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Impact of Heart Failure on Patients Undergoing Major Noncardiac Surgery

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Background: **Changes in the demographics and epidemiology of patients with cardiovascular comorbidities who undergo major noncardiac surgery require an updated assessment of which patients are at greater risk of mortality or readmission. The authors evaluated short-term outcomes among patients with heart failure, coronary artery disease (CAD), or neither who underwent major noncardiac surgery.**

Methods: **Patients were aged 65 and older, had Medicare fee-for-service coverage, and underwent 1 of 13 major noncardiac procedures from 2000 through 2004, excluding patients with end-stage renal disease and patients who did not have at least 1 yr of Medicare fee-for-service eligibility before surgery. Main outcome measures were operative mortality and 30-day all-cause readmission.**

Results: **Of 159,327 procedures, 18% were performed in patients with heart failure and 34% were performed in patients with CAD. Adjusted hazard ratios of mortality and readmission for patients with heart failure, compared with patients with neither heart failure nor CAD, were 1.63 (95% confidence interval, 1.52–1.74) and 1.51 (95% confidence interval, 1.45–1.58), respectively. Adjusted hazard ratios of mortality and readmission for patients with CAD, compared with patients with neither heart failure nor CAD, were 1.08 (95% confidence interval, 1.01–1.16) and 1.16 (95% confidence interval, 1.12–1.20), respectively. These effects were statistically significant. Patients with heart failure were at significantly higher risk for both outcomes compared with patients with CAD.**

Conclusions: **Elderly patients with heart failure who undergo major surgical procedures have substantially higher risks of operative mortality and hospital readmission than other patients, including those with coronary disease, admitted for the same procedures. Improvements in perioperative care are needed for the growing population of patients with heart failure undergoing major noncardiac surgery.**

This article is accompanied by an Editorial View. Please see: Fleisher LA: Implications of preoperative heart failure: The next frontier in perioperative medicine? ANESTHESIOLOGY 2008; 108:551–2.

ADVANCES in preoperative risk stratification, perioperative management, and surgery have led to substantial improvements in outcomes among patients undergoing major noncardiac surgical procedures over the past 30 yr. Previous research has outlined important steps for evaluating patients at risk for cardiovascular complications, especially patients with known coronary artery disease (CAD) and patients at risk for ischemic events.[1,2] Professional guidelines inform strategies for preventing cardiovascular events, largely based on evaluation for ischemia in high-risk patients and use of β-blockers in patients at moderate risk for cardiovascular events.[3–5] Great strides have been made for patients with coronary disease undergoing noncardiac procedures.

However, three concurrent trends point to the need for a critical evaluation of outcomes after major noncardiac procedures among patients with heart failure. First, the number of operations performed is expected to increase. More than 10 million major noncardiac surgical procedures are performed each year, including more than 4 million procedures in patients aged 65 yr and older.# In the next 10–20 yr, it is estimated that the number of procedures will increase by 25%. Second, over the same time period, the elderly population will increase by more than 50%.[6]** Finally, the prevalence of heart failure in the general population continues to grow.[7–9] These trends combine to predict a growth in surgical volume among patients with heart failure, making major noncardiac surgery in this population an important public health concern.[8,10]

Previous studies have found that heart failure confers a significant risk of morbidity and mortality after noncardiac surgery. It is not known whether recent improvements in perioperative management have translated into similar improvements in the outcomes of patients with heart failure relative to other patients.[11–15] As a result, the relative risk that patients with heart failure face compared with patients with CAD or patients with neither heart failure nor CAD is unclear. We hypothesized that heart failure continues to confer excess risk rel-

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http://www.cdc.gov/nchs/fastats/insurg.htm. Accessed October 26, 2007.

** http://www.census.gov/population/www/. Accessed October 26, 2007.

ative to other conditions, including CAD, across a spectrum of 13 common and important major noncardiac procedures.

