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ORIGINAL ARTICLE

Costs and factors associated with heart failure following kidney transplantation – a single-center retrospective cohort study

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SUMMARY

The number of adults with heart failure (HF) will increase by ~50% between 2012 and 2030. Among kidney transplant recipients, HF accounts for 16% of all post-transplant admissions. We describe the burden of HF and predictors of healthcare utilization following kidney transplantation. We retrospectively identified adults who underwent kidney transplantation at our institution (01/2007–12/2017). Data were acquired from electronic health records, with healthcare utilization obtained from a statewide database. The HF incidence rate and prevalence were estimated for each year, total charges for HF and non-HF patients were compared, and logistic regression was employed for a 3-year predictive model of healthcare utilization associated with HF. Among 1731 kidney transplant recipients, the post-transplant HF incidence rate ranged from 1.91 (year 3) to 6.80 (year 10) per 100 person-years, while the prevalence increased from 31.7% (year 1) to 48.1% (year 10). Median charges were $75 837 (HF) compared to $42 940 (non-HF) per person-year ($P < 0.001$). Pretransplant HF [odds ratio (OR) = 3.12] and an eGFR < 45 (OR = 4.73) were the strongest predictors of HF encounters ($P < 0.05$ for both). We observed a high and increasing prevalence of HF, which was associated with twice the costs. Kidney transplant recipients would benefit from interventions aimed at mitigating HF risk factors.

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Introduction

The number of United States (US) adults living with heart failure (HF) is expected to increase by nearly 50% between 2012 and 2030, resulting in a prevalence of over 8 million by 2030 [1]. The projected cost of HF in 2030 is $69.7 billion, which would be equivalent to about $244 for every US adult. Patients with renal dysfunction are at increased risk of HF [2–5]. Although kidney transplantation may decrease the risk of HF when compared to remaining on dialysis [6], HF still results in significant healthcare utilization among kidney transplant recipients [6,7]. In an analysis of 389 138 hospitalizations following kidney transplantation, HF hospitalizations increased by 24% between 2005 and 2011 and accounted for nearly one in every six post-transplant admissions [7].

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Heart failure has been associated with a threefold increase in the rate of death and graft loss in kidney transplant recipients, as demonstrated by Lentine *et al.* [8] in an analysis of 27 011 US patients between 1995 and 2001. This analysis also identified several potentially mutable HF risk factors; including anemia, angina, myocardial infarction (MI), peripheral vascular disease (PVD), hypertension, and smoking. As the prevalence of HF has significantly increased since this study [1,9], analyses assessing HF risk factors using contemporary data are needed. Moreover, there is a paucity of evidence describing the economic burden of HF following kidney transplantation. Therefore, we sought to describe the occurrence of and costs associated with HF, as well as predictors of HF encounters among kidney transplant recipients using comprehensive resource utilization data obtained from a statewide database.

Materials and methods

Population and setting

This is a retrospective cohort study of all adult (≥18 years of age) solitary kidney transplant recipients ($N = 1731$) conducted at the Medical University of South Carolina, Charleston, SC between January 2007 and December 2017. This study was approved by the Medical University of South Carolina Institutional Review Board (#Pro00064075).

Data sources

Patient data were acquired from electronic health records using a number of sources to create a comprehensive dataset, rich with baseline characteristics and clinical outcomes. Data sources included Practice Partner (outpatient electronic health record) prior to May 2012 and EPIC (outpatient and inpatient electronic health record) from July 2011. Elements from United Network for Organ Sharing registry containing Organ Procurement and Transplantation Network data were acquired for the entire cohort. Key social determinant of health data was obtained from our Transplant Database (Velos) before September 2014 and EPIC following this date. Natural language processing was applied to unstructured text fields using IBM Watson Content Analytics to extract Banff scores and vital signs that predated electronic capture. De-identified resource utilization data were acquired through a data use agreement with the South Carolina All-Payer Public Use data files maintained by the SC Department of Revenue and Fiscal Affairs (RFA) Office. This dataset contains all hospitalizations and emergency room visits, charges, and diagnosis codes for all SC residents, regardless of payer.

