Racial and ethnic disparities in longitudinal trajectories of hospitalizations in patients diagnosed with heart failure

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ABSTRACT

Background Racial and ethnic disparities in hospitalizations among heart failure (HF) patients have been well documented. However, little is known about racial and ethnic differences in the long-term trajectories of hospital admissions that follow the diagnosis of HF.

Methods We used electronic health records (EHR) of 5,606 patients with newly-diagnosed HF between January 1, 2015 and July 28, 2018 in the Duke University Health System. Patients were followed for up to 5 years (until July 28, 2023) to identify all-cause hospital admissions after their initial diagnosis of HF. Group-based trajectory models were used to identify major trajectories of hospitalization, and multinomial logistic regression models were used to identify patients' clinical and nonclinical characteristics associated with the trajectories of admissions.

Results In our study cohort (mean age 74.8 ± 5.8 years), we identified 4 distinct trajectories of hospitalization during follow up: 45.6% (Group 1: $N = 2,556$) had "low risks" of hospitalization, 36.6% (Group 2: $N = 2,052$) had elevated risks of admission shortly after diagnosis ("early risk" group), 9.9% (Group 3: $N = 553$) had elevated risks at later stages of illness ("late risk" group), and 7.9% (Group 4: $N = 445$) had consistently "high risks" of hospitalization. Non-Hispanic Black patients were more likely to exhibit early risks of hospitalization (odds ratio [OR], 1.33; 95% confidence interval [CI], 1.16-1.52; $P < .001$), late risks of hospitalization (OR = 1.92; 95% CI, 1.58-2.34; $P < .001$), or consistently high risks of hospitalization (OR = 1.89; 95% CI, 1.52-2.35; $P < .001$) compared with non-Hispanic White patients. Diabetes, chronic kidney disease, and residence in a disadvantaged neighborhood significantly contributed to the excess risks of admissions among non-Hispanic Black patients. We found no significant differences in patterns of admissions between patients from other racial and ethnic groups compared with non-Hispanic White patients.

Conclusions Non-Hispanic Black patients had early, late, and consistently high risks of hospitalization following the diagnosis of HF compared with non-Hispanic White patients. These findings have important implications for targeting interventions to reduce hospitalizations during the course of HF management. (Am Heart J 2025;287:32–40.)

Heart failure (HF) remains the leading cause of hospitalization among older adults and studies have shown that racial and ethnic minority groups with HF are readmitted more often than non-Hispanic White patients.[1-4] To date, most of the evidence documenting racial and ethnic disparities in hospitalizations has been based on Medicare claims and hospital discharge records among patients with an initial (index) hospitalization of HF.[1,4-6] Moreover, these studies have focused almost exclusively on short-term outcomes (ie, 30-day readmission) and have largely overlooked the longer-term risks of hospitalizations that occur following a diagnosis of HF. Consequently, identifying when patients are at risk of hospitalization has remained a challenge and racial and ethnic disparities in readmissions have persisted.[1,7,8]

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Recent studies of HF patients have now begun to demonstrate that the risks of hospitalization vary over the course of the illness and disease progression.[5,9,10] For example, studies have shown that hospital admissions occurred most frequently shortly after a diagnosis of HF;[9-11] and that the longitudinal patterning of admissions following a diagnosis of HF was not uniform across racial and ethnic groups.[1,5,12] However, studies have not fully characterized the longitudinal risks of admission that HF patients may face and whether there are racial and ethnic differences in the trajectories of hospital admissions that develop over time. Therefore, a more comprehensive understanding of the timing and frequency of hospitalizations that occur over the course of the disease will provide critical knowledge for planning the immediate and long-term delivery of care in patients diagnosed with HF.

This study used longitudinal electronic health record (EHR) data from a large healthcare system to investigate racial and ethnic disparities in trajectories of hospital admissions following the diagnosis of HF. Our overall objectives were threefold: first, to characterize the major patterns of hospitalizations that occurred over time after the initial diagnosis of HF; second, to examine whether and to what extent patients from racial and ethnic minority groups were more likely to follow trajectories with elevated risks of hospitalization during the course of their illness; and third, to identify the potential clinical and nonclinical factors contributing to racial and ethnic disparities in the risks of hospitalizations over time.

