Identification of echocardiographic subgroups in patients with coronary heart disease combined with heart failure based on latent variable stratification

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A R T I C L E   I N F O

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A B S T R A C T

Background: The prognosis of chronic heart failure is poor, and it remains a challenge to classify patients for better personalized intervention. This study aimed to explore potential subgroups in patients with coronary heart disease and chronic heart failure using comprehensive echocardiographic indices.

Methods: 5126 patients with coronary heart disease with chronic heart failure were included. Latent class analysis was applied to identify the grouping patterns of patients based on echocardiographic indices. Network maps and radar charts of echocardiographic indices were drawn to visualize the distribution of echocardiographic findings. The incidence of adverse outcomes was presented on the Kaplan-Meier curve and compared using the log-rank test. The Cox regression model was used to analyze the relationship between subgroups and mortality.

Results: Three groups were identified: eccentric hypertrophy, concentric hypertrophy, and decreased diastolic function. Network plots showed a higher correlation between left atrial diameter, left ventricular mass index, and left ventricle ejection fraction in the eccentric hypertrophy group than in the other groups. The Kaplan-Meier curve showed a significant difference in mortality between the three subgroups (P < 0.001). Multivariate Cox analysis indicated that the eccentric hypertrophy group had the highest risk of death (HR = 1.586, 95% CI: 1.310–1.921, P < 0.001) compared with the other groups.

Conclusion: Patients with coronary heart disease and chronic heart failure can be classified into three subgroups based on echocardiographic indices. This grouping has been shown to be an independent risk factor for mortality in these patients. Accurate subgrouping based on echocardiographic indices is important for identifying high-risk patients.

1. Introduction

Chronic heart failure (CHF) is the terminal stage of several cardiac diseases. The incidence of heart failure (HF) continues to rise due to aging population, and it is estimated that >60 million people worldwide suffer from HF. Despite significant improvements in current HF treatments, clinical outcomes remain poor [1,2]. Studies have shown that the 1-year mortality and rehospitalization rates for CHF are as high as 7.2% and 31.9%, respectively [3]. Proper assessment of the prognosis and risk classification of patients with CHF is urgently needed for effective clinical management and treatment [4].

The current common clinical classification for CHF is the New York Heart Classification (NYHA). However, it is highly subjective because it is based on a patient’s perceived clinical symptoms. Another classification of CHF is based on left ventricular ejection fraction (LV EF), which is of clinical importance, and physicians make different treatment recommendations based on it [2]. The LV EF is mostly obtained from echocardiography, which is a noninvasive, accessible, non-radioactive, objective, and real-time dynamic technique. It is considered the gold standard tool for evaluating cardiac structure and function in addition to

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being an ideal tool for the diagnosis and prognostic assessment of CHF [5]. LVEF is an important predictor of prognosis in patients with CHF [6,7]. In recent years, researchers have noted that the size of the left atrium (LA), right atrium (RA), and right ventricle (RV) are also associated with the prognosis of patients with CHF [8–10]. Nonetheless, most studies only focused on a subset of echocardiographic indices and it was difficult to evaluate the overall indices. Therefore, we aimed to comprehensively evaluate patients with CHF based on the size of each heart chamber and cardiac function among the echocardiographic indices. Coronary heart disease (CHD) is the most common cause of CHF [11]. Studies have shown that the concomitant presence of CHF and CHD can increase the risk of death, and CHD is an important therapeutic target to improve the morbidity and mortality associated with CHF [12]. We may need to use echocardiographic parameters to stratify this high-burden comorbidity. Therefore, patients with CHD and CHF were selected as research participants in this study.

Latent class analysis (LCA) can be used to explore the characteristics of categorical latent variables behind observed categorical variables that are statistically correlated. Furthermore, the method deals with several indices simultaneously and provides a way to combine the information from all the indices to make a diagnosis [13]. LCA has been widely used in medicine, sociology, and psychology to divide a whole into different categories [14,15]. In this study, we incorporated overall echocardiographic indices into the LCA to identify subgroups of individuals with similar echocardiographic appearances, analyzed the network relationships between echocardiographic indices in different subgroups, and assessed the impact of this classification on all-cause mortality. Patients with CHF were classified scientifically and accurately to guide individualized interventions.

