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Phenotype-Specific Cardiovascular Risk in Patients with Heart Failure Un-dergoing ERCP: A Nationwide Inpatient Sample Analysis

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Abstract

Background: *Heart failure (HF) is associated with increased peri-procedural risk, yet outcomes following endoscopic retrograde cholangiopancreatography (ERCP) across HF phenotypes remain poorly defined. Given the distinct pathophysiology of HF with preserved ejection fraction (HFpEF) and reduced ejection fraction (HFrEF), we compared post-ERCP outcomes between these groups using a national inpatient database.*

Methods: *We conducted a retrospective cohort study using the Nationwide Inpatient Sample from 2016–2020. Adult hospitalized patients with HF who underwent ERCP were identified using ICD-10 codes and stratified into HFpEF and HFrEF. The primary outcome was in-hospital mortality. Secondary outcomes included acute HF exacerbation, acute coronary syndrome (ACS), cardiac arrest, cardiogenic shock, intubation, acute respiratory failure, and acute kidney injury (AKI). Multivariable logistic regression adjusted for de-mographics, hospital characteristics, and comorbidities.*

Results: *Among 9,765 patients with HF undergoing ERCP, 5,848 had HFpEF and 3,917 had HFrEF. Patients with HFpEF were older (77.1 vs. 74.0 years) and more frequently female (55.6% vs. 34.8%) (both p<0.001). In-hospital mortality (3.9% vs. 4.4%, p=0.23) and length of stay were similar between groups. Compared with HFpEF, HFrEF was associated with higher odds of ACS (odds ratio (OR) 1.38, 95% CI 1.15–1.66), cardiogenic shock (OR 5.26, 95% CI 3.13–8.86), intubation (OR 1.26, 95% CI 1.07–1.47), and AKI (OR 1.24, 95% CI 1.13–1.35) (all p<0.01). No significant differences were observed in acute HF exacerbation, cardiac arrest, or acute respiratory failure. Hypertension and coronary artery disease were associated with lower odds of several adverse outcomes.*

Conclusions: *Patients with HFrEF undergoing ERCP experience higher rates of serious post-procedural complications despite similar in-hospital mortality, underscoring the need for HF phenotype–specific peri-procedural risk stratification.*

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Abbreviations

The following abbreviations are used in this manuscript:

ACS	Acute Coronary Syndrome
ADHF	Acute Decompensated Heart Failure
AKI	Acute Kidney Injury
AFIB	Atrial Fibrillation
AHRQ	Agency for Healthcare Research and Quality
CVA	Cerebrovascular Accident
COPD	Chronic Obstructive Pulmonary Disease
CKD	Chronic Kidney Disease
CIS	Confidence Intervals
CAD	Coronary Artery Disease
DM	Diabetes Mellitus
ERCP	Endoscopic Retrograde Cholangiopancreatography
GDMT	Guideline-Directed Medical Therapy
HCUP	Healthcare Cost and Utilization Project
HF	Heart Failure
HFPEF	Heart Failure with Preserved Ejection Fraction
HFREF	Heart Failure with Reduced Ejection Fraction
HTN	Hypertension
ICD-10	International Classification of Diseases, 10TH Edition
IRB	Institutional Review Board
NIS	Nationwide Inpatient Sample
NSTEMI	Non-ST-Elevation Myocardial Infarction
OR	Odds Ratio
PVD	Peripheral Vascular Disease
SPSS	Statistical Package for The Social Sciences
SD	Standard Deviation
STEMI	St-Elevation Myocardial Infarction

Introduction

HF is a complex clinical syndrome associated with substantial morbidity and mortality, impaired functional capacity, and significant healthcare expenditures Affecting over 64 million individuals worldwide, HF prevalence continues to rise due to population aging, advances in medical therapy, and improved survival following myocardial infarction [1-3]. As a result, an increasing number of patients with HF are undergoing invasive and minimally invasive medical procedures.