Methods

Study participants

Patients with an initial diagnosis of HF in the Duke University Health System were included in the study. Patients with HF were identified based on International Classification of Diseases, Ninth Revision Clinical Modification (ICD-9-CM) and Tenth Revision (ICD-10-CM) diagnosis codes (*ICD-9-CM*: 428*, 402.01, 402.11, 402.91, 404.01, 404.03, 404.11, 404.13, 404.91, 404.93; *ICD-10-CM*: I50*, I11.0, I13.0, I13.2)[13-15] assigned during either an outpatient visit or a hospitalization. Specifically, systolic HF was defined using the codes: 428.20, 428.1, 428.21, 428.22, 428.23, I50.20, I50.21, I50.22, and I50.23. Diastolic HF was defined using the codes: 428.30, 428.31, 428.32, 428.33, 428.40, 428.41, 428.42, 428.43, I50.30, I50.31, I50.32, I50.33, I50.40, I50.41, I50.42, I50.43. Unspecified HF was defined using the codes: I50.1, I50.9, 428.0, and 428.9. HF with hypertension/chronic kidney disease was defined using the codes: 402.01, 402.11, 402.91, 404.01, 404.03, 404.11, 404.13, 404.91, 404.93, I11.0, I13.0, and I13.2. To ensure that we only included newly-diagnosed patients, all patients were required to have at least 1 hospital/clinic encounter in the prior year and have no prior indication of HF in their EHR. Incident HF diagnoses that occurred between January 1, 2015 and July 28, 2018 were included to allow all patients to be followed for up to 5 years (until July 28, 2023). Eligible patients were also limited to those residing within the 6 contiguous counties served by the Duke Health system (Chatham, Durham, Granville, Orange, Person, and Wake counties) to maximize the likelihood that patients' admissions were captured in the health system. In addition, we only included patients who were age 65+ at the time of their HF diagnosis to facilitate comparisons with the majority of research on HF patients.[16,17] Patients over the age of 90 were not included in the analyses to limit the potential impact of survival bias on the results.

Of the 6,437 patients with an incident diagnosis of HF, we excluded patients who had missing date of death ($n = 1$), were discharged to hospice care after their initial HF diagnosis in an inpatient setting ($n = 98$), or died within 90 days after their diagnosis ($n = 489$)—ie, did not survive the first interval of observation as described below. Patients were also excluded if they had an index diagnosis of rheumatic HF ($n = 3$) or had missing information on their body mass index (BMI), marital status, smoking status, or area deprivation index (ADI) ($n = 240$). The final analytic cohort included 5,606 newly-diagnosed HF patients with a mean follow-up of 4.03 years (Supplementary Figure 1). All EHR data were extracted using Duke Enterprise Data Unified Content Explorer (DEDUCE)[18] and Epic's enterprise data warehouse (Caboodle).[19] The study was approved by the Institutional Review Board at Duke University (PRO00110816) and did not require informed consent.

Measures

Primary outcome

All hospital admissions that occurred following an initial diagnosis of HF were identified based on admission and discharge dates ascertained from the patients' EHR.[20] We included all admissions that occurred within 60 months (5 years) of the patients' HF diagnosis and the time intervals for the counts of hospital admissions were assessed in preliminary analyses. We found that 3-month intervals provided an optimal balance of data points and variability in the number of observed hospitalizations over the study period. These intervals are also informative for routine clinical care and for timing possible interventions.[11,21-23] Our previous research has shown that rates of (re)admission in the current data were comparable to rates reported by other hospitals in North Carolina and in national reports.[24-26]

Race and ethnicity

Patients' race and ethnicity were ascertained from the EHR and categorized as non-Hispanic Black patients ($n = 1,557$), non-Hispanic White patients ($n = 3,755$), or other racial and ethnic group ($n = 294$). The limited number of patients in the other racial and ethnic group

who identified as Hispanic patients ($n = 76$), Asian patients ($n = 72$), or another demographic group ($n = 146$) prohibited further categorizations for analysis.