Materials and Methods

Data Sources

Data were obtained from the Medicare 5% standard analytic files, comprising longitudinal inpatient, outpatient, and physician claims for a nationally representative 5% sample of the Medicare population. We used inpatient claims to identify and characterize procedures and to identify postdischarge readmissions. We used diagnosis codes from all claims to identify comorbidities, and we used the Medicare denominator file to determine each patient's participation in fee-for-service Medicare and to gather demographic and mortality information. American Hospital Association survey data were used to determine whether hospitals were members of the Council of Teaching Hospitals and Health Systems. The institutional review board of the Duke University Health System (Durham, North Carolina) approved this study.

Participants and Procedures

Patients aged 65 and older with Medicare fee-for-service coverage who underwent major noncardiac surgery between January 1, 2000, and December 31, 2004, were eligible for the study. We excluded patients with end-stage renal disease and patients who did not have at least 1 yr of Medicare fee-for-service eligibility before surgery. We used claims from this previous eligibility period to capture data on comorbidities present at the time of surgery, which we used for risk adjustment.

We studied 13 major noncardiac procedures commonly performed in elderly patients. These included selected vascular procedures (*i.e.*, carotid endarterectomy, lower extremity bypass, and open abdominal aortic aneurysm repair); orthopedic procedures (*i.e.*, hip replacement, knee replacement, spinal fusion, and above-knee and below-knee amputation); abdominal procedures (*i.e.*, open and laparoscopic cholecystectomy); and cancer resections for colon, abdominal, and pulmonary cancers. As in previous studies,[16,17] claims for cancer resections had to be accompanied by appropriate cancer diagnoses. The appendix shows the *International Classification of Diseases*, 9th Revision, Clinical Modification†† (ICD-9-CM), codes for the procedures included in the analysis (appendix).

For each patient, we selected the first procedure performed during the study window for inclusion in the analysis, and we defined the inpatient claim corresponding to the procedure as the index hospitalization. Details of the index hospitalization, including admission source and urgency, served as the basis for risk adjustment.

†† http://www.cdc.gov/nchs/icd9.htm. Accessed October 26, 2007.

Disease Groups and Comorbidities

To evaluate outcomes by disease group, we classified patients as having heart failure, CAD, or neither at the time of the procedure. We avoided misclassifying preexisting conditions as surgical complications by only considering diagnoses in claims that occurred before the index hospitalization.

Patients were determined to have heart failure if they had a heart failure diagnosis (ICD-9-CM code 428, 402.x1, 404.x1, or 404.x3) on any inpatient claim or on three or more outpatient or physician claims (within 20 months) before the date of the procedure. We used data back to 1991 to determine heart failure status. We also subdivided the heart failure group into patients with CAD and patients without CAD to determine whether there was additional risk associated with having both conditions. Patients were determined to have CAD if any claim before the date of the procedure included a diagnosis of CAD (ICD-9-CM code 410.x, 411.x, 412, 413, or 414). We used data back to 1999 to make this determination. Patients without heart failure or CAD at the time of surgery constituted a comparison group.

Other comorbidities present at the time of surgery were also captured. Using claims during the year before the index hospitalization, we ascertained whether patients had diabetes mellitus, history of stroke, hypertension, chronic obstructive pulmonary disorder, renal disease, peripheral vascular disease, or dementia. These comorbidities were defined using ICD-9-CM codes validated by Quan *et al.*[18] and Birman-Deych *et al.*[19] Clinical factors in the Revised Cardiac Risk Index[13] correspond to the following comorbid conditions in this study: heart failure, CAD, diabetes mellitus, history of stroke, and renal disease.

Outcome Measures

The main outcome measures in this study were operative mortality and 30-day all-cause readmission. Operative mortality was defined as death before discharge or as death after discharge but within 30 days of the procedure. For patients who were discharged alive, readmission was defined as a subsequent inpatient admission for any reason within 30 days of discharge. We did not include transfers or subsequent admissions for rehabilitation.