HF is a heterogeneous clinical syndrome encompassing distinct phenotypes with differing pathophysiology, comorbidity profiles, and responses to physiologic stress. HFpEF is characterized by diastolic dysfunction, increased myocardial stiffness, and elevated filling pressures, commonly in the setting of long-standing hypertension. In contrast, HFrEF is driven by systolic dysfunction, frequently related to ischemic heart disease and adverse ventricular remodeling [4]. These differences translate into different hemodynamic profiles and varying vulnerability to anesthesia-related hypotension, intravascular volume shifts, and systemic inflammatory stress.

Patients with HF are known to experience higher rates of adverse outcomes following surgical and procedural interventions, including increased peri-procedural morbidity and short-term mortality, largely due to reduced cardiopulmonary reserve and impaired tolerance of hemodynamic perturbations [5]. These risks are increasingly relevant as the prevalence of HF continues to rise, and procedural utilization expands.

Patients with HF undergoing ambulatory and inpatient procedures are known to experience worse outcomes, including higher postoperative complication rates and increased short-term mortality [5]. ERCP is a commonly performed minimally invasive procedure, with approximately 500,000 cases annually in the United States, and is associated with reported adverse event rates ranging from 4% to 10% [6].

As the utilization of ERCP increases, understanding procedural risk in patients with HF has become increasingly important. Prior investigations have examined ERCP outcomes in selected high-risk cohorts, most notably patients with chronic liver disease, demonstrating increased rates of post-procedural complications and resource utilization [7]. These studies underscore the importance of patient-specific risk stratification when considering ERCP in medically complex populations. However, patients with HF have not been a primary focus of ERCP-specific outcomes research.

Despite well-established phenotypic differences in HF pathophysiology and outcomes across other clinical settings, the existing literature has not evaluated whether post-ERCP outcomes differ between patients with HFpEF and HFrEF. This represents a critical gap in the literature, as extrapolation from non-ERCP procedural data may inadequately capture the physiologic stressors associated with ERCP. Addressing this gap is essential to inform phenotype-specific peri-procedural risk assessment and optimize multidisciplinary management strategies for patients with HF undergoing ERCP. Therefore, the present study aims to compare post-ERCP outcomes between patients with HFpEF and HFrEF using a nationwide inpatient database.

Materials and Methods

Overview of the Nationwide Inpatient Sample

The Nationwide Inpatient Sample (NIS), part of the Healthcare Cost and Utilization Project (HCUP) and maintained by the Agency for Healthcare Research and Quality (AHRQ), is a large administrative database representing hospitalizations across the United States. It contains information on patient demographics, diagnoses, performed procedures, and hospital-level characteristics. Because each hospital's admission is recorded as a separate entry, the same individual may appear more than once if multiple hospitalizations occur.

Data Source and Variables of Interest

Conditions relevant to this study were identified using codes from the International Classification of Diseases and Tenth Revision (ICD-10). Patients younger than 18 years of age were excluded from the analysis. Due to the de-identified nature of the NIS database, this study was deemed exempt from Institutional Review Board (IRB) review at Northwell Health.

Study Design

A retrospective cohort design was employed using data from the NIS database. Data from inpatient hospitalizations was obtained from the NIS database from years 2016 to 2020. Baseline risk factors were identified using ICD-10 codes. The study population included adult patients aged 18 years or older with a recorded diagnosis of HF. This manuscript was drafted according to the STROBE reporting guideline, and editing was completed according to the STROBE reporting checklist.

Patients were stratified into two groups: patients with HFpEF and patients with HFrEF.

Baseline characteristics such as age, sex, race and sociodemographic factors such as hospital location, insurance, median household income were collected. These variables are captured in the NIS as standardized administrative elements documented for each hospitalization. Multiple comorbidities were identified, such as hypertension (HTN), peripheral vascular disease (PVD), cerebrovascular accident (CVA), atrial fibrillation (Afib), coronary artery disease (CAD), chronic obstructive pulmonary disease (COPD), chronic kidney disease (CKD), diabetes mellitus (DM), dyslipidemia, obesity (defined as a body mass index > 30) and smoking. The list of ICD-10 codes used is provided in the supplemental table (**Appendix Table A**).

