular diseases worldwide, with a substantial and growing prevalence. Globally, an estimated 64.3 million individuals are affected by HF, more than half of whom present with heart failure with preserved ejection fraction (HFpEF). This trend is influenced by advancements in diagnostic modalities and evolving clinical definitions of HF. In developed nations, HF prevalence accounts for approximately 1%–2% of the general population [1]. According to the 2019 Global Burden of Disease (GBD) study, Asia bears a considerable burden, with 31.89 million HF cases, corresponding to an age-standardized rate (ASR) of 722.45 per 100,000 population. Notably, Indonesia exhibits one of the highest prevalence rates in Asia at 900.90 per 100,000 population (0.94% of the popula-

Corresponding author:
Yogi Andrew Taruk Padang
E-mail: yogiandrew17@gmail.com

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tion), second only to China. Furthermore, HF incidence in Asia is alarmingly high, with China reporting 275 new cases per 100,000 individuals annually, equivalent to 3 million new diagnoses among adults aged ≥25 years, while Japan observes an incidence of 10 per 1,000 individuals aged ≥65 [2].

The high prevalence and incidence of HF pose significant clinical and economic challenges, primarily due to elevated rehospitalization rates and associated healthcare costs. A study by O'Connor et al. [3] analyzing systolic HF (ejection fraction [EF] <40%) using the EVEREST program data revealed that among 4,133 patients, 2,159 (52.2%) experienced at least one rehospitalization, with HF exacerbation being the leading cause (31.1% of cases). Rehospitalization rates were 24.1% within 30 days, 18.2% between 31–60 days, and surged to 58.7% beyond 60 days post-discharge. The financial burden is equally concerning; in the United States, the mean cost per rehospitalized HF patient was USD 14,631, driven by a 90-day readmission rate of 40.2% [4]. A comparative analysis further demonstrated that rehospitalized HF patients incurred significantly higher costs (USD 15,618 ± 25,264) than non-rehospitalized patients (USD 11,845 ± 22,710) [5].

Lung ultrasound (LUS) has emerged as a pivotal tool for evaluating pulmonary edema in acute heart failure (AHF) and is now standard practice in emergency departments (EDs) and intensive care units (ICUs). Assessing congestion, particularly when extrapulmonary signs are subtle, remains clinically challenging. However, integrated clinical scoring systems incorporating multiple indicators have proven superior to physical examination alone in quantifying congestion severity [6]. LUS detects lung congestion with accuracy comparable to computed tomography (CT), displaying B-lines, vertical hyperechoic artifacts resembling lighthouse beams that correlate with interstitial edema. This noninvasive, bedside modality enables real-time assessment, making it invaluable in HF management. Echocardiography, the primary diagnostic tool for evaluating left ventricular filling pressures, can be augmented by LUS to identify pulmonary interlobular septal edema via B-line quantification, which reflects the degree of pulmonary congestion. Studies suggest that a B-line threshold of ≥10 across eight lung zones (or >2 zones with ≥3 B-lines each) reliably indicates significant congestion, with sensitivity exceeding 90% for diagnosing alveolar-interstitial syndrome and AHF. Consequently, B-line monitoring may offer an objective means to assess therapeutic efficacy in AHF [7].

Despite advances in HF management, many patients are discharged with residual congestion, a key predictor of rehospitalization and mortality. Detecting subclinical congestion prior to discharge remains difficult, underscoring the need for multimodal assessment strategies. Optimizing treatment, including diuretic titration, to resolve persistent congestion is critical to improving outcomes [6].

Given these considerations, LUS-derived B-line quantification may serve as an independent predictor of rehospitalization in HF. This study aims to evaluate the utility of B-line counts in stratifying rehospitalization risk, with the primary endpoint being HF-related readmission within 90 days post-discharge.

MATERIALS AND METHODS

Study design and population

This retrospective cohort study included patients admitted to the Inpatient Unit of the Integrated Heart Center at Wahidin Sudirohusodo Hospital with a diagnosis of congestive heart failure. Participants were enrolled from the hospital's Heart Failure Registry between March and July 2023.

Inclusion and exclusion criteria

The study included hospitalized adults aged 18 years or older with a primary diagnosis of congestive heart failure and a left ventricular ejection fraction below 50% on admission echocardiography. Patients were excluded if they underwent interventional procedures such as cardiac resynchronization therapy or valve replacement; had pericardial disease, including effusion or constrictive pericarditis; exhibited atrioventricular dyssynchrony, such as complete heart block or recent pacemaker implantation; or declined participation in study procedures.

Data collection

Clinical data were extracted from the Heart Failure Registry and supplemented by medical record review when necessary. Collected variables included demographic information (age, sex, and body mass index); medical history, including comorbidities and prior heart failure medications; admission data comprising laboratory results obtained within 24 hours of hospitalization and echocardiography findings; and pre-discharge assessment through lung ultrasonography to quantify B-lines.

Lung ultrasonography protocol

The protocol was based on European Association of Cardiovascular Imaging (EACVI) recommendations for LUS in acute and chronic heart failure, which describe various scanning protocols ranging from 4 to 28 zones, with the patient in the supine or semi-recumbent position. In this study, a total of eight scanning zones were used, with four zones per hemithorax. B-lines were evaluated using a portable Philips Lumify ultrasound device equipped with a

linear probe. The transducer was placed in the intercostal space, and the number of B-lines in each examination zone was summed as a representation of extravascular lung water. Total B-line counts were categorized as mild congestion for 6–15 B-lines, moderate congestion for 16–30 B-lines, and severe congestion for >30 B-lines. Patients underwent lung ultrasound and echocardiography by a trained examiner under the supervision of an experienced cardiologist within 24 hours before discharge.

Follow-up and outcomes

Patients were monitored for 90 days post-discharge through telephone interviews with patients or their families and hospital record reviews. The primary endpoint was rehospitalization due to congestive heart failure exacerbation within the 90-day follow-up period.