Covariates

Patients' nonclinical characteristics were available in the EHR and included age (years), sex (male or female), marital status (married or not), smoking history (never, former, or current), and health insurance (Medicare fee-for-service [FFS], Medicare Advantage, or other). Eighty patients with unknown health insurance were included in the other category. We used 9-digit zip codes from the patients' residential address in the EHR to link information on ADI, a Census-based composite measure of neighborhood socioeconomic conditions.[27-29] Clinical characteristics included setting of HF diagnosis (outpatient or inpatient), BMI (kg/m^2), and diagnoses of major cardiovascular and comorbid conditions including hypertension, diabetes mellitus, hyperlipidemia, anemia, atrial fibrillation (or flutter), coronary heart disease, stroke (or transient ischemic attack), chronic kidney disease (CKD), chronic obstructive pulmonary disease (COPD), malignancy (excluding malignant neoplasms of skin), and depression. Baseline diagnoses were identified in the 1-year period preceding the index diagnosis of HF and extracted using ICD 9/10 codes.[30] All-cause mortality was identified in the EHR and adjudicated using the Death Master Files from National Technical Information Services and the North Carolina Death Index from the Social Security Administration.[18] Mortality was included as a modeled component of nonrandom attrition when classifying trajectories of hospitalization over time (described below).[31,32]

Statistical analyses

We calculated the distributions of the patients' clinical and nonclinical characteristics by race and ethnicity using chi-square and Kruskal-Wallis tests for categorical and continuous variables, respectively. We then used group-based trajectory models (GBTM) to characterize the major patterns of hospitalizations that occurred over time following the diagnosis of HF. This is a data-driven method that makes no assumption about the distribution of trajectories in a population and instead uses statistical criteria to approximate the distribution of multiple trajectories in the population.[31,33] In recognizing that HF patients are heterogenous in their risks of hospitalizations over time, this method allowed us to identify groups of patients who exhibited probabilistically similar patterns of hospitalization over time. The GBTM models were estimated using the *traj* package in Stata 18.0 (StataCorp LP, College Station, TX).[34]

Based on the distributions of admissions and preliminary assessments of alternative specifications of GBTM (ie, logit and censored normal models), we used a zero-inflated Poisson model to estimate hospitalizations over time. We assessed GBTM models with up to 8 trajectory groups and up to fourth-order polynomials to characterize the trajectory curves. The optimal number of trajectory groups and polynomial functions were identified based on the lowest value of the Bayesian information criteria (BIC), highest average posterior probabilities (AvePP) of group membership, and smallest 95% confidence intervals (CI).[35] The GBTM models also incorporated mortality ("dropout" function in *traj*) to directly account for differential attrition in each of the trajectory groups.[31,32] Thus, the trajectories are estimated among those who continue to remain alive in the group (*ie*, the survivors' data; see Supplementary Figure 2 and Supplementary Figure 3).[36,37] The parameter estimates for the final model are in Supplementary Table 2 and plots of the estimated trajectories, observed means, and 95% CIs are in Supplementary Figure 4. To facilitate interpretation of the results, we assigned descriptive labels to each of the trajectory groups (*eg*, "early risk" group).

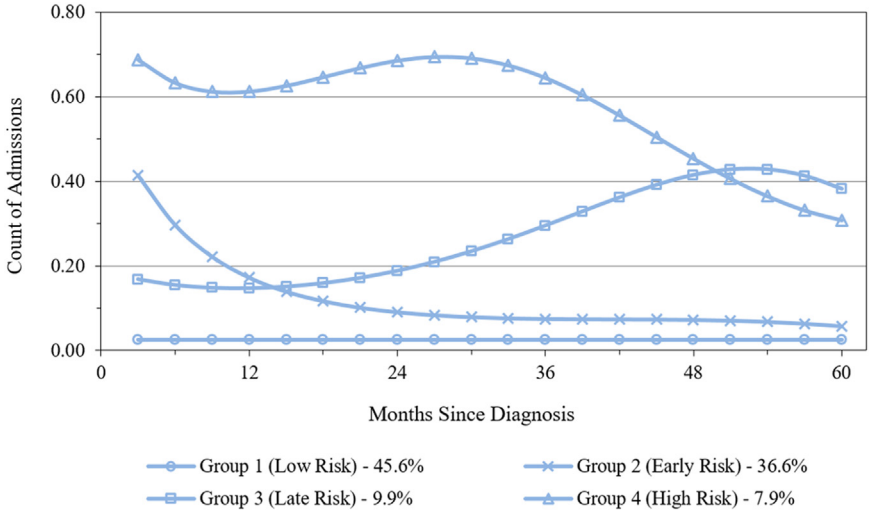
Next, we used multinomial logistic regression models to examine the associations between race and ethnicity and trajectory group membership using three models: model 1 (unadjusted), model 2 (model 1 + nonclinical characteristics), and model 3 (model 2 + clinical characteristics). Karlson-Holm-Breen (KHB) methods were then used to quantify the extent to which each of the covariates attenuated the association between race and ethnicity and trajectory group membership.[38-40] The KHB method is a mediation analysis for nested multinomial models that allowed us to evaluate the effects of the covariates (*ie*, percent mediating) with their inclusion in Model 3.