Statistical Analysis

We report demographic characteristics, comorbidities, and admission and procedure characteristics, and unadjusted outcomes for each disease group using numbers and percentages for categorical variables and means and SDs for continuous variables. For categorical variables, we tested for differences between disease groups using Cochran-Mantel-Haenszel general association tests, controlling for type of procedure. For continuous variables, we tested for differences using Cochran-Mantel-Haenszel mean score tests, again controlling for type of procedure.

Table 1. Frequency of Procedures and Distribution of Disease Groups within Procedure

Procedure	Overall, n	Heart Failure	Coronary Artery Disease	Comparison Group
All procedures	159,327	29,356 (18.4)	54,822 (34.4)	75,149 (47.2)
Above-knee amputation	2,809	1,469 (52.3)	715 (25.5)	625 (22.2)
Below-knee amputation	2,476	1,183 (47.8)	685 (27.7)	608 (24.6)
Carotid endarterectomy	16,834	3,418 (20.3)	8,746 (52.0)	4,670 (27.7)
Colon cancer resection	10,541	1,957 (18.6)	3,052 (29.0)	5,532 (52.5)
Hip replacement	37,899	7,261 (19.2)	10,838 (28.6)	19,800 (52.2)
Knee replacement	36,449	3,920 (10.8)	11,537 (31.7)	20,992 (57.6)
Laparoscopic cholecystectomy	17,830	3,710 (20.8)	5,932 (33.3)	8,188 (45.9)
Lower extremity bypass	7,305	2,325 (31.8)	3,059 (41.9)	1,921 (26.3)
Open abdominal aortic aneurysm repair	3,411	564 (16.5)	1,904 (55.8)	943 (27.6)
Open cholecystectomy	7,724	1,702 (22.0)	2,434 (31.5)	3,588 (46.5)
Other abdominal cancer resections	4,407	603 (13.7)	1,632 (37.0)	2,172 (49.3)
Pulmonary cancer resections	2,927	334 (11.4)	1,175 (40.1)	1,418 (48.4)
Spinal fusion	8,715	910 (10.4)	3,113 (35.7)	4,692 (53.8)

Values are expressed as number (percentage) unless otherwise indicated.

We developed regression models to estimate the effects of heart failure and CAD on operative mortality and 30-day readmission. We modeled both outcomes using a Cox proportional hazards model. To account for clustering of procedures by hospital, we used the method described by Lin and Wei[20] to calculate robust standard errors. We report unadjusted hazard ratios with 95% confidence intervals (CIs) from models that included indicators for disease group and type of procedure. From models that also included age, sex, race, admission characteristics, comorbidities, and hospital teaching status, we report adjusted hazard ratios with 95% CIs. Confounders were selected based on previous work in this area.[14]

We performed several additional analyses. First, we repeated the models described above after dividing the heart failure population into two groups, those with CAD and those without. This allowed us to determine whether there was additional risk associated with having both heart failure and CAD, compared with having heart failure alone. We tested for differences in risk by comparing the parameter estimates for each heart failure group in these models using Wald chi-square tests. Second, we repeated the models described above including only patients undergoing elective procedures. By restricting the analysis to elective admissions, we addressed the possibility that patients with heart failure were referred to surgery later and at more advanced disease states than were patients without heart failure for similar procedures. Third, in an attempt to limit the impact of other important risk factors on our results, we estimated the models after excluding patients with known diabetes mellitus, history of stroke, or renal disease. These are the other clinical risk factors, beyond CAD and heart failure, in the Revised Cardiac Risk Index.[13] Finally, to compare observed mortality and readmission rates with those for similar patients not undergoing noncardiac surgery, we calculated 30-day mortality and hospital admission rates for all elderly Medicare beneficiaries in the 5% national sample who were alive on January 1, 2002. Determination of heart failure and CAD status in this group was the same as that described for the study cohort.

We used SAS version 9.1.3 for all analyses (SAS Institute Inc., Cary, NC).