The primary outcome was mortality. Secondary outcomes were acute HF exacerbation, ACS, cardiac arrest, cardiogenic shock, acute respiratory failure, intubation, and AKI.

Statistical Analysis

The collected data were coded, tabulated, and statistically analyzed using IBM Statistical Package for Social Sciences (SPSS) Statistics (Version 30.0, IBM Corp., Chicago, USA). Qualitative data were summarized as counts and percentages, with comparisons performed using the Chi square test and Fisher's Exact test. Multivariate binary logistic regression was conducted to evaluate the independent association of HF with the outcomes, accounting for relevant covariates and demographic factors. Results are reported as odds ratios (ORs) with 95% confidence intervals (CIs). Statistical significance was defined as a p-value less than 0.05.

Results

The dataset revealed 9,765 patients with HF who underwent ERCP between 2016 and 2020: 5,848 patients with HFpEF and 3,917 patients with HFrEF were included in this study.

Demographic Characteristics

The mean age at admission for patients with HFpEF was 77.11 years of age (Standard Deviation (SD) = 10.7) compared to 73.96 years of age (SD = 12.56) in patients with HFrEF (p-value < 0.001). 55% of patients with HFpEF were females, compared to 34.8% of patients with HFrEF (p-value < 0.001). The racial distribution of patients was similar in both groups. Patients with HFpEF were majorly White (77%), followed by Black (8.5%), Hispanic (7.5%), Asian (3.5%), and Native American (0.6%). Patients with HFrEF were also majorly White (74.3%), followed by Black (10.3%), Hispanic (9%), Asian (2.8%) and Native American (0.7%).

Hospital locations were reviewed, with the most common location being East North Central (19.6%) for patients with HFpEF, and South Atlantic (18.8%) for patients with HFrEF. In addition, patient insurance coverage was also reviewed with government insurance comprising 90.3% of patients with HFpEF, compared to 86.7% of patients with HFrEF. Median household income displayed different trends in both groups. Most commonly, 26.2% of patients with HFpEF were in the 26-50th percentile group, compared to 27.8% of patients with HFpEF being in the 0-25th percentile group. Results are displayed in **Table 1.**

Table 1: Demographics of patients with HF and ERCP (n=9,765) HF (HFpEF: Heart Failure with preserved ejection Fraction, HFrEF: Heart Failure with reduced Ejection Fraction, SD: standard deviation).

	HFpEF (%) (n=5,848)	**HFrEF (%) (n=3,917)**	**p-value**
Age (Mean, SD)	77.11, 10.7	73.96, 12.56	<0.001
Sex: Female	3253 (55.6)	1363 (34.8)	<0.001
Race			0.001
White	4380 (77)	2825 (74.3)	
Black	486 (8.5)	390 (10.3)	
Hispanic	428 (7.5)	341 (9)	
Asian	201 (3.5)	105 (2.8)	
Native American	33 (0.6)	26 (0.7)	
Other	161 (2.8)	114 (3)	
Hospital location			<0.001
New England	457 (7.8)	225 (5.7)	
Mid-Atlantic	922 (15.8)	570 (14.5)	
East North Central	1149 (19.6)	642 (16.4)	
West North Central	474 (8.1)	326 (8.3)	
South Atlantic	865 (14.8)	738 (18.8)	
East South Central	308 (5.3)	245 (6.3)	
West South Central	518 (8.9)	390 (10)	
Mountain	282 (4.8)	227 (5.8)	
Pacific	874 (14.9)	556 (14.2)	