Statistical analysis

Descriptive analysis presented categorical variables as frequencies and percentages, while continuous variables were reported as mean ± standard deviation for parametric data or median and interquartile range for nonparametric data. Comparative analysis employed the Mann-Whitney U test to compare B-line counts between rehospitalized and non-rehospitalized groups, given the non-normal distribution of the data. Receiver operating characteristic curve analysis determined the optimal B-line cutoff for predicting rehospitalization, with the Youden index used to maximize sensitivity and specificity. Variables showing a statistically significant association with rehospitalization in univariate analysis were further analyzed using multivariate logistic regression to adjust for potential confounders.

Ethical considerations

The study protocol received approval from the Research Ethics Committee of Hasanuddin University Faculty of Medicine under reference number 1032/UN4.6.4.5.31/PP36/2024. All procedures adhered to the ethical principles outlined in the Declaration of Helsinki and complied with local regulatory requirements.

TABLE 1. Baseline characteristics of the study population

Variables	n (%)	Mean ±SD
Age (years)		58.58 ± 12.28
Gender		
Male	88 (73.3)	
Female	32 (26.7)	
B-line		22.05 ± 9.04
90-day rehospitalization		
Yes	51 (42.5)	
No	69 (57.5)	
Laboratory findings		
eGFR (mL/min/1.73 m²)		66.75 ± 28.81
Creatinine (mg/dL)		1.50 ± 1.42
NT-proBNP (pg/mL)		163.10 ± 66.01
NA	23 (19.67)	
Echocardiography		
Ejection fraction (%)		34.62 ± 9.14
PCWP (mmHg)		23.85 ± 46.70
Average E/e' (unitless)		17.70 ± 37.66
Comorbidity		
Coronary artery disease	34 (28.33)	
Ischemic heart disease	65 (54.17)	
Hypertensive heart disease	46 (38.33)	
Peripheral artery disease	0 (0)	
Pulmonary hypertension	3 (2.5)	
Congenital heart disease	1 (0.83)	
Atrial fibrillation	19 (15.83)	
Hypertension	66 (55)	
Diabetes mellitus	37 (30.83)	
Valvular heart disease	33 (27.5)	
Rheumatic heart disease	2 (1.67)	
Cardiomyopathy	95 (79.17)	
Dyslipidemia	25 (20.83)	
Cerebrovascular disease	6 (5.0)	
Asthma	0 (0)	
COPD	1 (0.83)	
Chronic kidney disease	16 (13.33)	
Pneumonia	27 (22.5)	
Medication		
ACEi/ARB	92 (76.67)	
ARNI	7 (5.83)	
Calcium channel blocker	3 (2.5)	
Beta blocker	58 (48.33)	
Diuretics	102 (85)	
Aldosterone antagonists	70 (58.33)	
Tolvaptan	0 (0)	
Ivabradin	3 (2.5)	
Digoxin	20 (16.67)	
SGLT2 inhibitor	1 (0.83)	
History of smoking		
Yes	68 (56.67)	
No	52 (43.33)	

Values are n (%) or mean ± SD, unless stated otherwise.

RESULTS

From the registry (N = 270), 96 patients were excluded due to incomplete admission or pre-discharge laboratory/echocardiography/LUS data, and 54 were excluded due to loss to follow-up, leaving 120 in the final cohort. Missingness occurred primarily because (1) patients were discharged before completion of pre-discharge testing due to operational constraints, (2) some laboratory samples were not processed or were damaged, and (3) telephone follow-up contact could not be established for some patients.

As summarized in Table 1, the study population comprised 120 heart failure patients with reduced ejection fraction. The mean age was 58.58 ± 12.28 years, with a male predominance (73.33%). Rehospitalization within 90 days occurred in 42.5% of patients. Pulmonary congestion, assessed via B-line count, was elevated (mean 22.05 ± 9.04), indicating

TABLE 2. Relationship between variables and 90-day rehospitalization

Variables	No rehospitalization (n = 69)		Rehospitalization (n = 51)		p-value
	n (%)	Mean ± SD	n (%)	Mean ± SD	
Age (years)		59.80 ± 10.71		56.94 ± 14.07	0.209[a]
Gender					
Male	51 (73.91)		37 (72.55)		0.867[b]
Female	18 (26.09)		14 (27.45)		
Laboratory findings					
eGFR (mL/min/1.73 m²)		73.99 ± 26.32		56.95 ± 29.37	**0.001**[a]
Creatinine (mg/dL)		1.21 ± 0.71		1.89 ± 1.96	**0.011**[a]
NT-proBNP (pg/mL)		156.29 ± 52.67		170.77 ± 78.77	0.667[a]
NA	17 (24.64		6 (11.76)		
Echocardiography					
Ejection fraction (%)		36.83 ± 9.24		31.63 ± 8.18	**0.004**[a]
PCWP (mmHg)		18.19 ± 4.66		31.50 ± 71.11	**0.039**[a]
Average E/e' (unitless)		13.14 ± 3.76		23.87 ± 57.35	**0.039**[a]
Comorbidity					
Coronary artery disease					
Yes	20 (28.99)		14 (27.45)		0.854[b]
No	49 (71.01)		37 (72.55)		
Ischemic heart disease					
Yes	44 (63.77)		21 (41.18)		**0.014**[b]
No	25 (36.23)		30 (58.82)		
Hypertensive heart disease					
Yes	30 (43.48)		16 (31.37)		0.178[b]
No	39 (56.52)		35 (68.63)		
Peripheral artery disease					
Yes	0 (0)		0 (0)		1.000[b]
No	69 (100)		51 (100)		
Pulmonary hypertension					
Yes	1 (1.45)		2 (3.92)		0.391[b]
No	68 (98.55)		49 (96.08)		
Congenital heart disease					
Yes	0 (0)		1 (1.96)		0.243[b]
No	69 (100)		50 (98.04)		
Atrial fibrillation					
Yes	9 (13.04)		10 (19.61)		0.330[b]
No	60 (86.96)		41 (80.39)		
Hypertension					
Yes	41 (59.42)		25 (49.02)		0.258[b]
No	28 (40.58)		26 (50.98)		
Diabetes mellitus					
Yes	20 (28.99)		17 (33.33)		0.610[b]
No	49 (71.01)		34 (66.67)		
Valvular heart disease					
Yes	18 (26.09)		15 (29.41)		0.687[b]
No	51 (73.91)		36 (70.59)		
Rheumatic heart disease					
Yes	1 (1.45)		1 (1.96)		0.829[b]
No	68 (98.55)		50 (98.04)		
Cardiomyopathy					
Yes	2 (2.9)		1 (1.96)		0.745[b]
No	67 (97.1)		50 (98.04)		
Dyslipidemia					
Yes	13 (18.84)		12 (23.53)		0.532[b]
No	56 (81.16)		39 (76.47)		
Cerebrovascular disease					
Yes	4 (5.8)		2 (3.92)		0.641[b]
No	65 (94.2)		49 (96.08)		
Asthma					
Yes	0 (0)		0 (0)		1.000[b]
No	69 (100)		51 (100)		
COPD					
Yes	1 (1.45)		0 (0)		0.388[b]
No	68 (98.55)		51 (100)		