Additional sensitivity analyses were also conducted. First, ejection fraction (EF) was not available within ±1 year of HF diagnosis for many patients. Among those with EF measures ($N = 2124$), the mean EF was 47.1% (± 11.2%), and the background characteristics of patients with EF did not significantly differ from those in the overall study cohort. Sensitivity analyses also showed that the trajectories of hospitalizations were consistent with the overall cohort, and EF was not significantly associated with trajectory group membership. Second, we also performed sensitivity analyses to assess differences by sex and found that the results were consistent for men and women. All analyses were performed using Stata 18.0 (StataCorp LP, College Station, TX). P values $< .05$ were considered statistically significant.

Results

The mean age of patients at the time of their HF diagnosis was 74.8 years (± 5.8), with initial diagnoses for systolic HF (22.6%), systolic/diastolic combined HF (30.7%), HF with HTN/CKD (17.1%), or unspecified HF (29.7%). The majority of patients were female (51.3%), Medicare FFS (61.2%) or Medicare Advantage (29.7%) beneficia-

Figure 1. Estimated trajectories of hospital admissions following the diagnosis of heart failure in older adults ($N = 5,606$).
Note: Estimates were obtained using a group-based trajectory model with a zero-inflated Poisson distribution of admissions over time. Group 1 characterizes patients with Low risks of admissions (average posterior probability [AvePP] = 0.74). Group 2 characterizes patients with Early risks of admissions (AvePP = 0.74). Group 3 characterizes patients with Late risks of admissions (AvePP = 0.73). Group 4 characterizes patients with High risks of admissions (AvePP = 0.81).



ries, and non-Hispanic White (67.0%) or non-Hispanic Black (27.8%) patients. Overall, non-Hispanic Black patients were more likely to be unmarried, live in disadvantaged areas, have higher BMI, greater prevalence of comorbidities, and to be diagnosed with HF in an inpatient setting compared with non-Hispanic White patients and other racial and ethnic groups (Supplementary Table 1). Approximately 37% of patients died during the 5-year follow-up period, and there were no significant differences in survival among the racial and ethnic groups.

Figure 1 presents the estimated trajectories of hospital admissions following the diagnosis of HF. The GBTM models identified 4 distinct trajectories of hospitalization during follow up that we interpretively characterized as: (1) "low risk" group, (2) "early risk" group, (3) "late risk" group, and (4) "high risk" group. Approximately 45.6% of HF patients ($N = 2,556$) had "low risks" of hospitalization, 36.6% had elevated risks of admission shortly after diagnosis ("early risk" group), 9.9% had elevated risks at later stages of illness ("late risk" group), and 7.9% had consistently "high risks" of hospitalization ($N = 445$). Table 1 shows the clinical and nonclinical characteristics of patients in each trajectory group. Patients categorized as having low risks of hospitalization were generally healthier, with fewer comorbidities ($P < .001$), were diagnosed with HF in an outpatient setting ($P < .001$), lived in less disadvantaged areas ($P < .001$), and were more likely to be non-Hispanic White patients ($P < .001$).

Results from the multinomial logistic regression models that estimated the association between race and ethnicity and trajectory group membership (Table 2) showed that non-Hispanic Black patients were significantly more likely to exhibit early risks of hospitalization (odds ratio [OR], 1.33; 95% CI, 1.16-1.52; $P < .001$), late risks (OR = 1.92; 95% CI, 1.58-2.34; $P < .001$), or consistently high risks (OR = 1.89; 95% CI, 1.52-2.35; $P < .001$) compared with non-Hispanic White patients. These associations were only partially attenuated in the fully-adjusted model. We found no significant differences in the patterns of admissions between patients from other racial and ethnic groups compared with non-Hispanic White patients.