Insurance			<0.001
Government insurance	5279 (90.3)	3394 (86.7)	
Private insurance	504 (8.6)	464 (11.9)	
Uninsured and self-pay	65 (1.1)	57 (1.5)	
Median household income			0.012
0-25th percentile	1468 (25.5)	1076 (27.8)	
26-50th percentile	1511 (26.2)	1050 (27.1)	
51-75th percentile	1463 (25.4)	936 (24.2)	
76-100th percentile	1322 (22.9)	811 (20.9)	

In-Hospital Mortality and Length of Stay

Both groups had similar lengths of in-hospital stay, with patients with HFpEF being hospitalized on average for 9.46 days (SD =10.57) and patients with HFrEF for 9.53 days (SD= 10.48).

In addition, in-hospital mortality was also comparable among both groups. 3.9% of patients with HFpEF and 4.4% of patients with HFrEF passed away while being hospitalized (p-value = 0.23). Results are displayed in Table 2.

Table 2: Length of in-hospital stay and in-hospital mortality in patients with HF (HFpEF: Heart Failure with preserved ejection Fraction, HFrEF: Heart Failure with reduced Ejection Fraction, LOS: length of stay).

	HFpEF	HFrEF	p-value
LOS (mean, SD)	9.46, 10.57	9.53, 10.48	0.757
In-hospital mortality	228 (3.9)	172 (4.4)	0.23

Clinical Comorbidities

The most common comorbidity among both groups was hypertension, with 90.2% of patients with HFpEF and 85.6% of patients with HFrEF having hypertension.

Patients with HFpEF also commonly had DM (44.3%), CAD (41.9%), Dyslipidemia (41.1%), and CKD (39.3%). On the other hand, patients with HFrEF had CAD (56.9%), DM (44%), Dyslipidemia (41.4%), and CKD (39.4%). Both groups had a similar proportion of smokers (29.2% vs 28.5%). Results are displayed in Table 3.

Table 3: Comorbidities of patients with HF and ERCP (n=9,765) (HFpEF: Heart Failure with preserved ejection Fraction, HFrEF: Heart Failure with reduced Ejection Fraction, hypertension (HTN), peripheral vascular disease (PVD), cerebrovascular accident (CVA), atrial fibrillation (Afib), coronary artery disease (CAD), chronic obstructive pulmonary disease (COPD), chronic kidney disease (CKD), diabetes mellitus (DM)).

	HFpEF (%) (n=5,848)	HFrEF (%) (n=3,917)	p-value
HTN	5275 (90.2)	3355 (85.6)	<0.001
PVD	169 (2.9)	99 (2.5)	0.281
CVA	598 (10.2)	392 (10)	0.722
Afib	2141 (36.6)	1442 (36.8)	0.848
CAD	2449 (41.9)	2230 (56.9)	<0.001
COPD	1659 (28.4)	864 (22)	<0.001
CKD	2298 (39.3)	1546 (39.4)	0.874

DM	2591 (44.3)	1725 (44)	0.783
Obesity	1441 (24.6)	658 (16.8)	<0.001
Dyslipidemia	2406 (41.1)	1621 (41.4)	0.823
Smoking	1648 (28.2)	1116 (28.5)	0.746

Outcomes

Different multivariate binary logistic regressions were conducted to evaluate the association between HF and post-ERCP outcomes in hospitalized patients. The analysis adjusted for age, sex, race, hospital location, insurance, median household income and comorbidities.

Acute HF Exacerbation

There was no significant difference in the risk of post-ERCP acute heart failure exacerbation between patients with HFrEF and HFpEF (OR 0.92, $p = 0.104$). The crude incidence was 24.8% in HFrEF and 27.4% in HFpEF, corresponding to an absolute difference of −2.6%. Increasing age and female sex were associated with higher odds of acute HF exacerbation (OR 1.006, $p = 0.006$ and OR 1.193, $p < 0.001$, respectively). Hypertension and coronary artery disease were associated with lower odds of acute HF exacerbation; however, these findings should be interpreted with caution given the potential for residual confounding. Results are displayed in Table 4.