Outcomes

Heart failure

Outcomes for this study were the occurrence of HF and HF-associated healthcare utilization post-transplant. International classification of diseases, ninth revision (ICD-9) diagnostic codes (398.91, 422, 425, 428, 402.x1, 404.x1, 404.x3, V42.1) were used to identify HF using two HF definitions: (i) a diagnostic code for HF in the primary diagnostic position only and (ii) a diagnostic code for HF in any diagnostic position [8]. The incidence rate and prevalence of HF for each year post-transplant were estimated using both of the aforementioned definitions. A predictive model was developed for 3-year HF encounters (including emergency department visits and hospital admissions) defined by a diagnostic code for HF in the primary diagnostic position only, as this has been demonstrated to identify HF encounters with the highest validity [10]. Only encounters occurring 90 days after transplant were analyzed because we used the information in the first 90 days post-transplantation to construct clinical predictors of interest for this analysis. Patients with missing data and those with less than 3 years of follow-up were excluded from the predictive modeling.

Charges

Total charges for HF and non-HF patients post-transplant also served as an outcome for this study. The median charge per patient-year post-transplant was determined and compared between HF and non-HF patients. Median post-transplant charges stratified by maximum estimated glomerular filtration rate (eGFR) <45 vs. ≥45 ml/min/1.73 m^2 within 90 days post-transplant are also described among patients with and without HF prior to transplant. Charges were obtained from the SC RFA database, which consists of hospital admissions, emergency room visits, outpatient surgeries, imaging, radiation therapy, and other outpatient services from all short-term acute care hospitals and licensed freestanding medical centers in SC. While SC RFA data are comprehensive as these institutions are required by law to submit the aforementioned information, only direct medical charges are captured.

Covariates of interest

Sociodemographic and clinical information were obtained from UNOS data files and included the following: age, sex, race, insurance type, body mass index, donor type, kidney donor profile index, delayed graft function, waiting time, and distance from recipient residence to the transplant center. Key social determinants of health utilized in the analyses included the following: education status, employment, receiving disability at the time of transplant, marital status, and smoking status. Electronic health record data and administrative claims obtained from our center and the SC RFA were utilized to supplement UNOS variables and provide vital signs, laboratory data, and comprehensive comorbidity assessment. The vital signs and laboratory values obtained from electronic health record data at our center included systolic blood pressure, pulse pressure, hemoglobin, and estimated glomerular filtration rate glucose. Means, standard deviations, maximums, and regressed slopes were used to represent dynamic variables, capturing effects of, direction of, and magnitude of change within the first 90 days post-transplantation. Administrative data were used to capture pretransplant comorbidities, including history of heart failure, atherosclerotic cardiovascular disease, arrhythmias, and valvular disease. Hospital and emergency department admissions 365 days prior to transplant and 90 days post-transplant were quantified from SC RFA data.

Statistical analysis

Descriptive statistics are displayed as means ± standard deviations (continuous variables) and percentages (categorical variables). For the baseline comparison between HF and control (Non-HF) groups, chi-square tests (Fisher's exact for low counts) were used for categorical variables and independent two-sample *t*-tests were used for comparison of continuous variables. For the total charge comparison between HF and non-HF patients, Wilcoxon–Mann–Whitney tests were used to compare medians. Firth (to account for a low number of events) multivariable logistic regression was used for the 3-year predictive model of HF encounters utilizing baseline and up to 90 days post-transplant follow-up data [11–13]. Because data in the first 90 days after transplant were used to construct clinical predictors of interest, only HF encounters occurring 90 days after transplant were analyzed. Profile penalized likelihood confidence intervals were estimated in the model. Statistical significance was determined at the two-sided 5% level. A backward selection process was used in the model, with an exit *P*-value at the 10% level employed for variable selection. Several sensitivity analyses were also conducted. First, a forward selection process was used, with an exit *P*-value at the 10% level employed for variable selection. Additionally, time-to-event survival analysis with a backward selection process was used, with exit *P*-values at both the 10% and 20% levels employed for variable selection. Lastly, we ran our main analysis (i.e., Firth multivariable logistic regression using a backwards selection process) but excluded patients experiencing HF events postallograft failure. Only the first HF encounter was analyzed in all models. IBM SPSS Modeler 17 (IBM Corp, Armonk, NY, USA) and SAS 9.4 (SAS Institute, Cary, NC, USA) were used for the statistical analysis.