Table 3 presents the KHB results from the fully-adjusted analyses (Table 2, Model 3) to examine the covariates that contributed to the excess risks of admissions among non-Hispanic Blacks patients relative to non-Hispanic White patients. Differences in clinical and nonclinical characteristics accounted for about 28.7% of the likelihood of non-Hispanic Black patients exhibiting an early-risk trajectory, 24.3% of the likelihood of exhibiting a late-risk trajectory, and 55.8% of the likelihood of exhibiting a high-risk trajectory compared with non-Hispanic White patients. Notably, diabetes (10.9%-14.2%), CKD (10.5%-18.1%), and residence in disadvantaged areas (7.9%-19.3%) contributed most to the association between race and trajectory group membership.

Discussion

This study is the first prospective investigation of racial and ethnic disparities in trajectories of hospitalizations following the diagnosis of HF. Using longitudinal EHR

Table 1. Baseline characteristics of patients diagnosed with HF by trajectory group membership ($N = 5,606$).

	Group 1 (Low risk) $N = 2,556$	Group 2 (Early risk) $N = 2,052$	Group 3 (Late risk) $N = 553$	Group 4 (High risk) $N = 445$	*P*-value
Nonclinical characteristics	Mean (SD) or N (%)				
Age (years)	74.7 (5.7)	74.9 (5.8)	74.9 (6.0)	74.6 (5.7)	.574
Gender					.006
Female	1,296 (50.7)	1,019 (49.7)	302 (54.6)	257 (57.7)	
Male	1,260 (49.3)	1,033 (50.3)	251 (45.4)	188 (42.3)	
Race and ethnicity					<.001
Non-Hispanic Black	595 (23.3)	592 (28.8)	207 (37.4)	163 (36.6)	
Non-Hispanic White	1,809 (70.8)	1,356 (66.1)	328 (59.3)	262 (58.9)	
Other race and ethnicity	152 (5.9)	104 (5.1)	18 (3.3)	20 (4.5)	
Marital status					<.001
Married	1,069 (41.8)	922 (44.9)	261 (47.2)	231 (51.9)	
Not married	1,487 (58.2)	1,130 (55.1)	292 (52.8)	214 (48.1)	
Smoking history					<.001
Never smoked	1,033 (40.4)	755 (36.8)	186 (33.6)	136 (30.5)	
Former smoker	1,374 (53.8)	1,156 (56.3)	334 (60.4)	270 (60.7)	
Current smoker	149 (5.8)	141 (6.9)	33 (6.0)	39 (8.8)	
Health insurance					<.001
Medicare	1,535 (60.0)	1,256 (61.2)	371 (67.1)	269 (60.5)	
Medicare advantage	748 (29.3)	618 (30.1)	151 (27.3)	146 (32.8)	
Other/Unknown	273 (10.7)	178 (8.7)	31 (5.6)	30 (6.7)	
Area-level disadvantage	3.6 (2.4)	3.8 (2.5)	4.0 (2.4)	4.4 (2.6)	<.001
Clinical characteristics	Mean (SD) or N (%)				
Location of HF diagnosis					<.001
Outpatient	1,527 (59.7)	896 (43.7)	247 (44.7)	140 (31.5)	
Inpatient	1,029 (40.3)	1,156 (56.3)	306 (55.3)	305 (68.5)	
HF Type at baseline					
Systolic HF	607 (23.8)	468 (22.8)	119 (21.5)	74 (16.6)	<.001
Diastolic/Combined HF	775 (30.3)	611 (29.8)	165 (29.8)	167 (37.5)	
HF, unspecified	782 (30.6)	608 (29.6)	173 (31.3)	99 (22.3)	
HF with HTN/CKD	392 (15.3)	365 (17.8)	96 (17.4)	105 (23.6)	
Body mass index (kg/m^2)	30.4 (7.4)	29.7 (7.5)	31.3 (8.2)	30.6 (7.8)	<.001
Diagnoses and comorbidities					
Hypertension	2,099 (82.1)	1,797 (87.6)	502 (90.8)	411 (92.4)	<.001
Diabetes mellitus	899 (35.2)	887 (43.2)	292 (52.8)	257 (57.8)	<.001
Hyperlipidemia	1,574 (61.6)	1,339 (65.3)	384 (69.5)	300 (67.4)	.001
Anemia	693 (27.1)	807 (39.3)	211 (38.2)	228 (51.2)	<.001
Atrial fibrillation or flutter	941 (36.8)	836 (40.7)	196 (35.4)	184 (41.4)	.011
Coronary heart disease	1,172 (45.9)	1,099 (53.6)	314 (56.8)	246 (55.3)	<.001
Stroke or TIA	323 (12.6)	397 (19.4)	122 (22.1)	109 (24.5)	<.001
Chronic kidney disease	697 (27.3)	778 (37.9)	254 (45.9)	257 (57.8)	<.001
COPD	539 (21.1)	570 (27.8)	177 (32.0)	165 (37.1)	<.001
Malignancy	382 (14.9)	404 (19.7)	103 (18.6)	96 (21.6)	<.001
Depression	420 (16.4)	407 (19.8)	116 (20.9)	136 (30.6)	<.001
Died during study period	662 (25.9)	858 (41.8)	243 (43.9)	319 (71.7)	<.001