Table 4: Multivariable Logistic Regression Analysis of Acute HF Exacerbation Following ERCP in Patients with Heart Failure (OR: Odds Ratio, CI: Confidence Interval, HFrEF: Heart Failure with reduced Ejection Fraction, HTN: hypertension, CAD: coronary artery disease, COPD: chronic obstructive pulmonary disease).

	OR	95% Lower CI	95% Upper CI	p-value
HFrEF	0.92	0.832	1.017	0.104
Age	1.006	1.002	1.011	0.006
Female	1.193	1.083	1.314	<0.001
HTN	0.686	0.595	0.79	<0.001
CAD	0.836	0.759	0.921	<0.001
COPD	1.034	0.929	1.151	0.539
Obesity	0.991	0.881	1.115	0.879

Acute Coronary Syndrome

Patients with HFrEF had higher odds of developing ACS following ERCP compared to those with HFpEF (OR 1.38, $p < 0.001$). Hypertension was associated with lower odds of ACS (OR 0.724, $p = 0.013$), while coronary artery disease was associated with increased risk (OR 1.548, $p < 0.001$). These associations should be interpreted cautiously given the limitations of administrative data. Results are displayed in Table 5.

Table 5: Multivariable Logistic Regression Analysis of Acute Coronary Syndrome Following ERCP in Patients with HF (OR: Odds Ratio, CI: Confidence Interval, HFrEF: Heart Failure with reduced Ejection Fraction, HTN: hypertension, CAD: coronary artery disease, COPD: chronic obstructive pulmonary disease).

	OR	95% Lower CI	95% Upper CI	p-value
HFrEF	1.38	1.15	1.657	<0.001
Age	1.002	0.993	1.01	0.69
Female	1.197	0.999	1.436	0.052
HTN	0.724	0.561	0.935	0.013
CAD	1.548	1.291	1.857	<0.001

COPD	0.84	0.682	1.034	0.101
Obesity	0.797	0.629	1.01	0.061

Cardiac Arrest

The incidence of cardiac arrest was low in both groups (1.3% in HFrEF vs 0.8% in HFpEF). There was no statistically significant difference between groups after adjustment (OR 1.498, p = 0.071). Increasing age was associated with a slightly lower risk (OR 0.973, p = 0.001), though the clinical significance of this finding is uncertain. Results are displayed in Table 6.

Table 6: Multivariable Logistic Regression Analysis of Cardiac Arrest Following ERCP in Pa-tients with HF (OR: Odds Ratio, CI: Confidence Interval, HFrEF: Heart Failure with reduced Ejection Fraction, HTN: hyper-tension, CAD: coronary artery disease, COPD: chronic obstructive pulmonary disease).

	OR	95% Lower CI	95% Upper CI	p-value
HFrEF	1.498	0.966	2.321	0.071
Age	0.973	0.957	0.989	0.001
Female	0.751	0.484	1.164	0.201
HTN	0.763	0.431	1.349	0.352
CAD	0.81	0.522	1.257	0.347
COPD	0.985	0.597	1.624	0.952
Obesity	1.14	0.697	1.865	0.602

Cardiogenic Shock

Following ERCP, patients with HFrEF had over a fivefold increased odds of developing cardi-ogenic shock compared to those with HFpEF (OR 5.263, p < 0.001). However, the absolute in-cidence remained low, occurring in 1.8% of HFrEF patients compared to 0.4% of HFpEF patients, corresponding to an absolute risk increase of 1.4% (number needed to harm ≈ 71). Female sex was also associated with an increased risk of cardiogenic shock (OR 1.718, p = 0.015). These results are displayed in Table 7.

Table 7: Multivariable Logistic Regression Analysis of Cardiogenic Shock Following ERCP in Patients with HF (OR: Odds Ratio, CI: Confidence Interval, HFrEF: Heart Failure with reduced Ejection Fraction, HTN: hypertension, CAD: coronary artery disease, COPD: chronic obstructive pulmonary disease).