Results

A total of 1731 adults underwent kidney transplantation between January of 2007 and December of 2017 at our institution and were included in the study cohort (Fig. 1). Approximately 25% (n = 439) of patients met the definition of HF based on the presence of a HF diagnostic code in any diagnostic position. A total of 8% (n = 135) of patients had a HF diagnostic code in the primary position, of which 31 had HF prior to transplant (Table S1).

Patient characteristics

Demographics of included patients stratified by HF and non-HF groups are displayed in Table 1. Regardless of the HF definition utilized, HF patients were older and were more likely to have a history of other cardiovascular conditions [including atherosclerotic cardiovascular disease (ASCVD), arrhythmias, and valvular disease]. Those with HF were also more likely to have a mean pulse >90 bpm, more variation in pulse pressure, an estimated glomerular filtration rate (eGFR) <45 ml/min/1.73 m^2, and hospital and ED utilization in the 90 days post-transplant timeframe. Among those with HF as identified by a diagnostic code in any position, the 5 most common reasons for encounters are listed in Table S2. These encounters appeared to be caused by either infections or complications of the graft.

Heart failure incidence rate and prevalence

During post-transplant year one through eight, the incidence rate of HF, as identified by HF diagnostic codes

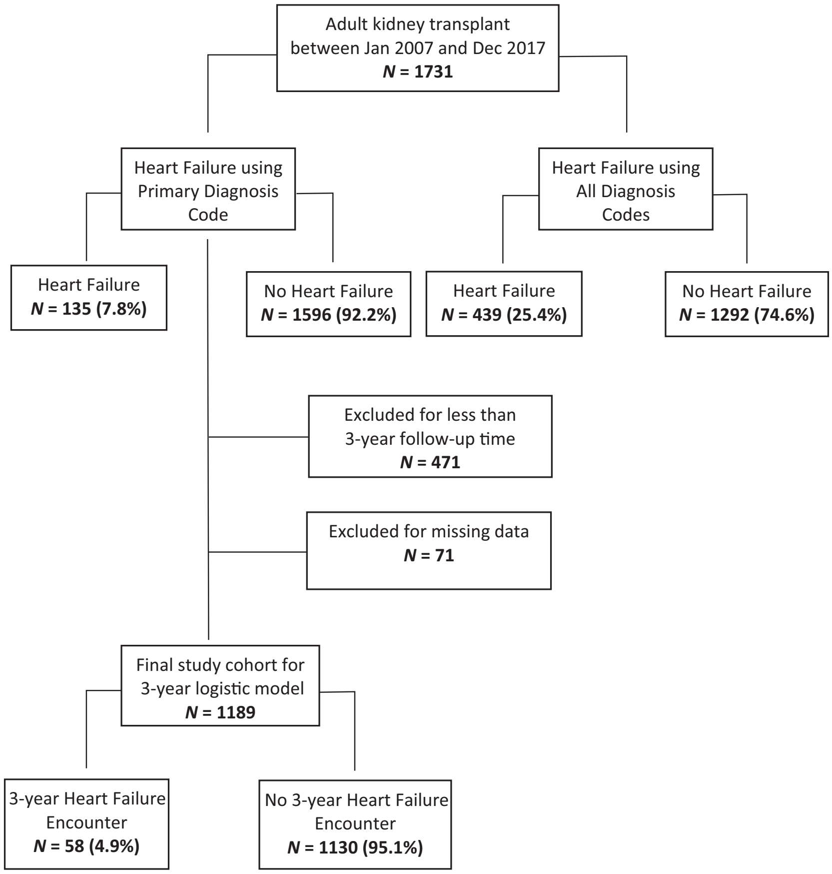

Figure 1 Study flow diagram.

in any position, ranged from 1.9 to 4.2 per 100 person-years (Fig. 2a; Table S3). This increased to 6.3 and 6.8 per 100 person-years in post-transplant year nine and ten, respectively. Trends were similar when HF was identified using only HF diagnostic codes in the primary position, ranging from 0.8 to 1.8 per 100 person-years in post-transplant years one through eight and increasing to 3.9 and 3.7 per 100 person-years in post-transplant year nine and ten.