Abbreviations: COPD, chronic obstructive pulmonary disease; HF, heart failure; SD, standard deviation; TIA, transient ischemic attack.

data from a large healthcare system, our findings provide unique insights into the timing and long-term patterning of hospitalizations among HF patients and the major factors contributing to racial and ethnic disparities in these trajectories. Overall, we found that non-Hispanic Black patients were more likely to experience greater short-term and long-term risks of hospitalizations compared with non-Hispanic White patients following a diagnosis of HF. These disparities persisted after adjusting for various clinical and nonclinical factors.

Our study identified 4 clinically distinct trajectories of hospital admissions following the diagnosis of HF—marked by varying levels of risk and the timing of the hospitalization(s). A sizeable portion of patients (46%) had low/no admissions during the 5 years after their diagnosis. However, a slightly smaller proportion of patients (37%) experienced elevated risks of hospitalization shortly after being diagnosed with HF (within the first 6-12 months). This pattern is consistent with prior research demonstrating the acute nature of HF and the need for immediate management strategies soon after a diagnosis.[11,12] Alternatively, we found that some patients (10%) experienced a steady increase in admissions much later in the progression of their HF (2 years after diag-

Table 2. Multinomial estimates of the association between race and ethnicity and trajectory group membership in patients diagnosed with heart failure ($N = 5,606$).

	Group 2 (Early risk)		Group 3 (Late risk)		Group 4 (High risk)	
	RRR (95% CI)	*P*-value	RRR (95% CI)	*P*-value	RRR (95% CI)	*P*-value
Model 1						
Race and ethnicity						
Non-Hispanic White	1.00		1.00		1.00	
Non-Hispanic Black	1.33 (1.16-1.52)	<.001	1.92 (1.58-2.34)	<.001	1.89 (1.52-2.35)	<.001
Other race and ethnicity	0.91 (0.70-1.18)	.490	0.65 (0.40-1.08)	.097	0.91 (0.56-1.47)	.697
Model 2						
Race and ethnicity						
Non-Hispanic White	1.00		1.00		1.00	
Non-Hispanic Black	1.26 (1.09-1.46)	.002	1.82 (1.46-2.26)	<.001	1.49 (1.17-1.88)	.001
Other race and ethnicity	0.96 (0.74-1.25)	.773	0.75 (0.45-1.24)	.255	1.01 (0.62-1.65)	.957
Model 3						
Race and ethnicity						
Non-Hispanic White	1.00		1.00		1.00	
Non-Hispanic Black	1.24 (1.07-1.45)	.006	1.69 (1.34-2.13)	<.001	1.38 (1.07-1.78)	.012
Other race and ethnicity	0.92 (0.71-1.21)	.568	0.71 (0.42-1.18)	.186	0.95 (0.57-1.58)	.849

Abbreviations: CI, confidence interval; RRR, relative risk ratio.
Note: Group 1 (Low risk) is the reference group in the multinomial model. Model 1 is unadjusted. Model 2 adjusted for age, sex, marital status, smoking history, health insurance, and area-level disadvantage. Model 3 adjusted for Model 2 covariates + location of HF diagnosis, BMI, hypertension, diabetes, hyperlipidemia, anemia, atrial fibrillation, coronary heart disease, stroke (or TIA), chronic kidney disease, COPD, malignancy, and depression.