Variables	No rehospitalization (n = 69)		Rehospitalization (n = 51)		p-value
	n (%)	Mean ± SD	n (%)	Mean ± SD	
Chronic kidney disease					
Yes	3 (4.35)		13 (25.49)		**<0.001[b]**
No	66 (95.65)		38 (74.51)		
Pneumonia					
Yes	18 (26.09)		9 (17.65)		0.274[b]
No	51 (73.91)		42 (82.35)		
Medication					
ACEi/ARB					
Yes	54 (78.26)		38 (74.51)		0.631[b]
No	15 (21.74)		13 (25.49)		
ARNI					
Yes	4 (5.8)		3 (5.88)		0.984[b]
No	65 (94.2)		48 (94.12)		
Calcium channel blocker					
Yes	1 (1.45)		2 (3.92)		0.391[b]
No	68 (98.55)		49 (96.08)		
Beta blocker					
Yes	35 (50.72)		23 (45.1)		0.542[b]
No	34 (49.28)		28 (54.9)		
Diuretics					
Yes	56 (81.16)		46 (90.2)		0.171[b]
No	13 (18.84)		5 (9.8)		
Aldosterone antagonists					
Yes	35 (50.72)		35 (68.63)		**0.049[b]**
No	34 (49.28)		16 (31.37)		
Tolvaptan					
Yes	0 (0)		0 (0)		1.000[b]
No	69 (100)		51 (100)		
Ivabradin					
Yes	1 (1.45)		2 (3.92)		0.391[b]
No	68 (98.55)		49 (96.08)		
Digoxin					
Yes	10 (14.49)		10 (19.61)		0.457[b]
No	59 (85.51)		41 (80.39)		
SGLT2 inhibitor					
Yes	1 (1.45)		0 (0)		0.388[b]
No	68 (98.55)		51 (100)		
History of smoking					
Yes	39 (56.52)		29 (56.86)		0.970[b]
No	30 (43.48)		22 (43.14)		

Values are n (%) or mean ± SD, unless stated otherwise. [a]Mann-Whitney test; [b]Chi-square test

significant interstitial fluid accumulation. Laboratory findings revealed moderate renal impairment, with a mean eGFR of 66.75 ± 28.81 mL/min/1.73 m² and creatinine of 1.51 ± 1.42 mg/dL. NT-proBNP levels averaged 163.01 ± 66.11 pg/mL (missing in 19.67% of cases). Echocardiographic markers of diastolic dysfunction included elevated left ventricular filling pressures (mean PCWP 23.85 ± 6.47 mmHg; E/e' 17.77 ± 3.67). Hypertension (55%, n = 66) and ischemic heart disease (54.17%, n = 65) were prevalent comorbidities, while chronic kidney disease (13.33%, n = 16) and atrial fibrillation (15.83%, n = 19) were less common. Pharmacotherapy predominantly included diuretics (85%, n = 102), ACEi/ARBs (76.67%, n = 92), and aldosterone antagonists (58.33%, n = 70). ARNI (5.83%, n = 7) and SGLT2 inhibitor (0.83%, n = 1) use was minimal.

Table 2 outlines factors associated with 90-day rehospitalization. Renal dysfunction was prominent in rehospitalized patients (eGFR 56.95 ± 29.37 vs. 73.99 ± 26.32 mL/min/1.73 m², p = 0.001; creatinine 1.89 ± 1.96 vs. 1.21 ± 0.71 mg/dL, p = 0.011). NT-proBNP did not differ significantly (p = 0.667). Echocardiographic parameters correlated strongly with outcomes; rehospitalized patients had lower EF (31.63 ± 8.18% vs. 36.83 ± 9.24%; p = 0.004), higher PCWP (31.5 ± 11.71 vs. 18.19 ± 4.66 mmHg; p = 0.039), and elevated E/e' (23.87 ± 57.35 vs. 13.14 ± 3.76; p = 0.039). Among comorbidities, chronic kidney disease was more frequent in rehospitalized patients (25.49% vs. 4.35%; p < 0.001), whereas ischemic heart disease was less common (41.18% vs. 63.77%; p = 0.014). Aldosterone antagonist use was higher in rehospitalized patients (68.63% vs. 50.72%; p = 0.049), though other medications showed no significant associations.