Results

A total of 159,327 eligible patients underwent one of the selected major noncardiac procedures from 2000 through 2004. Hip and knee replacements were the most common procedures; above-knee and below-knee amputations were the least common. Table 1 shows the frequency of all procedures and their distributions within disease groups. Overall, 18.4% of the procedures were performed in patients with heart failure, 34.4% were performed in patients with CAD, and 47.2% were performed in patients with neither condition. However, some procedures had substantially different distributions.

Patients with heart failure were slightly older and were more likely to be nonwhite than patients in the CAD and comparison groups (table 2). They also were more likely to have been admitted from a skilled nursing facility or for urgent or emergent reasons. Aside from CAD, every comorbidity was more prevalent in the heart failure group than in the other groups. Patients with CAD were more likely than patients in the other groups to be men and to have been admitted to a teaching hospital. In terms of age, race, and admission urgency, however, the CAD group was similar to the comparison group. This was not true for comorbidities. Although patients in the CAD group were not as sick as patients in the heart failure group, every reported comorbidity was more prevalent in the CAD group than in the comparison group. Of patients in the heart failure group, 55% had three or more of the clinical risk factors in the Revised Cardiac Risk Index,[13] compared with 10% of patients in

Table 2. Baseline Characteristics of the Study Population by Disease Group

Characteristic	Heart Failure (n = 29,356)	Coronary Artery Disease (n = 54,822)	Comparison Group (n = 75,149)	*P* Value
Age, mean ± SD, yr	79.4 ± 7.0	76.3 ± 6.5	75.6 ± 6.7	<0.001
Male	12,321 (42.0)	26,744 (48.8)	25,851 (34.4)	<0.001
Race				<0.001
Black	2,484 (8.5)	2,828 (5.2)	4,208 (5.6)	
White	25,933 (88.3)	50,259 (91.7)	68,904 (91.7)	
Other	939 (3.2)	1,735 (3.2)	2,037 (2.7)	
Teaching hospital	4,926 (16.8)	10,786 (19.7)	12,223 (16.3)	<0.001
Admitted from a skilled nursing facility	426 (1.5)	244 (0.4)	282 (0.4)	<0.001
Surgery admission type				<0.001
Urgent	5,651 (19.2)	7,550 (13.8)	10,929 (14.5)	
Emergent	8,797 (30.0)	10,414 (19.0)	14,029 (18.7)	
Comorbidities				
Chronic obstructive pulmonary disease	13,276 (45.2)	17,056 (31.1)	16,699 (22.2)	<0.001
Coronary artery disease	23,771 (81.0)	54,822 (100.0)	0 (0.0)	<0.001
Dementia	2,685 (9.1)	2,792 (5.1)	3,108 (4.1)	<0.001
Diabetes mellitus	12,740 (43.4)	16,747 (30.5)	14,747 (19.6)	<0.001
History of stroke	7,887 (26.9)	11,794 (21.5)	8,531 (11.4)	<0.001
Hypertension	25,367 (86.4)	45,175 (82.4)	50,215 (66.8)	<0.001
Peripheral vascular disease	13,584 (46.3)	19,891 (36.3)	13,456 (17.9)	<0.001
Renal disease	4,450 (15.2)	2,861 (5.2)	1,994 (2.7)	<0.001

Values are expressed as number (percentage) unless otherwise indicated.

the CAD group and less than 1% of patients in the comparison group. These are patients described as high risk in the latest guidelines.[2]

There were significant differences in operative mortality by disease group (table 3). Overall mortality among patients with heart failure was 8.0%, more than double the mortality among patients with CAD and more than triple the mortality in the comparison group. Although overall mortality was certainly influenced by the procedure distributions within each group, we observed excess mortality in the heart failure group for every procedure, from relatively low-risk procedures such as laparoscopic chole-