Table 3. Estimated percentage of association between race and ethnicity and trajectory group membership attributable to study covariates in older adults diagnosed with heart failure ($N = 5,606$).

	Early risk vs low risk	Late risk vs low risk	High risk vs low risk
Nonclinical characteristics (%)	**13.84**	**1.53**	**26.61**
Age (years)	1.24	−1.14	2.04
Sex (male)	−1.36	2.22	3.61
Marital Status (married)	4.56	−0.89	2.53
Former smoker (vs never)	−0.89	−1.76	−2.64
Current smoker (vs never)	0.42	0.03	1.37
Medicare advantage (vs Medicare)	−1.07	−5.50	0.17
Other/unknown (vs Medicare)	0.30	0.68	0.25
Area-level disadvantage (logged)	10.64	7.89	19.28
Clinical characteristics (%)	**14.88**	**22.81**	**29.21**
Location of HF diagnosis (inpatient)	8.48	2.47	5.50
Body mass index (kg/m^2)	−6.39	3.40	−0.05
Hypertension	4.28	3.13	3.48
Hyperlipidemia	0.46	−0.11	0.54
Diabetes	12.69	10.91	14.20
Anemia	6.79	1.53	4.65
Atrial fibrillation	−10.51	−0.62	−7.99
Coronary heart disease	−6.00	−4.83	−2.20
Stroke or TIA	−0.33	−0.20	−0.20
Chronic kidney disease	10.54	10.86	18.11
COPD	−3.01	−2.60	−2.78
Malignancy	−0.24	−0.09	−0.14
Depression	−1.88	−1.04	−3.91
Total (%)	**28.72**	**24.34**	**55.82**
P-value*	.027	.006	<.001

Abbreviations: COPD, chronic obstructive pulmonary disease; HF, heart failure; TIA, transient ischemic attack.
Note. Percentages were estimated using the Karlson–Holm–Breen (KHB) method and are reported for non-Hispanic Black patients (vs non-Hispanic White patients) while adjusting for other racial and ethnic groups.
* *P*-values indicate the effect of clinical and nonclinical characteristics on the association between race and ethnicity and trajectory group membership.

nosis). For these patients, a protracted care-management plan should be prioritized to address the longer-term needs for maintaining effective self-care and reducing the degenerative toll of HF and other comorbidities. Finally, we found that nearly 1-in-10 patients exhibited consistently high risks of hospitalization over time. These findings further underscore the chronic and progressive nature of HF and the challenges that remain in managing the long-term sequelae of this condition in some patient populations.[1,7,8,11]

Our study also identified significant racial and ethnic disparities in the trajectories of hospitalizations that followed a diagnosis of HF. We found that non-Hispanic Black patients were significantly more likely to exhibit early, late, and overall high risks of hospitalization compared with non-Hispanic White patients. Most notably, results showed that non-Hispanic Black patients were approximately 90% more likely to experience consistently high risks of admissions relative to non-Hispanic White patients. Adjusting for the patients' clinical and nonclinical characteristics accounted for the majority (55.8%) of the excess risks observed in non-Hispanic Black patients. In particular, we found that living in disadvantaged areas contributed most to the association between race and trajectory group membership (~20%) and suggests that inadequate medical, logistical, and financial support systems in disadvantaged areas prevent optimal management of HF and increase the likelihood of hospitalizations. To mitigate these excess admissions, healthcare providers should remain vigilant in monitoring non-Hispanic Black patients—especially those from disadvantaged backgrounds and with multiple comorbidities—for potentially preventable exacerbations that may develop early and often in the course of their care.

The lack of associations for patients identified in other racial and ethnic groups also warrants comment. Overall, these findings are consistent with prior studies that have shown the disparities in (re)admissions are primarily between non-Hispanic White and Black patients;[1,7,8] and much less pronounced among other patient populations.[3,8] However, we also cannot rule out the current lack of findings due to the limited number of Hispanic and Asian patients, as well as the lack of information on patients' identifying as other racial and ethnic groups. Therefore, future studies should include diverse patient populations to characterize the longitudinal patterns of admissions that occur after the diagnosis of HF.