	OR	95% Lower CI	95% Upper CI	p-value
HFrEF	5.263	3.128	8.855	<0.001
Age	0.974	0.958	0.99	0.002
Female	1.718	1.112	2.654	0.015
HTN	0.845	0.478	1.491	0.561
CAD	0.713	0.455	1.118	0.14
COPD	0.987	0.586	1.661	0.96
Obesity	0.637	0.347	1.17	0.146

Intubation and Acute Respiratory Failure

Patients with HFrEF had higher odds of requiring intubation compared to those with HFpEF (OR 1.259, p = 0.004), corresponding to absolute rates of 9.6% versus 7.5%, respectively (absolute difference +2.1%). Acute respiratory failure occurred in 18.3% of HFrEF patients and 20.5% of HFpEF patients. Chronic obstructive pulmonary disease was associated with increased odds of both intubation (OR 1.259, p = 0.007) and acute res-piratory failure (OR 1.479, p < 0.001). Hy-pertension and coronary artery disease were associated with lower odds of these outcomes; however, these findings should be interpreted cautiously given potential residual confounding and dataset limitations. Results are displayed in Tables 8 and 9.

Table 8: Multivariable Logistic Regression Analysis of Intubation Following ERCP in Patients with HF (OR: Odds Ratio, CI: Confidence Interval, HFrEF: Heart Failure with reduced Ejection Fraction, HTN: hypertension, CAD: coronary artery disease, COPD: chronic obstructive pul-monary disease).

	OR	95% Lower CI	95% Upper CI	p-value
HFrEF	1.259	1.074	1.474	0.004
Age	0.985	0.978	0.991	<0.001
Female	0.874	0.748	1.021	0.09
HTN	0.604	0.493	0.739	<0.001
CAD	0.63	0.537	0.739	<0.001
COPD	1.259	1.064	1.489	0.007
Obesity	1.066	0.888	1.279	0.495

Table 9: Multivariable Logistic Regression Analysis of Acute Respiratory Failure Following ERCP in Patients with HF (OR: Odds Ratio, CI: Confidence Interval, HFrEF: Heart Failure with reduced Ejection Fraction, HTN: hypertension, CAD: coronary artery disease, COPD: chronic obstructive pulmonary disease).

	OR	95% Lower CI	95% Upper CI	p-value
HFrEF	0.919	0.822	1.028	0.141
Age	0.997	0.992	1.002	0.269
Female	1.003	0.901	1.117	0.957
HTN	0.632	0.543	0.734	<0.001
CAD	0.684	0.613	0.762	<0.001
COPD	1.479	1.319	1.658	<0.001
Obesity	1.043	0.917	1.185	0.522

AKI

Patients with HFrEF had higher odds of developing AKI following ERCP compared to those with HFpEF (OR 1.238, $p < 0.001$), with absolute rates of 44.3% and 39.4%, respectively (absolute difference +4.9%). Increasing age was associated with a slightly increased risk (OR 1.01 per year, $p < 0.001$), while female sex was associated with lower odds of AKI (OR 0.726, $p < 0.001$). Obesity was also associated with increased risk (OR 1.439, $p < 0.001$). Results are displayed in Table 10.

Table 10: Multivariable Logistic Regression Analysis of Acute Kidney Injury Following ERCP in Patients with HF (OR: Odds Ratio, CI: Confidence Interval, HFrEF: Heart Failure with re-duced Ejection Fraction, HTN: hypertension, CAD: coronary artery disease, COPD: chronic ob-structive pulmonary disease).