Figure 1 demonstrates a significant disparity in B-line counts between rehospitalized and non-rehos-

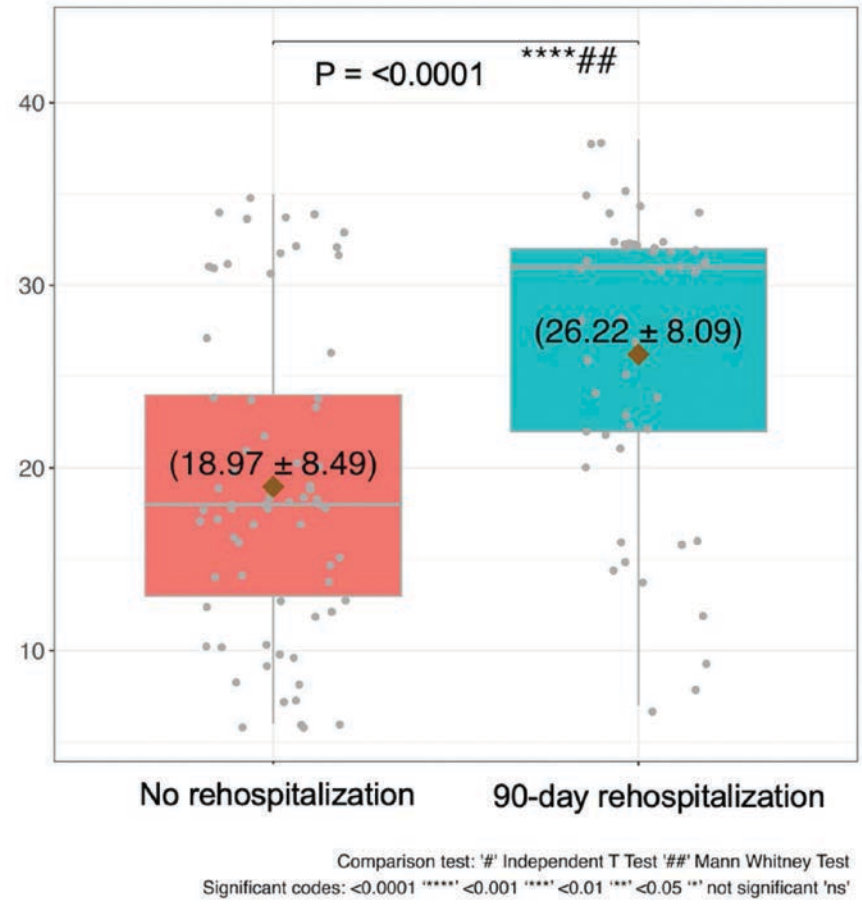

FIGURE 1. Comparison of B-line parameters according to 90-day rehospitalization status in patients with heart failure

Patients with B-line ≥20 had a 7.2-fold higher rehospitalization risk (OR 7.216, 95% CI: 3.091–16.846; p < 0.0001; Figure 3).

Receiver operating characteristic (ROC) analysis was performed to evaluate the ability of pre-discharge variables to predict 90-day rehospitalization. Figure 4 illustrates the ROC curves and optimal cutoff values (Youden index) for pre-discharge echocardiographic and renal parameters associated with 90-day rehospitalization. Optimal cutoffs (Youden index) and diagnostic performance were: Average E/e' cutoff 11.54 (sensitivity 86.3%, specificity 36.2%, accuracy 57.5%, AUC 61.0%), PCWP cutoff 16.21 (sensitivity 86.3%, specificity 36.2%, accuracy 57.5%, AUC 61.0%), eGFR cutoff 63 mL/min/1.73 m² (sensitivity 54.9%, specificity 69.6%, accuracy 63.3%, AUC 61.7%), serum creatinine cutoff 1.26 mg/dL (sensitivity 54.9%, specificity 72.5%, accuracy 65.0%, AUC 63.6%), and left ventricular ejection fraction cutoff 32%