2. Methods

2.1. Study population

This was a multicenter, prospective cohort study. Patients diagnosed with CHD and CHF between April 2014 and March 2019 in three hospitals in Shaxi Province, China were selected. The study protocol was approved by the ethics committee of Shaxi Medical University, and informed consent was obtained from all the patients prior to enrollment.

The inclusion criteria were as follows: 1) age ≥ 18 years; 2) met the 2013 American College of Cardiology guidelines for the diagnosis of HF [16]; 3) NYHA class II-IV, 4) CHD diagnosis. At least 50% stenosis of the main coronary vessels or at least one of the main vessels positive for coronary artery disease [17], and 5) within the past month received HF treatment. The exclusion criteria were as follows: 1) acute cardiovascular event within the past 2 months; 2) comorbid psychiatric disorders; and 3) refusal to participate in the study.

2.2. Data-collection and follow-up

Case information during hospitalization and echocardiographic information at discharge were collected. The survival information of the patients was collected via a telephone follow-up every 3 months, and death was defined as the outcome event.

2.2.1. Clinical data

We used the Chronic Heart Failure Case Report Form which was developed by our research group to collect information from patients' electronic medical records. Data collected include patient's age, gender, body mass index (BMI), blood pressure, heart rate, NYHA class, history of smoking, and history of alcohol consumption. Additionally, we collected data on existing complications. Laboratory findings and echocardiographic indices were also recorded along with the patient's medication and surgical treatment.

2.2.2. Echocardiographic indices

The following echocardiographic indices were used in the LCA: right atrial diameter (RAD), left atrial diameter (LAD), right atrial diameter (RAD), right ventricular inner diameter (RVD), left ventricular mass index (LVMI), relative wall thickness (RWT), left ventricular ejection fraction (LVEF), the ratio of early to late peak velocities (E/A), left ventricular end-diastolic dimension (LVDd), left ventricular posterior wall thickness (LVPWT), and interventricular septal thickness (IVST).

The corresponding values of each echocardiography index were assigned according to the updated cardiac chamber quantification guidelines of the American Society of Echocardiography and the European Association of Cardiovascular Imaging (Table S1) [18]. Left ventricular (LV) mass was quantified using the linear method and the LVMI was calculated as \( 0.8 \times 1.04 \times \left[ \text{LVEDV} + \text{LVPWT} + \text{IVST} \right]^{3} - \text{LVDd}^{3} + 0.61 / \text{body surface area} \). This was calculated as 0.0061 × height (cm) + 0.0128 × weight (kg) - 0.1529 using Hsu Wen-Sheng's formula.

We used the Chronic Heart Failure Case Report Form which was We used the Chronic Heart Failure Case Report Form which was

The early (E) and late (A) diastolic mitral inflow velocities were measured, and the ratio of early to late peak velocities (E/A) was obtained. E/A values <1 or >2 indicate diastolic dysfunction [21]. LV hypertrophy (LHV) was defined as an LVMI >5 g/m\(^2\) in women and >115 g/m\(^2\) in men. The LV geometric configuration can be divided into four categories based on LVMI and RWT. Normal geometry was defined as RWT <0.42 and no LVH; concentric remodeling as RWT >0.42 and no LVH; concentric hypertrophy as RWT >0.42 and LVH; and eccentric hypertrophy as RWT >0.42 and LVH [8].

All echocardiography tests were conducted with Toshiba ssh-880cv Doppler ultrasonography and performed and calibrated by an experienced sonographer.

2.2.3. Follow-up and outcome

All patients were followed up routinely at 3-month intervals from discharge with a cohort follow-up cut-off date of February 2022. The outcome of this study was all-cause mortality, including cardiovascular deaths such as fatal myocardial infarction, HF deaths, and unanticipated sudden deaths, and non-cardiovascular deaths.

2.3. Statistical analysis

Quantitative data are expressed as mean ± standard deviation (SD) when normally distributed and compared using one-way ANOVA; when not normally distributed, they are presented as median (interquartile range) and compared using the Kruskal–Wallis H test. Qualitative data are presented as numbers (percentages), and the chi-square test was used for comparisons between groups.