When HF was defined by HF diagnostic codes in any position, HF prevalence was 31.7% prior to transplant and steadily increased to 48.1% in post-transplant year ten (Fig. 2b; Table S3). HF prevalence as identified by a HF diagnostic code in the primary position was 15.8% prior to transplant and increased to 25.8% in post-transplant year ten.

Overall charges

Overall median charges among patients with HF were $75 837 and $83 858 per person-year for HF defined by HF diagnostic codes in any and the primary diagnostic position, respectively (Fig. 3, Table S4), while median charges were $42 940 and $48 251 per person-year for non-HF patients ($P < 0.001$ for both HF versus non-HF comparisons). Regardless of the HF definition used, both emergency department and hospital utilization charges were substantially higher among HF versus non-HF patients ($P < 0.001$ for all).

Predictors of heart failure associated healthcare utilization during the 3 years post-transplant

Of 1731 patients in our study, 542 had less than 3 years of follow-up time or missing data (Fig. 1), leaving 1189 patients for inclusion in our 3-year healthcare utilization predictive model (Table S5). During these 3 years post-transplant time period, 58 (4.9%) patients had a HF emergency department or hospital encounter as indicated by a HF diagnostic code in the primary position. A history of HF prior to transplant and a maximum eGFR <45 ml/min/1.73 m^2 in the 90 days post-transplant were both associated with more than three times the odds of HF encounters ($P < 0.001$ for both; Table 2). A history of ASCVD and cardiac arrhythmias as well as a mean systolic blood pressure >130 mmHg in the 90 days post-transplant were associated with 1.9–2.7 times higher odds of HF encounters ($P < 0.05$ for

Table 1. Demographics of included kidney transplant recipients.