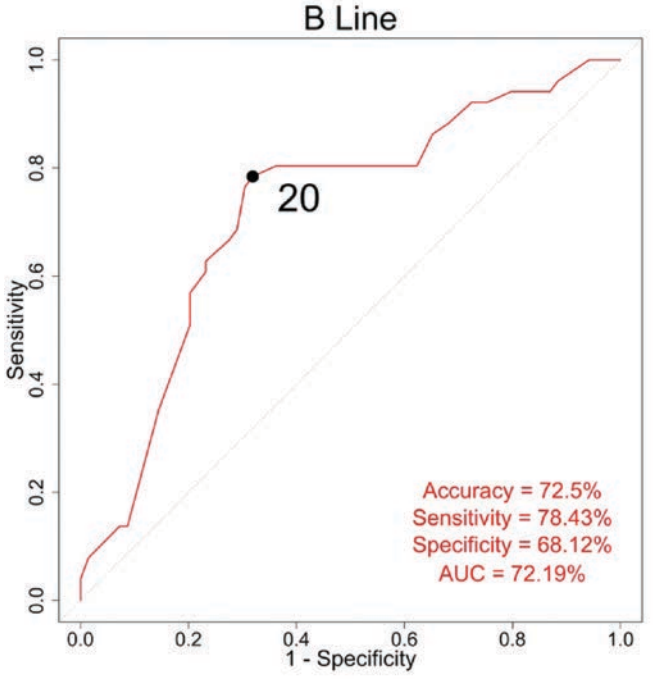

FIGURE 2. Receiver operating characteristic curve for the B-line cutoff value

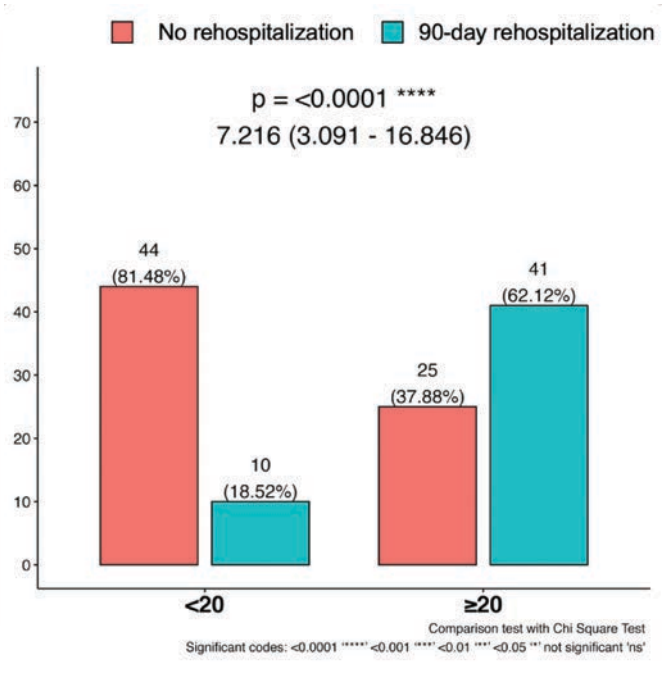

FIGURE 3. Relationship between the B-line cutoff value and 90-day rehospitalization

pitalized groups (26.22 ± 8.09 vs. 18.97 ± 8.49; p < 0.0001). Figure 2 shows that ROC analysis identified a B-line cutoff of 20 (AUC 72.19%, sensitivity 78.43%, specificity 68.12%) for predicting rehospitalization. (sensitivity 51.0%, specificity 78.3%, accuracy 66.7%, AUC 65.6%).

Figure 5 demonstrates that pre-discharge markers of congestion, renal dysfunction, and systolic im-

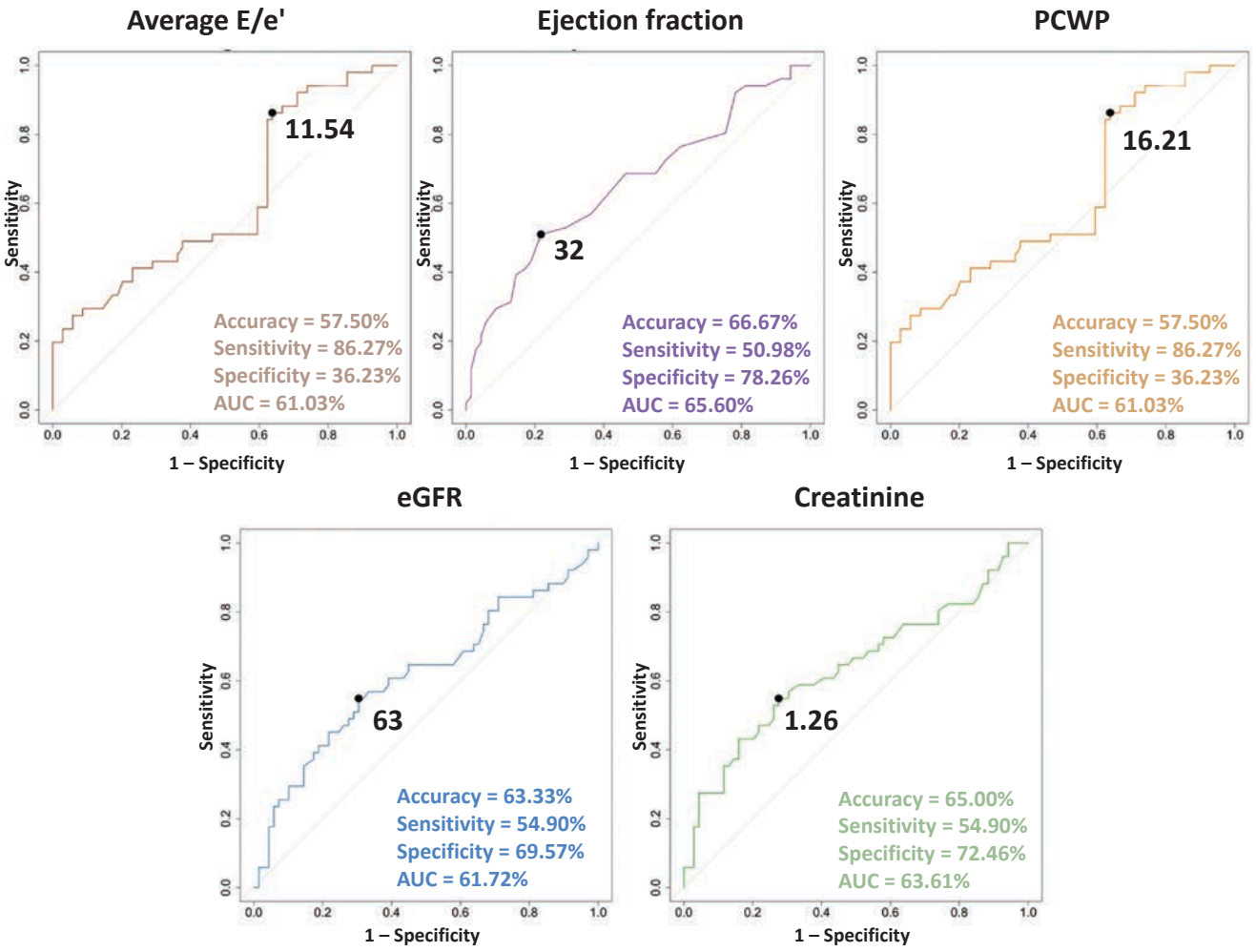

FIGURE 4. Receiver operating characteristic curves for cutoff values of pre-discharge variables