Patients were assigned to non-overlapping subgroups in a data-driven manner using LCA [22]. The main information criteria for evaluating the LCA model are the Akaike information criterion (AIC), Bayesian information criterion (BIC), and sample size-adjusted Bayesian information criterion (aBIC) [23]; the smaller their values, the better the model fits. BIC was dominant when the sample size was >1000. Additionally, the classification accuracy index was entropy, which ranges from zero to one. The closer the value was to 1, the more accurate the classification [24]. The significance test index includes the Lo–Mendell–Rubin test (LMRT) and bootstrapped likelihood ratio test (BLRT). The choice of multiple models, according to Preacher and Merkle, is heavily dependent on the sampling results, and the model with the next best data results is often chosen in studies [25]. After grouping, the network and radar charts of echocardiographic indices were plotted for each subgroup to visually depict the echocardiographic distribution within the groups.

Baseline characteristics of the three groups were compared using the
The incidence of adverse outcomes among the different groups was presented on the Kaplan–Meier curve and compared using the log-rank test. Hazard ratios and 95% confidence intervals (CIs) were calculated for each group using the Cox proportional hazard regression model. Univariate Cox regression analysis was performed for the initial screening of variables, and thereafter, significant variables were included in the multivariate Cox regression analysis, and those significantly associated with outcomes were screened using the forward stepwise method. The test level $\alpha$ was set at 0.05, and the differences were considered significant at $P < 0.05$.

All statistical analyses and comparisons between groups were

| Group | K | AIC | BIC | aBIC | Entropy | LMRT | BLRT | Probability |
|-------|---|-----|-----|------|---------|------|------|-------------|
| 1     | 8 | 44,613.568 | 44,665.904 | 44,640.483 | 0.619 | <0.001 | <0.001 | 0.63/0.37 |
| 2     | 17 | 43,040.886 | 43,152.102 | 43,098.082 | 0.643 | <0.001 | <0.001 | 0.34/0.20/0.46 |
| 3     | 26 | 42,487.326 | 42,657.420 | 42,574.801 | 0.647 | <0.001 | <0.001 | 0.19/0.25/0.31 |
| 4     | 35 | 42,196.696 | 42,425.669 | 42,314.451 | 0.614 | <0.001 | <0.001 | 0.25/0.15/0.09/0.21/0.30 |
| 5     | 44 | 42,119.994 | 42,407.846 | 42,268.029 | 0.638 | 0.0003 | <0.001 | 0.15/0.20/0.04/0.26/0.17/0.18 |
| 6     | 53 | 42,083.633 | 42,430.536 | 42,261.947 | 0.635 | 0.4387 | <0.001 | 0.25/0.06/0.05/0.14/0.19/0.20/0.11 |

AIC, Akaike information criterion; BIC, Bayesian information criterion; aBIC, sample size-adjusted Bayesian information criterion; LMRT, Lo-Mendell-Rubin test; BLRT, Bootstrapped likelihood ratio test.

Fig. 1. A. Differences between the normalized values of each continuous variable in the three latent classes. The continuous variables of the three subgroups are normalized, where all the mean values are scaled to 0 and the standard deviation is scaled to 1, and the value of the standardized variable $+1$ means that the mean of the given group is one standard deviation higher than the mean in the model. RAD, right atrium diameter; LAD, left atrium diameter; RVD, right ventricular inner diameter; LVMI, left ventricular mass index; RWT, relative wall thickness; LVEF, left ventricle ejection fraction.

B. Differences in categorical variables (E/A) in the 3-class model. E/A, the ratio of early to late peak velocities.

Student–Newman–Keuls test, Kruskal–Wallis H test, and chi-square test. The incidence of adverse outcomes among the different groups was presented on the Kaplan–Meier curve and compared using the log-rank test. Hazard ratios and 95% confidence intervals (CIs) were calculated for each group using the Cox proportional hazard regression model. Univariate Cox regression analysis was performed for the initial screening of variables, and thereafter, significant variables were included in the multivariate Cox regression analysis, and those significantly associated with outcomes were screened using the forward stepwise method. The test level $\alpha$ was set at 0.05, and the differences were considered significant at $P < 0.05$.

All statistical analyses and comparisons between groups were
performed using SPSS19.0 software. Missing data were filled using the missForest package in the R software, version 4.1.1. Decision trees were constructed to predict the clusters by using the rpart R program. LCA models were constructed using Mplus version 8.0. Network plots were constructed using Cytoscape version 3.9.0.

3. Results

3.1. Baseline characteristics

The study cohort consisted of 5126 patients (95.0%) with CHF because 270 patients failed to meet the follow-up study. The baseline patient characteristics are shown in Table S2. Overall, 628 patients (12.2%) died during the follow-up period. Patients who died were older, had a lower BMI, had a faster heart rate, and were more likely to have a combination of atrial fibrillation (AF), valvular disease, chronic obstructive pulmonary disease (COPD), diabetes, and chronic renal failure (CRF).