Variables	All	Primary diagnosis			All diagnosis		
	All N = 1731 (100%)	Heart failure N = 135 (7.8%)	Nonheart failure N = 1596 (92.2%)	P-value	Heart failure N = 439 (25.4%)	Nonheart failure N = 1292 (74.6%)	P-value
Age at transplant (≥60)	598 (34.5%)	68 (50.4%)	530 (33.2%)	<0.0001	189 (43.0%)	409 (31.7%)	<0.0001
Female	684 (39.5%)	50 (37.0%)	634 (39.7%)	0.5397	171 (39.0%)	513 (39.7%)	0.7802
African American	948 (54.8%)	76 (56.3%)	872 (54.6%)	0.7099	261 (59.5%)	687 (53.2%)	0.0224
Medicare	1234 (71.3%)	115 (85.2%)	1119 (70.1%)	0.0002	350 (79.7%)	884 (68.4%)	<0.0001
DGF (delayed graft function)	286 (16.5%)	26 (19.3%)	260 (16.3%)	0.3725	84 (19.1%)	202 (15.6%)	0.088
BMI ≥35	255 (14.7%)	20 (14.8%)	235 (14.7%)	0.9773	67 (15.3%)	188 (14.6%)	0.7166
Dialysis before transplant	1430 (82.6%)	119 (88.2%)	1311 (82.1%)	0.0771	392 (89.3%)	1038 (80.3%)	<0.0001
Distance to transplant center, miles	95.4 ± 74.7	97.0 ± 65.2	95.3 ± 75.5	0.7668	91.5 ± 64.6	96.7 ± 77.8	0.1690
Waiting time, years	1.65 ± 1.61	1.73 ± 1.57	1.64 ± 1.61	0.5455	1.74 ± 1.54	1.62 ± 1.63	0.1497
Married	1056 (61.0%)	90 (66.7%)	966 (60.5%)	0.1602	274 (62.4%)	782 (60.5%)	0.4834
Employed	541 (31.3%)	34 (25.2%)	507 (31.8%)	0.1132	94 (21.4%)	447 (34.6%)	<0.0001
Received disability	810 (46.8%)	73 (54.1%)	737 (46.2%)	0.0775	248 (56.5%)	562 (43.5%)	<0.0001
Finished high school	1514 (87.5%)	110 (81.5%)	1404 (88.0%)	0.0288	378 (86.1%)	1136 (87.9%)	0.3195
Smoker	127 (7.3%)	15 (11.1%)	112 (7.0%)	0.0798	45 (10.3%)	82 (6.4%)	0.0067
History of heart failure	558 (32.2%)	74 (54.8%)	484 (30.3%)	<0.0001	265 (60.4%)	293 (22.7%)	<0.0001
History of ASCVD	550 (31.8%)	71 (52.6%)	479 (30.0%)	<0.0001	210 (47.8%)	340 (26.3%)	<0.0001
History of myocardial infarction	175 (12.8%)	36 (26.7%)	139 (8.7%)	<0.0001	80 (18.2%)	95 (7.3%)	<0.0001
History of peripheral vascular disease	263 (15.2%)	36 (26.7%)	227 (14.2%)	0.0001	105 (23.9%)	158 (12.2%)	<0.0001
History of cerebrovascular disease	225 (13.0%)	23 (17.0%)	202 (12.7%)	0.1462	78 (17.8%)	147 (11.4%)	0.0006
History of unstable angina	90 (5.2%)	16 (11.9%)	74 (4.6%)	0.0003	39 (8.9%)	51 (4.0%)	<0.0001
History of cardiac arrhythmias	525 (30.3%)	65 (48.2%)	460 (28.8%)	<0.0001	188 (42.8%)	337 (26.1%)	<0.0001
History of valvular disease	240 (13.9%)	27 (20.0%)	213 (13.4%)	0.0317	96 (21.9%)	144 (11.2%)	<0.0001
History of chronic pulmonary disease	483 (27.9%)	47 (34.8%)	436 (27.3%)	0.0622	165 (37.6%)	318 (24.6%)	<0.0001
Donor type (deceased)	1464 (84.6%)	116 (85.9%)	1348 (84.5%)	0.6509	45 (10.3%)	222 (17.2%)	0.0005
KDPI	40.5 ± 30.0	47.4 ± 33.3	39.9 ± 29.6	0.0054	46.7 ± 30.8	38.4 ± 29.4	<0.0001
ED + IP visits 365 days pretransplant	1.50 ± 4.02	1.78 ± 2.16	1.47 ± 4.14	0.1542	1.80 ± 2.36	1.40 ± 4.45	0.0171
ED + IP visits 90 days post-transplant	0.82 ± 1.30	1.24 ± 1.61	0.78 ± 1.26	0.0017	1.18 ± 1.54	0.70 ± 1.18	<0.0001
SBP mean 90 days post-transplant (>130)	1412 (81.8%)	113 (84.3%)	1299 (81.6%)	0.4310	367 (83.8%)	1045 (81.1%)	0.2132
Pulse pressure std 90 days post-transplant	13.6 ± 4.0	14.5 ± 4.4	13.5 ± 4.0	0.0101	14.5 ± 4.2	13.3 ± 3.9	<0.0001
Pulse mean 90 days post-transplant (>90)	253 (14.7%)	9 (6.7%)	244 (15.3%)	0.0068	49 (11.2%)	204 (15.8%)	0.0174
Glucose mean 90 days post-transplant (>180)	225 (13.3%)	24 (18.9%)	201 (12.9%)	0.0557	75 (17.6%)	150 (11.9%)	0.0026
eGFR max 90 days post-transplant (<45)	338 (20.3%)	39 (31.2%)	299 (19.4%)	0.0016	114 (27.0%)	224 (18.0%)	<0.0001
HGB mean 90 days post-transplant (≤10)	531 (31.9%)	49 (39.2%)	482 (31.3%)	0.0668	161 (38.2%)	370 (29.7%)	0.0013
HGB slope/month 90 days post-transplant	0.53 ± 1.75	0.35 ± 1.37	0.55 ± 1.78	0.1320	0.49 ± 1.24	0.55 ± 1.90	0.5763

ASCVD, atherosclerotic cardiovascular disease; BMI, body mass index; ED, emergency department; eGFR, estimated glomerular filtration rate; HGB, hemoglobin; IP, inpatient; KDPI, kidney donor profile index; SBP, systolic blood pressure; Std, standard deviation.