The findings from this study have important implications for clinical practice. Consistently, and not unexpectedly, co-existing diagnoses of diabetes and CKD largely contributed to the excess risks of admissions among non-Hispanic Black patients. The interrelationships among metabolic risk factors and CKD within the cardiovascular-kidney-metabolic (CKM) syndrome are strongly associated with adverse cardiovascular and kidney outcomes.[41-44] Notably, older adults and Black adults in the US often have advanced stages of the CKM syndrome.[41,42,44,45] Thus, targeting interventions in non-Hispanic Black patients who are managing these complex conditions holds the most immediate promise in reducing racial disparities in hospitalizations. Our study also demonstrated the importance of social determinants of health and their contribution to the excess risks of hospital admissions among non-Hispanic Black patients.[8,46,47] Although we recognize that area-level disadvantage is not amenable to medical intervention, knowledge about these risks can aid in clinical decision-making, personalizing care, and aggressively screening patients to prevent new or recurrent admissions in vulnerable patient groups.

This study had several strengths, including the use of longitudinal EHR data and robust data-driven methods to characterize the major trajectories of hospital admissions in HF patients. Importantly, our study reorients research attention to patient-centered changes over the course of the HF syndrome rather than focusing on aggregated metrics (*ie*, 30-day readmissions). In doing so, we will be more equipped to prevent 30-day readmissions by better identifying and eliminating the patients' prior (index) hospitalization—and any others that may precede it. The diagnosis of HF marks a critical timepoint that prompts the initiation of guideline-recommended care and provides opportunities to address disparities before poor outcomes cascade over time. The results of this study provide new evidence to help address these challenges.

Several limitations of this study should be acknowledged. First, the findings from our study are limited to patients diagnosed with HF in the Duke University Health System and may not be generalizable to all HF patients. Relatedly, our study does not account for attrition from the healthcare system or admissions that may have occurred elsewhere during the course of HF. We encourage future studies to assess the patterns of additional (or different) trajectories of hospitalizations that may be observed in other healthcare systems. Second, we acknowledge the possibility of immortal time bias from only including patients who survived for at least 90 days after their HF diagnosis. Third, there may be additional factors (*eg*, glomerular filtration rate, [in]frequency of outpatient care) that may have contributed to racial and ethnic disparities in the trajectories of hospitalizations. As previously noted, we lacked adequate data on EF to fully examine trajectories of hospitalizations based on HF type (*ie*, preserved or reduced EF). We also acknowledge that guideline-directed medical therapy, medication class, and dosing frequency can impact the progression of HF, however, such assessments are outside the scope of the current analysis. Relatedly, we could not account for commensurate changes in HF severity, comorbidities, or interventions (*eg,* ventricular assist devices, heart transplantation, or cardiac rehabilitation). Nevertheless, the covariates included in our analysis accounted for

a sizeable portion (24%-56%) of the excess admissions observed in non-Hispanic Black patients. Furthermore, the clinical and nonclinical characteristics that we included are readily accessible in the patients' EHR and can quickly inform providers of newly-diagnosed patients at greater risks of hospitalization during the course of their illness. We also acknowledge that diagnoses of HF in outpatient settings may be less accurate than inpatient diagnoses. Finally, the observational study design prevented any causal interpretations.

In summary, this study is the first to characterize the longitudinal trajectories of hospital admissions following the diagnosis of HF and examine the racial and ethnic disparities in these patterns. Multifaceted interventions that consider the patients' clinical characteristics along with their socioeconomic conditions are needed to better promote health equity and improve outcomes in HF patients.

Data accessibility

MED and RD had full access to the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis.

Data availability

Due to the sensitive nature of the data used in this study, qualified researchers trained in human subject confidentiality protocols may send requests to the corresponding author to access the data that support the findings of this study.

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Conflict of Interest

None.

CRediT authorship contribution statement

Matthew E. Dupre: Writing – review & editing, Writing – original draft, Supervision, Software, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Radha Dhingra:** Writing – review & editing, Software, Investigation, Formal analysis. **Hanzhang Xu:** Writing – review & editing, Investigation. **Bradley G. Hammill:** Writing – review & editing, Investigation. **Scott M. Lynch:** Writing – review & editing, Investigation. **Jessica S. West:** Writing – review & editing, Investigation, Funding acquisition. **Michael D. Green:** Writing – review & editing, Investigation. **Lesley H. Curtis:** Writing – review & editing, Investigation. **Eric D. Peterson:** Writing – review & editing, Investigation.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.ahj.2025.04.006.

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