3.2. Latent class analysis

A total of 5126 patients were included in the LCA model. The fitting statistics of the LCA models from categories 1 to 7 are shown in Table 1. The results showed that the AIC and BIC were smaller, and the entropy was closest to 1 for the four classifications; however, the clinical interpretability was poorer than that of the three classifications. Therefore, so on balance the three classification models were chosen. Table S3 shows that the echocardiographic indices used in the LCA were highly differentiated between the subgroups.

Group 1 (1718 cases) accounted for 33.5% of total patients. The results showed that LVMI was the largest, RWT was the smallest, and both systolic and diastolic functions were decreased. Therefore, this group was named “eccentric hypertrophy group”. Group 2 (1036 cases) accounted for 20.2% of total patients. RWT was the largest, and systolic and diastolic function were mostly normal. This group was, therefore, named “concentric hypertrophy group”. Group 3 (2372 cases) accounted for 46.3% of total cases. Only patients with E/A values <1 or >2 accounted for a higher proportion. Hence, this group was named the “diastolic decline group”.

The result of network plots was shown in Fig. 3. There was a strong correlation between the LAD, LVMI, and LVEF in the eccentric hypertrophy group. The concentric hypertrophy group had a possible simultaneous increase in LAD, RAD, and RVD, and the correlation intensity of E/A, LAD, and RVD in the decreased diastolic function group was higher than in the other groups.

3.3. Clinical characteristics per group

The clinical data of the three groups were compared. The results showed that patients in the eccentric hypertrophy group were more likely to be male and had the fastest heart rate, lowest BMI, higher NT-proBNP levels, higher NYHA class, and combined with old myocardial infarction (OMI), diabetes, COPD, CRF. Patients in the concentric hypertrophy group were more likely to be female, older, and more likely to have associated AF, valvular disease, and hypertension. Blood lipid levels were slightly higher in the decreased diastolic function group, and more patients had undergone percutaneous coronary intervention (PCI) or coronary artery bypass grafting (CABG) (Table 2).

3.4. Decision tree to identify echocardiographic groups in CHF: “EFVMD” algorithm

The decision tree identified LVMI, LVEF, RWT and E/A as the most relevant variables to correctly classify patients. The global accuracy of
the decision tree was good (79.7%) (Fig. 4). Adding clinical variables to the candidate variables for decision tree construction did not modify the decision algorithm. In the following sections, we refer to the constructed decision tree as the “EFVMD” algorithm.

3.5. Prognostic analysis

Fig. 5 shows the K-M survival curves for the three groups. Furthermore, as shown in Table S4, the log-rank test results showed differences in outcomes among groups, with sequential increases in mortality in the decreased diastolic function group (8.3%), concentric hypertrophy group (12.7%), and eccentric hypertrophy group (17.4%).

The results of the multivariate Cox proportional hazards model showed that patients with different cardiac structures had significantly different risks of mortality. The risk of death was higher in the eccentric hypertrophy group (HR = 1.586, 95% CI: 1.310–1.921, P < 0.001) than in the decreased diastolic function group, followed by the concentric hypertrophy group (HR = 1.256, 95% CI: 1.005–1.569, P = 0.045). Additionally, advanced age (HR = 1.044, 95% CI: 1.036–1.053, P < 0.001), high NYHA class (HR = 1.737, 95% CI: 1.557–1.939, P < 0.001), combined diabetes (HR = 1.299, 95% CI: 1.100–1.534, P = 0.002), and CRF (HR = 1.483, 95% CI: 1.224–1.796, P < 0.001) were independent risk factors for death in patients with CHD combined with CHF. Patients with a higher BMI (HR = 0.929–0.971, P < 0.001) and those who had undergone PCI or CABG (HR = 0.712, 95% CI: 0.576–0.879, P = 0.002) had a lower risk of death. The result was shown in Table 3.