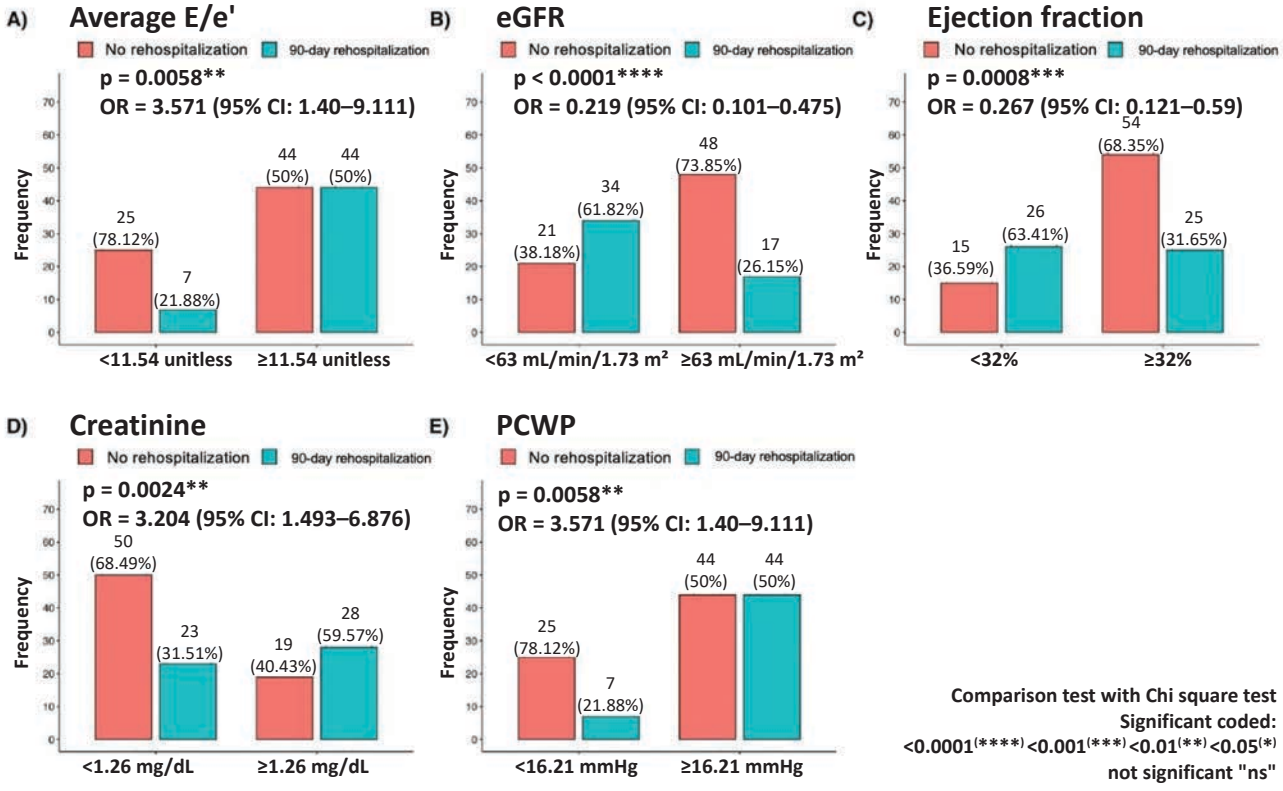

FIGURE 5. Relationship between variable cutoff values and 90-day rehospitalization

pairment were each significantly associated with 90-day rehospitalization in unadjusted categorical analyses. Patients with Average E/e' ≥11.54 experienced rehospitalization in 44/88 (50.0%) versus 7/32 (21.9%) for E/e' <11.54 (OR 3.571, 95% CI: 1.40–9.11; p = 0.0058), and similarly, patients with PCWP ≥16.21 mmHg had rehospitalization in 44/88 (50.0%) versus 7/32 (21.9%) for lower PCWP (OR 3.571, 95% CI: 1.40–9.11; p = 0.0058). Impaired renal function was also predictive: serum creatinine ≥1.26 mg/dL was associated with rehospitalization in 28/47 (59.6%) versus 23/73 (31.5%) for lower creatinine (OR 3.204, 95% CI: 1.49–6.88; p = 0.0024), whereas preserved renal function was protective (eGFR ≥63 mL/min/1.73 m² was associated with rehospitalization in 17/65 (26.2%) versus 34/55 (61.8%) for eGFR <63, OR 0.219, 95% CI: 0.101–0.475; p < 0.0001). Lower systolic function was likewise associated with higher readmission risk: left ventricular ejection fraction <32% had rehospitalization in 26/41 (63.4%) versus 25/79 (31.6%) for EF ≥32% (OR 0.267, 95% CI: 0.121–0.59; p = 0.0008).

DISCUSSION

The principal finding of this investigation is that quantification of B-lines by lung ultrasonography is a robust and clinically significant predictor of 90-day rehospitalization in patients with congestive heart failure. This observation carries substantial implications for contemporary HF management, particularly during the critical transition from inpatient to outpatient care. Our results substantiate and extend prior research demonstrating that residual congestion at discharge represents one of the most potent predictors of adverse outcomes in acute decompensated heart failure [6]. The clinical challenge lies in the frequent dissociation between overt signs of congestion and actual hemodynamic status, creating a compelling rationale for the incorporation of objective assessment tools such as B-line evaluation into standard practice protocols.

The role of persistent congestion at hospital discharge is highly relevant to patient outcomes. The immediate post-discharge interval, often referred to as the vulnerable phase, is a critical period in which many factors that worsen a patient's condition can occur [8]. Lung ultrasound evaluation with B-line assessment provides direct visualization of pulmonary congestion, thereby enabling a noninvasive bedside evaluation of extravascular lung water in individual patients [9].