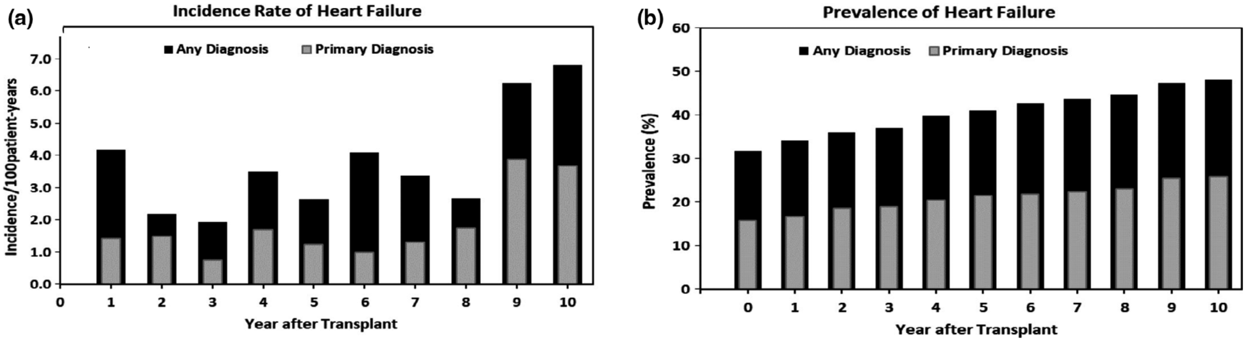

Figure 2 Incidence rate and prevalence of heart failure. (a) Incidence rate of heart failure and (b) prevalence of heart failure vs years post-transplant in kidney transplant patients. Values shown from ICD-9 codes for heart failure in the primary diagnoses position and any diagnoses position.

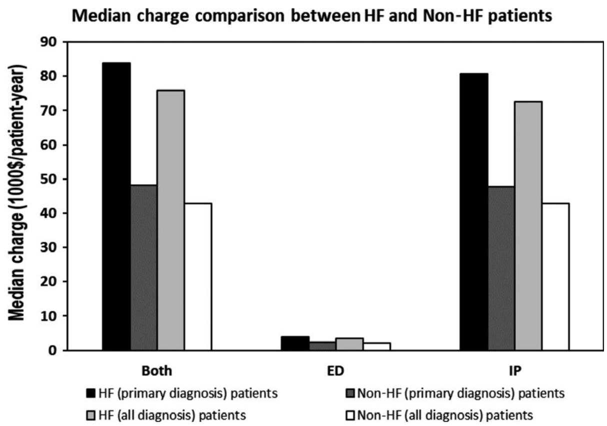

Figure 3 Median charge comparison between patients with and without heart failure. Comparisons were made between groups based upon HF as primary diagnosis and also with HF in all diagnoses. ED, emergency room; HF, heart failure; IP, inpatient.

all). Age ≥60 years, smoking, and mean glucose >180 mg/dl during the 90 days post-transplant were also associated with a higher odds of HF encounters, albeit not significant. Results consistent with the main analysis were observed in all sensitivity analyses.

Charges stratified by estimated glomerular filtration rate

Post-transplant charges stratified by eGFR (i.e., ≥45 and <45 ml/min/1.73 m^2) among those with and without HF prior to transplantation are shown in Fig. 4 and Table S6. In both eGFR groups, HF was associated with higher charges. Charges were approximately 2.5 times higher among those with prior HF and a maximum eGFR <45 ml/min/1.73 m^2 in the 90 days following transplantation when compared to patients without these characteristics.

Discussion

In this analysis of nearly 2000 kidney transplant recipients, we observed a high HF prevalence. Approximately one-third of patients had HF at the time of transplant. By 10 years post-transplant, nearly half of all patients had HF. HF was associated with significantly more healthcare utilization, leading to higher charges. Characteristics associated with HF-associated healthcare utilization during the 3 years following transplantation included a history of HF prior to transplantation, maximum eGFR <45 ml/min/1.73 m^2 in 90 days post-transplant, arrhythmias, and several well-established ASCVD risk factors (elevated blood pressure, history of ASCVD events).