4. Discussion

Echocardiography is an important imaging modality for patients with CHF. To our knowledge, this is one of only a few studies that focuses on patient grouping based on comprehensive echocardiographic indices. Patients with CHD combined with CHF were classified into three groups using LCA: eccentric hypertrophy, concentric hypertrophy, and decreased diastolic function. Our findings demonstrate that the easy-to-use EFVMD echocardiography algorithm presented here can identify individuals with CHF who are at high risk of death. The results of the study showed that the grouping of patients with CHF according to cardiac ultrasound findings was an independent risk factor for all-cause mortality. Patients in the eccentric hypertrophy group had the highest risk of death, followed by those in the concentric hypertrophy group, with a better prognosis in the decreased diastolic function group.

4.1. Comparison with CHF subgroups identified in previous studies

Owing to the inability of the current CHF classification model to adequately capture the heterogeneity of the disease, some scholars have conducted CHF subgroup studies in recent years to guide individualized clinical treatment and intervention. Ahmad et al. [26] performed a cluster analysis of 45 clinical variables measured at baseline and identified four clusters, which identified cluster 1 with similar characteristics to the patients in our eccentric hypertrophy group and the highest mortality rate. However, the study used too many variables, making clinical application difficult. Moreover, clustering algorithms determine the appropriate number of clusters that are inherently subjective and hypothesis-free, whereas LCA is based on a model that identifies an objective number of clusters that best fits the population and is statistically more robust than clustering algorithms [27]. Furthermore, the study was only applicable to patients with CHF with LVEF ≤35%.
Further limiting its application. Cohen et al. [28] performed latent class analysis using eight clinically available variables to identify different subgroups of heart failure with preserved ejection fraction (HFpEF), confirming the feasibility of LCA in classifying patients with HF. One of the identified subgroups had a higher proportion of patients with diabetes, chronic kidney disease, COPD, and NYHA class III-IV, and the worst clinical outcomes, consistent with the characteristics of the eccentric hypertrophy group we identified. Multiple previous studies and the present study showed that patients with HF combined with diabetes, CRF, and COPD have a poorer prognosis; therefore, more attention should be paid to patients with these characteristics in clinical practice. None of these HF classifications evaluated patients with CHF based on overall echocardiographic indices. The 2021 ESC Guidelines for the diagnosis and treatment of acute and chronic heart failure classify patients with HF according to LVEF [29]; however, the use of LVEF alone to assess cardiac function in patients with CHF is unilateral [30]. Nauta et al. [31] used LVM and RWT to classify LV geometry in patients with heart failure with reduced ejection fraction (HFREF). The eccentric hypertrophy and centripetal hypertrophy groups were defined. However, the cardiac ultrasound indices used in this study were incomplete and did not reflect the overall anatomy and physiology of the heart. In this study, the LCA method was used to classify patients with CHF more accurately and
objectively using echocardiographic indices of each chamber structure in addition to systolic and diastolic function. Kobayashi et al. [32] performed cluster analysis based on eight cardiac ultrasound indices, which also used LCA, and obtained echocardiographic phenotypes of three asymptomatic individuals with HF. The echocardiographic phenotypes identified in their study clearly resembled the phenotypic pattern of early cardiac changes in diabetic patients [33] and were similar to those in our study. Despite the differing study population, these findings would appear to reinforce our results.

4.2. Echocardiographic indices and prognosis

In this study, the network of echocardiographic indices showed a strong correlation between LVEF, LVMI, and LAD in the eccentric hypertrophy group, suggesting that the simultaneous presence of reduced LVEF, increased LVMI, and increased LAD may increase the risk of

Table 3

| β   | SE  | Wald | P    | HR  | 95% CI  |
|-----|-----|------|------|-----|---------|
| Age | 0.043 | 0.004 | <0.001 | 1.044 | 1.036–1.053 |
| BMI | −0.052 | 0.011 | <0.001 | 0.949 | 0.929–0.971 |
| NYHA | 0.552 | 0.056 | <0.001 | 1.737 | 1.557–1.939 |
| PCI/CABG | −0.340 | 0.108 | 0.002 | 0.712 | 0.576–0.879 |
| Diabetes | 0.262 | 0.085 | 9.534 | 0.002 | 1.299 | 1.100–1.534 |
| CRF | 0.394 | 0.098 | <0.001 | 1.483 | 1.224–1.796 |
| Group | 17.683 | <0.001 | |
| Group 1/Group 3 | 0.461 | 0.098 | 22.357 | <0.001 | 1.586 | 1.310–1.921 |
| Group 2/Group 3 | 0.228 | 0.114 | 4.015 | 0.045 | 1.256 | 1.005–1.569 |

HR, hazard ratio; CI, confidence interval; BMI, body mass index; NYHA, New York Heart Association; PCI, percutaneous coronary intervention; CABG, coronary artery bypass grafting; CRF, chronic renal failure.