From a pathophysiological perspective, B-lines originate from ultrasound interactions with fluid-thickened pulmonary interlobular septa, generating characteristic laser-like vertical artifacts that extend from the pleural line to the bottom of the screen without fading [10]. These sonographic markers provide direct, real-time visualization of pulmonary interstitial edema, offering several advantages over traditional assessment methods. Our findings align with prior investigations, particularly Rattarasarn et al. [6], who reported that residual B-lines >12 across eight lung zones predicted six-month rehospitalization with high accuracy (log-rank $\chi^2 = 7.74$, p = 0.004). In univariable analysis, the presence of ≥12 B-lines before discharge (HR = 2.15, 95% CI: 1.27–3.63) was an independent predictor of six-month events. Similar research from Gargani et al. [11] established that persistent pulmonary congestion, as defined by ≥15 B-lines, strongly predicts rehospitalization within six months. The slightly higher optimal cutoff (B-lines ≥20) identified in our study likely reflects differences in patient demographics, severity of illness, or the shorter (90-day) follow-up window examined. The ROC analysis indicates that a B-line cutoff of 20 provides reasonably good diagnostic performance for predicting 90-day rehospitalization, balancing sensitivity and specificity; the AUC of 72.19% denotes fair discriminatory ability.

The immediate post-discharge period represents a particularly vulnerable phase in heart failure management, often termed the “vulnerable phase”, during which patients face dramatically elevated risks of clinical deterioration and readmission [12]. Our data provide compelling support for the hemodynamic cascade theory of heart failure decompensation, wherein progressive elevation of left ventricular filling pressures (quantified in our cohort through both E/e' ratio and estimated PCWP) precedes the development of pulmonary congestion, with B-lines serving as an early marker of this transition [13]. This temporal sequence helps explain why B-line assessment at discharge may outperform traditional clinical examination in predicting subsequent rehospitalization risk.

The robust diagnostic performance of B-line quantification in our study (AUC 72.19%, sensitivity 78.43%, specificity 68.12%) reinforces growing evidence supporting its incorporation into standard clinical practice. Gargani et al. [12] have previously demonstrated that patients with <15 B-lines at discharge experience significantly lower readmission rates, suggesting that B-line assessment could inform both therapy titration and follow-up scheduling. Our findings extend this paradigm by providing specific, validated cutoff values for 90-day risk prediction in a real-world clinical population.

An equally important finding concerns the strong association between renal dysfunction and rehospitalization risk. The observed thresholds (eGFR <63 mL/min/1.73 m² and creatinine ≥1.26 mg/dL) align closely with prior studies of cardiorenal syndrome in heart failure populations [14,15]. The pathophysiological interplay between worsening renal function

and volume overload creates a vicious cycle that likely explains the substantially elevated rehospitalization risk in this subgroup. These observations gain further support from the CLUSTER-HF trial, which documented a 45% reduction in clinical worsening events when lung ultrasound-guided management protocols were implemented [11].

In this study, NT-proBNP showed no significant difference between the rehospitalized and non-rehospitalized groups. Although NT-proBNP is an important marker for evaluating volume overload and left ventricular dysfunction, it was not associated with 90-day rehospitalization in our cohort. NT-proBNP data were unavailable for a proportion of patients: 24.64% in the non-rehospitalization group and 11.76% in the rehospitalization group. Missingness was attributed to damaged samples and patient refusal of blood sampling. Given the limited extent of missing data, we do not expect this to have materially affected the main findings; however, it may have reduced power for biomarker-based comparisons.

In some cases, clinical improvement was observed before patients were discharged from the hospital. However, when congestion was evaluated through bedside lung ultrasound, a significant number of persistent B-lines were found. Higher pre-discharge B-line counts were associated with higher rehospitalization risk, underscoring the importance of objective congestion assessment at discharge.

These findings highlight the importance of evaluating the number and characteristics of B-lines in pulmonary ultrasound examinations to assess prognosis and optimize therapy before discharge. Incorporating lung ultrasound into discharge assessment may support more targeted decongestion and follow-up planning, with the goal of reducing rehospitalization rates.

This study has several limitations that should be acknowledged. First, the retrospective, single-center design limits the ability to infer causality and may reduce the generalizability of the findings to other populations and clinical settings. The sample size was moderate, and the number of events limited statistical power for detailed subgroup analyses and for precise estimation of some effect sizes. Second, selection bias may have occurred because patients were included only if complete pre-discharge assessments and follow-up data were available; a substantial number of registry patients were excluded for incomplete data or loss to follow-up, which may have introduced bias if excluded patients differed systematically from those analyzed. Third, despite multivariable adjustment, residual confounding remains possible because not all potential confounders (for example, outpatient socioeconomic factors, adherence to medications, dose and timing of diuretics, or detailed comorbidity severity indices) could be fully captured or controlled. Fourth, measurement and classification biases are possible. B-line quantification can vary with operator experience, the ultrasound probe and machine settings, patient positioning, and timing of the examination relative to diuretic administration; we performed examinations with trained personnel and a standardized protocol, but we did not report formal interobserver or intraobserver reliability metrics in this study. Fifth, some variables had missing values (notably NT-proBNP), which may have attenuated observed associations or limited adjustment for biochemical severity of HF. Sixth, the adjudication of rehospitalization events relied on telephone interviews and chart review rather than blinded independent adjudication, introducing potential misclassification of outcomes and cause of readmission. Seventh, the relatively low use of contemporary guideline-directed medical therapies (e.g., ARNI and SGLT2 inhibitors) in this cohort may limit the applicability of findings to current practice environments where these agents are more widely used; medication patterns could also confound associations with rehospitalization. Eighth, the follow-up period was limited to 90 days; longer follow-up would clarify the durability of B-line predictive utility and its relationship to longer-term outcomes such as mortality. Finally, we did not perform external validation of the B-line cutoff identified here; therefore, the cutoff of ≥20 B-lines requires prospective validation in independent and ideally multicenter cohorts before routine clinical implementation.

To address these limitations, future studies should consider prospective, multicenter designs with larger sample sizes and standardized, blinded outcome adjudication; formal assessment of interobserver reproducibility for B-line quantification; comprehensive data capture of medication dosing and adherence; inclusion of more complete biomarker data; evaluation of the incremental value of B-lines over contemporary clinical prediction models; external validation of cutoffs; and randomized trials testing B-line-guided management strategies to determine whether LUS-guided interventions reduce rehospitalizations and improve patient-centered outcomes.