From previous literature, we know that HF prevalence among patients on dialysis is high, ranging from 35% to 70% across these observational studies [14–20]. It is likely a result of increased traditional risk factors (e.g., older age, hypertension, diabetes, anemia, ASCVD) and dialysis-specific risk factors (e.g., fluid overload, high-output state with the presence of an arteriovenous fistula, increased sympathetic nervous system activation) [16,21,22]. When compared to continuing dialysis, kidney transplantation is associated with lower rates of new-onset HF and HF-associated morbidity [6,18]. In an analysis of 11 369 patients with diabetes from US Renal Data System (USRDS), renal transplantation decreased the hazard of HF to 0.64 when compared to patients receiving maintenance dialysis [hazard ratio (HR) = 0.64; 95% confidence interval (CI) = 0.54–0.77] [6]. Further, left ventricular ejection fraction (LVEF) increased from a pretransplant mean of 31.6% ± 6.7% to 52.2% ± 12.0% 12 months post-transplant in an analysis of 103 patients with HF [18]. New York Heart Association (NYHA) Functional Classification also

Table 2. Firth logistic model for heart failure within 3 years post-transplant.*

Variables	OR (95% CI)	*P*
Age ≥ 60 vs. <60	1.712 (0.965–3.041)	0.0660
Smoker	2.215 (0.877–4.988)	0.0887
History of congestive heart failure	3.123 (1.739–5.757)	0.0001
History of cardiac arrhythmias	1.907 (1.065–3.415)	0.0299
History of ASCVD†	2.666 (1.492–4.853)	0.0009
SBP mean 90 days post-transplant >130 vs. ≤130	2.279 (1.013–6.011)	0.0463
Glucose mean 90 days post-transplant >180 vs. ≤180	1.799 (0.890–3.472)	0.0999
eGFR max 90 days post-transplant <45 vs. ≥45	4.731 (2.694–8.369)	<0.0001

ASCVD, atherosclerotic cardiovascular disease; eGFR, estimated glomerular filtration rate; OR, odds ratio; SBP, systolic blood pressure.

*The AUC (c-statistic) for the model was 0.819.

†ASCVD consisted of myocardial infarction/cerebrovascular disease/peripheral vascular disease/unstable angina.

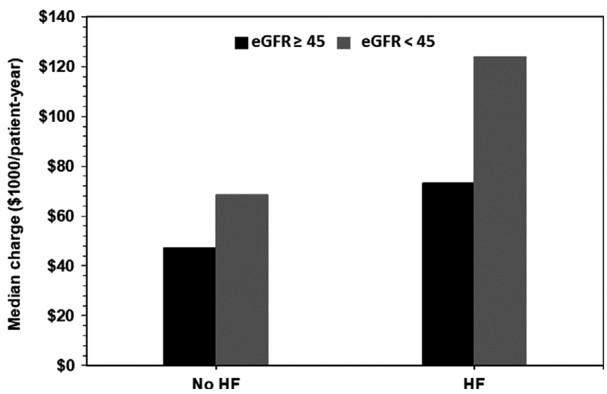

Figure 4 Median charges among kidney transplant recipients with and without heart failure prior to transplant and stratified by eGFR*. eGFR, estimated glomerular filtration rate; HF, heart failure. *Heart failure defined by a diagnostic codes for heart failure in the primary coding position.

significantly improved following transplantation in these patients. While no patients were NYHA class I prior to transplant, 73% of patients deemed to be NYHA class I after transplant [18]. Nonetheless, our study demonstrates that HF still represents a common comorbidity among kidney transplant recipients, as we observed a high HF incidence rate (ranging from 1.9 to 6.8 per 100 person-years) and prevalence (ranging from 31.7% to 48.1%) following renal transplantation.