Fig. 4. EFVMD algorithm for echocardiographic groups using the decision tree. LVMI, left ventricular mass index; RWT, relative wall thickness; LVEF, left ventricle ejection fraction; E/A, the ratio of early to late peak velocities.

Fig. 5. Kaplan–Meier curve and log-rank test. Figure shows the differences in outcomes among groups. The image on the right is a partial enlargement of the image on the left. The unit of time on the horizontal axis is month.
adverse events. The changes in LVEF were negatively associated with the risk of adverse events. Dunlay et al. showed that decreased EF was associated with increased mortality in patients with HF, and that this correlation existed in patients with HFrEF and HFrEF [34]. Previous studies showed that a higher LVMI was associated with a risk of cardiovascular mortality [35,36]. In our study, LVMI increased sequentially in the eccentric hypertrophy, concentric hypertrophy, and decreased diastolic function groups, and the risk of mortality increased sequentially, which is in line with the findings of previous studies. LAD responds to left atrial size and studies have found a strong relationship between LA enlargement and mortality in patients with CHF [37]. A Canadian study also confirmed that increased LAD was associated with an increased risk of all-cause mortality and hospitalization in CHF [38]. Increased pulmonary venous and small arterial pressures following left atrial failure further increase the right heart afterload, leading to a reduction in right heart function. Previous studies have shown that RVD is an important prognostic index for CHF [39]. The significantly worse prognosis in the eccentric hypertrophy and centripetal hypertrophy groups in this study had a higher LAD, RVD, and RAD, indicating that patients in both groups had progressed to advanced disease and developed cardiac enlargement.

However, our study on the effect of RWT on prognosis contradicts the results of previous studies. Yamaguchi et al. [40] found that RWT was a risk factor for patients with acute decompensated HF and that survival was lower in the high RWT group than in the low RWT group, which was confirmed in another Japanese study [41]. In our study, the RWT was lower in the eccentric hypertrophy group, but the mortality was highest in the group. A possible reason for this is that the study was conducted in patients with CHF, whereas the aforementioned articles were had patients with acute decompensated HF. Additionally, LV diastolic function plays an important role in determining LV filling volume and output per beat, and previous studies have shown that diastolic dysfunction is associated with poor prognosis [42,43]. However, the prognosis of our decreased diastolic function group was better than that of the other groups, probably because of the group's lower LVMI and RWT and the normal configuration of the left ventricle.

4.3. Other clinical parameters and prognosis

Age is a recognized prognostic factor for CHF, and increasing age is usually accompanied by deterioration in cardiac structure and function [44]. It has been shown that older patients with CHF have significantly higher mortality rates than younger patients [45], which is consistent with our study. This present study showed a lower risk of death in patients with a higher BMI, possibly due to a better short-to medium-term prognosis in chronically obese patients through the interaction of adipocytes and cardiomyocytes, which initiates an antioxidant response in the myocardium [46]. However, the long-term prognosis needs to be further validated during follow-up. CHF, CRF, and diabetes often coexist, and the presence of each disease worsens the prognosis [42,43]. However, the prognosis of our decreased diastolic function group was better than that of the other groups, probably because of the group's lower LVMI and RWT and the normal configuration of the left ventricle.

4.4. Limitations of study

This study also had the following limitations: 1) our findings are based on Chinese adults and cannot be extrapolated to other races 2) The study did not include echocardiographic indices of patients during follow-up and only measured class-defining variables at baseline; however, these variables changed over time. In future studies, we could consider the trajectory of variables as an index for defining classes and explore the relationship between such classes and the risk of death in CHF. 3) Lack of external validation is the main limitation of this study. In the future, if appropriate prospective multicenter cohort data are available, we will further improve the study to improve the generalization of the EFVMD algorithm.

5. Conclusions

In summary, we applied LCA to identify three groups of patients with CHF based on echocardiography, which can be easily identified in clinical practice using a simple algorithm (EFVMD algorithm). The study showed that this grouping is an independent risk factor for death in patients with CHF, which has important implications for identifying patients at a high risk of CHF. Researchers and clinicians can design clinical trials and healthcare programs for different subgroups of patients.

Declaration of Competing Interest

None declared.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ijcard.2022.11.038.

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