CONCLUSION

This study establishes pre-discharge B-line quantification as an independent predictor of 90-day rehospitalization in patients with heart failure, with ≥20 B-lines indicating a high-risk profile. The integration of B-line assessment with echocardiographic markers of diastolic dysfunction and renal parameters provides a multidimensional risk stratification framework. These findings support the routine use of lung ultrasound during discharge planning to optimize decongestion therapy and potentially reduce

readmissions. Future studies should explore whether B-line–guided treatment protocols improve long-term outcomes, particularly in patients with concurrent renal impairment, and should validate the identified cutoff in multicenter cohorts

Authors' contributions:

YP — conceptualization, methodology, investigation, writing—original draft preparation;
AFM — conceptualization, methodology, investigation, resources, validation, writing—original draft preparation, writing—review and editing, supervision;
PK — conceptualization, methodology, investigation, resources, validation, writing—original draft preparation, writing—review and editing, supervision;
AAM — validation, writing—review and editing, supervision.
All authors read and approved the final version of the manuscript.

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Conflict of interest:

The authors declare no conflicts of interest.

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REFERENCES

1. Groenewegen A, Rutten FH, Mosterd A, Hoes AW. Epidemiology of heart failure. *Eur J Heart Fail.* 2020 Aug;22(8):1342-1356. doi: 10.1002/ejhf.1858.
2. Feng J, Zhang Y, Zhang J. Epidemiology and Burden of Heart Failure in Asia. *JACC Asia.* 2024 Mar 19;4(4):249-264. doi: 10.1016/j.jacasi.2024.01.013.
3. O'Connor CM, Miller AB, Blair JE, Konstam MA, Wedge P, Bahit MC, et al; Efficacy of Vasopressin Antagonism in heart Failure Outcome Study with Tolvaptan (EVEREST) investigators. Causes of death and rehospitalization in patients hospitalized with worsening heart failure and reduced left ventricular ejection fraction: results from Efficacy of Vasopressin Antagonism in Heart Failure Outcome Study with Tolvaptan (EVEREST) program. *Am Heart J.* 2010 May;159(5):841-849.e1. doi: 10.1016/j.ahj.2010.02.023.
4. Kilgore M, Patel HK, Kielhorn A, Maya JF, Sharma P. Economic burden of hospitalizations of Medicare beneficiaries with heart failure. *Risk Manag Healthc Policy.* 2017 May 10;10:63-70. doi: 10.2147/RMHP.S130341.
5. Kwok CS, Abramov D, Parwani P, Ghosh RK, Kittleson M, Ahmad FZ, et al. Cost of inpatient heart failure care and 30-day readmissions in the United States. *Int J Cardiol.* 2021 Apr 15;329:115-122. doi: 10.1016/j.ijcard.2020.12.020.
6. Rattarasarn I, Yingchoncharoen T, Assavapokee T. Prediction of rehospitalization in patients with acute heart failure using point-of-care lung ultrasound. *BMC Cardiovasc Disord.* 2022 Jul 24;22(1):330. doi: 10.1186/s12872-022-02781-9.
7. Goffi A, Kruisselbrink R, Volpicelli G. The sound of air: point-of-care lung ultrasound in perioperative medicine. *Can J Anaesth.* 2018 Apr;65(4):399-416. English. doi: 10.1007/s12630-018-1062-x.
8. Waranugraha Y, Rohman MS, Anjarwani S. Hemodynamic Congestion at Hospital Discharge Predicts Rehospitalization during Short Term Follow Up in Acute Heart Failure Patients. *Indones J Cardiol*. 2019;40. doi: 10.30701/ijc.v40i3.805.
9. Coiro S, Rastogi T, Girerd N. How and When to Use Lung Ultrasound in Patients with Heart Failure? *Rev Cardiovasc Med.* 2022 May 30;23(6):198. doi: 10.31083/j.rcm2306198.
10. Bhoil R, Ahluwalia A, Chopra R, Surya M, Bhoil S. Signs and lines in lung ultrasound. *J Ultrason.* 2021 Aug 16;21(86):e225-e233. doi: 10.15557/JoU.2021.0036.
11. Gargani L, Pang PS, Frassi F, Miglioranza MH, Dini FL, Landi P, Picano E. Persistent pulmonary congestion before discharge predicts rehospitalization in heart failure: a lung ultrasound study. *Cardiovasc Ultrasound.* 2015 Sep 4;13:40. doi: 10.1186/s12947-015-0033-4.
12. Gargani L, Girerd N, Platz E, Pellicori P, Stankovic I, Palazzuoli A, et al; This document was reviewed by members of the 2020–2022 EACVI Scientific Documents Committee. Lung ultrasound in acute and chronic heart failure: a clinical consensus statement of the European Association of Cardiovascular Imaging (EACVI). *Eur Heart J Cardiovasc Imaging.* 2023 Nov 23;24(12):1569-1582. doi: 10.1093/ehjci/jead169.
13. Picano E, Scali MC, Ciampi Q, Lichtenstein D. Lung Ultrasound for the Cardiologist. *JACC Cardiovasc Imaging.* 2018 Nov;11(11):1692-1705. doi: 10.1016/j.jcmg.2018.06.023.
14. Al-Ahmad A, Rand WM, Manjunath G, Konstam MA, Salem DN, Levey AS, Sarnak MJ. Reduced kidney function and anemia as risk factors for mortality in patients with left ventricular dysfunction. *J Am Coll Cardiol.* 2001 Oct;38(4):955-62. doi: 10.1016/s0735-1097(01)01470-x.
15. Komukai K, Ogawa T, Yagi H, Date T, Sakamoto H, Kanzaki Y, et al. Decreased renal function as an independent predictor of re-hospitalization for congestive heart failure. *Circ J.* 2008 Jul;72(7):1152-7. doi: 10.1253/circj.72.1152.