Heart failure results in a significant economic burden that appears to be increasing, as demonstrated by numerous cost of illness studies [23,24]. Data from a review of seven cost of illness studies across five countries (US, United Kingdom, Sweden, The Netherlands, and New Zealand) suggest that HF accounts for an estimated 1–2% of all healthcare expenditures [23]. Data from an additional 16 cost of illness studies demonstrated that total annual HF costs per patient in 2016 US dollars ranged from $868 in South Korea to $25 532 in Germany, with most US studies reporting annual HF costs exceeding $20 000 per patient [24]. Moreover, these cost of illness studies suggest that HF costs are increasing and that inpatient hospitalization costs are the largest HF cost component, accounting for 44% to 96% of direct healthcare costs [23,24]. Our data confirm these findings, demonstrating that HF was associated with a significant economic burden following kidney transplantation. Transplant providers should use caution utilizing donor grafts that are associated with eGFR <45 – such as high KDPI deceased donor kidneys – in patients with HF prior to transplant, as our data demonstrate the highest resource utilization in transplant recipients with pre-existing HF who have a peak eGFR <45 within 90 days of transplantation. Furthermore, healthcare systems caring for kidney transplant recipients would clearly benefit from interventions aimed at decreasing the economic burden of HF in these patients. Several initiatives have been demonstrated to reduce HF admissions in the general population, including structured telephone support programs, home visits, and multidisciplinary HF clinics [25]. These interventions offer promising opportunities to be tested in the kidney transplant population, as well.

We identified characteristics associated with HF-associated utilization (history of HF and other cardiac conditions, elevated blood pressure, low eGFR) and patients with these characteristics who may benefit the most from the aforementioned interventions. Lentine *et al.* [8] found similar characteristics were associated with a higher rate of HF postkidney transplant in an evaluation of 27 011 kidney transplant recipients from US Renal Data System (USRDS). These characteristics included MI (HR = 1.41), angina (HR = 1.34), arrhythmias

(HR = 1.25), PVD (HR = 1.19), and hypertension (HR = 1.27; $P < 0.05$ for all). Diabetes, age, and smoking, (which were selected for inclusion in our model but were not significantly associated with HF encounters) were associated with a 1.14–2.49 increased rate of HF in the study by Lentine and colleagues ($P < 0.05$ for all). Other factors significantly associated with HF in the analysis by Lentine and colleagues but not our own included anemia (HR = 1.24; $P < 0.05$) and obesity (HR = 1.43; $P < 0.05$). Importantly, those with HF had a higher rate of graft loss (HR = 2.78; $P < 0.05$) and death (HR = 2.72; $P < 0.05$), which further demonstrates the detriment of HF in kidney transplant recipients.

Our study has some limitations worthy of discussion. First, we utilized a statewide administrative database to identify HF charges and encounters and this database did not have important clinical data, namely NYHA class and EF [26–28]. We thus were not able to evaluate outcomes stratified by NYHA class or HF subtypes (i.e., HF with reduced EF and HF with preserved EF) [28]. We were also not able to identify HF etiology (e.g., cardiac ischemia) or assess the impact of cardiac evaluations on post-transplant HF. Similarly, we did not have medication data and could not determine the adequacy of anti-failure medications or if patients were receiving agents known to reduce ASCVD or HF hospitalizations (e.g., angiotensin-converting enzyme inhibitors, angiotensin receptor blockers, beta-blockers) [28]. Moreover, although the use of resource utilization data from our entire state and not just our institution is a strength of our analysis, it worth noting that our results may be most applicable to patients being cared for in South Carolina. Lastly, we could not evaluate HF mortality, as cause of death was not available in our dataset.

In conclusion, these results demonstrate a high HF prevalence among kidney transplant recipients and HF was associated with nearly double the healthcare costs. Several factors associated with HF encounters (history of HF and other cardiac conditions, elevated blood pressure, and a low eGFR) were identified. As HF results in a significant economic burden, healthcare systems caring for kidney transplant recipients would likely benefit from targeted interventions aimed at mitigating HF encounters.

Authorship

EW and DJT: participated in research design, writing, performance of the research, and data analysis. ZS: participated in writing and data analysis. JB: participated in research design, writing, and data analysis. TAM: participated in writing, performance of the research, and data analysis. MC and DAD: participated in research design, writing, and performance of the research.

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Conflicts of interest

The authors have no conflicts of interest germane to this manuscript.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Table S1. Number of patients with heart failure prior to and following kidney transplantation.

Table S2. Five most common reasons for encounters among patients with heart failure as identified by a diagnostic code in the secondary position.

Table S3. Incidence rate and prevalence of heart failure among kidney transplant recipients.

Table S4. Median cost per patient-year.

Table S5. Demographics of included kidney transplant recipients with and without HF encounters at 3 years.

Table S6. Median charges stratified by eGFR.

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