	OR	95% Lower CI	95% Upper CI	p-value
HFrEF	1.238	1.132	1.353	<0.001
Age	1.01	1.006	1.014	<0.001
Female	0.726	0.666	0.792	<0.001
HTN	1.094	0.957	1.252	0.189
CAD	0.867	0.795	0.945	0.001
COPD	0.921	0.837	1.015	0.096
Obesity	1.439	1.297	1.596	<0.001

Discussion

In this nationwide analysis, we demonstrate that heart failure phenotype is a key determinant of peri-procedural cardiovascular risk in patients undergoing ERCP. Specifically, patients with HFrEF exhibited significantly higher odds of cardiogenic shock, acute coronary syndrome (ACS), respiratory failure requiring mechanical ventilation, and acute kidney injury compared with HFpEF patients. These findings suggest that heart failure phenotype is a critical modifier of pe-ri-procedural risk.

Phenotype-Specific Cardiovascular Vulnerability

The increased incidence of cardiogenic shock, ACS, and need for mechanical ventilation ob-served in patients with HFrEF likely reflects impaired cardiovascular reserve and reduced ability tolerate peri-procedural stress. HFrEF is characterized by diminished systolic function, chronic neurohormonal activation, and a high prevalence of underlying coronary artery disease, all of which limit the myocardium's capacity to adapt to acute hemodynamic perturbations.

Procedural stress associated with ERCP, including sedation, transient hypoxia, sympathetic ac-tivation, and fluid shifts, may precipitate a mismatch between myocardial oxygen supply and demand. This is particularly pronounced in HFrEF patients, in whom reduced cardiac output and impaired contractile reserve predispose to ischemia, hemodynamic instability, and end-organ hypoperfusion [8–10].

In contrast, while HFpEF patients remain susceptible to peri-procedural complications due to diastolic dysfunction and increased ventricular stiffness, they may better preserve cardiac output under stress, resulting in comparatively lower, though still elevated risk.

Peri-Procedural Hemodynamics and Cardiovascular Stress

ERCP represents a physiologically significant stressor, particularly in patients with underlying cardiac dysfunction. Sedation-related vasodilation, fluctuations in preload and afterload, and procedural stimulation can substantially alter cardiovascular dynamics. In HFrEF patients, re-ductions in systemic vascular resistance and preload may precipitate hypotension and decreased organ perfusion, increasing the risk of cardiogenic shock [9,10].

Additionally, the pro-inflammatory and pro-thrombotic state associated with procedural stress, including increased heart rate, blood pressure variability, platelet activation, and reduced fibri-nolysis, may contribute to plaque instability and coronary thrombosis [8,9]. This likely explains the significantly higher rates of post-procedural ACS observed in HFrEF patients in our study. Given the higher burden of ischemic heart disease in this population, even transient hemody-namic stressors may trigger clinically significant myocardial ischemia.

Cardiopulmonary Interactions and Risk of Respiratory Failure

Patients with HFrEF demonstrated significantly higher odds of requiring endotracheal intubation and invasive mechanical ventilation following ERCP compared with HFpEF patients. While pulmonary comorbidities such as COPD contribute to respiratory risk, our findings suggest that differences in baseline lung disease alone do not explain this disparity, as COPD was more prevalent among HFpEF patients in our cohort.

Rather, the increased risk of respiratory failure in HFrEF can reflect impaired cardiopulmonary reserve, heightened sensitivity to volume shifts, and limited tolerance to anesthesia-related he-modynamic changes. Reduced left ventricular function may predispose to pulmonary congestion and impaired gas exchange, particularly in the setting of procedural stress. These findings are consistent with prior literature demonstrating increased need for mechanical ventilation and as-sociated mortality risk in HFrEF populations [11].

Cardiorenal Interactions and Risk of Acute Kidney Injury

Our study also demonstrated an increased risk of acute kidney injury (AKI) in patients with HFrEF. This finding is consistent with the well-established cardiorenal syndrome observed in patients with reduced ejection fractions. Decreased cardiac output may lead to reduced renal perfusion, while elevated central venous pressures contribute to renal congestion, both of which impair kidney function [10,12,13].

Peri-procedural factors such as hypotension, volume shifts, and systemic stress may further ex-acerbate renal hypoperfusion, increasing susceptibility to AKI [14]. Prior studies have similarly demonstrated that more severe reductions in ejection fraction are associated with a higher risk of renal dysfunction [15]. These findings highlight the importance of careful hemodynamic man-agement and renal monitoring in HFrEF patients undergoing ERCP.

Interpretation of Paradoxical Associations

An unexpected finding in our study was the apparent protective association of CAD and hyper-tension with several adverse outcomes. Similar paradoxical relationships have been reported in prior literature. For example, Hoffman et al. demonstrated lower mortality following acute my-ocardial infarction among patients with a history of hypertension [16]. Additionally, analyses of administrative datasets have shown that certain comorbidities may appear protective due to coding practices, selection bias, or residual confounding rather than a true biologic effect [17].

It is also possible that patients with established cardiovascular disease are more likely to receive guideline-directed medical therapies, which may confer some degree of cardio protection in the peri-procedural setting. However, given the lack of medication data within the NIS, these find-ings should be interpreted with caution and are likely reflective of underlying limitations of administrative data rather than true protective effects.

Clinical Implications

These findings have important implications for clinical practice. Pre-procedural identification of heart failure phenotype may enhance risk stratification and inform peri-procedural management strategies. Patients with HFrEF may benefit from closer hemodynamic monitoring, individual-ized anesthesia approaches, and consideration of higher-acuity post-procedural care settings such as step-down or intensive care units.

Furthermore, a multidisciplinary approach involving cardiology, anesthesia, and critical care teams may be particularly important in high-risk patients. Early recognition of cardiovascular vulnerability may allow targeted interventions to mitigate complications and improve outcomes.

Limitations

This study highlights an important gap in existing knowledge and emphasizes the need for a targeted approach to address these challenges and ultimately improve outcomes in this patient population. The strengths of this study include the large sample size, the use of nationally rep-resentative data, and the comprehensive evaluation of associated risk factors.

However, several limitations are present. The cross-sectional nature of the study limits the ability to determine temporal relationships. Moreover, the database does not provide granular infor-mation regarding disease activity. This includes possible misclassification of HF phenotypes when relying on ICD-10 codes, the absence of medication and echocardiographic information, the absence of indications for ERCP and limited assessment of disease severity. The inherent limitation of the NIS database is that the NIS records hospitalizations and might not accurately reflect the entire population of patients with HF. The reliance on ICD-10 codes for acquiring variables of interest depends on provider accuracy and is vulnerable to documentation errors. Additionally, because the NIS database records hospitalizations as separate events, the same patient may be represented more than once; however, given the large sample size, this limitation is unlikely to substantially influence the overall findings.

An important limitation of this study is the inability to adjust for clinical disease severity. Ad-ministrative datasets rely on ICD-10 coding and do not capture detailed physiologic parameters, laboratory values, imaging findings, or endoscopic severity grading. Therefore, residual con-founding related to unmeasured disease severity may persist.

Future investigations should focus on prospective longitudinal studies aimed at identifying modifiable risk factors that could improve patient outcomes and guide management strategies.

Conclusion

In summary, our study demonstrates differences in post-ERCP outcomes across heart failure phenotypes. Patients with HFrEF had a higher risk of selected complications, including acute coronary syndrome and cardiogenic shock, compared with other HF groups. However, there was no significant difference in in in-hospital mortality between groups.

The observed inverse associations between comorbid conditions such as hypertension and cor-onary artery disease and certain complications should be interpreted with caution, as these findings may reflect residual confounding or methodological factors inherent to administrative datasets rather than a true protective effect.

Overall, these findings emphasize the importance of thorough pre-procedural risk assessment in patients with heart failure undergoing ERCP, while highlighting the need for further studies with more detailed clinical data to better characterize risk and underlying mechanisms.

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