Table 3. Outcomes by Disease Group, Overall, and for Each Procedure

Outcome	Heart Failure	Coronary Artery Disease	Comparison Group	*P* Value
Operative mortality	8.0	3.1	2.4	<0.001
Above-knee amputation	25.8	18.0	16.0	<0.001
Below-knee amputation	12.8	10.4	7.2	0.001
Carotid endarterectomy	2.5	1.2	0.9	<0.001
Colon cancer resection	11.9	6.3	5.4	<0.001
Hip replacement	8.4	3.9	2.8	<0.001
Knee replacement	0.9	0.4	0.3	<0.001
Laparoscopic cholecystectomy	5.6	2.1	1.8	<0.001
Lower extremity bypass	8.1	3.7	4.1	<0.001
Open abdominal aortic aneurysm repair	10.3	5.8	4.8	<0.001
Open cholecystectomy	15.9	7.7	6.9	<0.001
Other abdominal cancer resections	11.8	4.3	4.9	<0.001
Pulmonary cancer resections	10.2	6.0	5.1	0.003
Spinal fusion	3.8	2.1	1.3	<0.001
30-Day readmission	17.1	10.8	8.1	<0.001
Above-knee amputation	25.2	21.6	18.9	0.008
Below-knee amputation	24.1	23.4	19.9	0.143
Carotid endarterectomy	15.2	10.8	8.7	<0.001
Colon cancer resection	18.0	13.2	10.5	<0.001
Hip replacement	16.6	10.3	8.0	<0.001
Knee replacement	9.9	6.2	4.7	<0.001
Laparoscopic cholecystectomy	16.4	10.1	8.4	<0.001
Lower extremity bypass	27.2	18.2	16.2	<0.001
Open abdominal aortic aneurysm repair	14.8	11.3	10.4	0.040
Open cholecystectomy	17.3	12.6	11.8	<0.001
Other abdominal cancer resections	20.0	17.4	13.3	<0.001
Pulmonary cancer resections	17.4	15.5	11.3	0.001
Spinal fusion	13.3	9.4	7.7	<0.001

Values are expressed as the percentage of procedures with the event.

cystectomy to high-risk procedures such as above-knee amputation. Table 3 shows the observed mortality for each procedure by disease group.

Table 3 also shows 30-day all-cause readmission rates. Of the 159,327 patients in the study, 155,808 (97.8%) were discharged alive from the index hospitalization and were included in the readmission analysis. Readmission rates were 17.1% for patients with heart failure, 10.8% for patients with CAD, and 8.1% for patients in the comparison group. Compared with the mortality rates, procedure-specific readmission rates were less variable between disease groups. However, similar to the mortality rates, readmission rates for every procedure were higher among patients with heart failure than among other patients.

Regression analysis for both outcomes confirmed that the effect of heart failure on mortality was robust and significant, even after controlling for potential confounders (table 4). Adjusting only for type of procedure, the risk of operative mortality among patients with heart failure was two and a half times the risk among patients in the comparison group. Controlling for demographic and admission characteristics and comorbidities, the risk of mortality among patients with heart failure was 63% higher. Similarly, adjusting only for type of procedure, the hazard of 30-day readmission among patients with heart failure was 90% higher than among patients in the comparison group. After controlling for potential confounders, patients with heart failure were 51% more likely than patients in the comparison group to be readmitted. Patients with heart failure also had significantly higher risks of operative mortality and 30-day readmission when compared with patients with CAD. Controlling for confounders, the risk of operative mortality was 51% higher among patients with heart failure than among patients with CAD, and the hazard of 30-day readmission was 30% higher. The effect of CAD on both outcomes was also significant, although the magnitude of the effect was not as strong as that for heart failure.

Table 4. Regression Models of Outcomes for the Overall Study Population

Effect	Unadjusted*	Adjusted†
Operative mortality		
Heart failure group *vs.* comparison group	2.53 (2.38–2.70)	1.63 (1.52–1.74)
Coronary artery disease group *vs.* comparison group	1.26 (1.18–1.34)	1.08 (1.01–1.16)
Heart failure group *vs.* coronary artery disease group	2.02 (1.89–2.15)	1.51 (1.41–1.61)
Age (5-yr increment)	—	1.30 (1.28–1.33)
Race, nonwhite	—	0.85 (0.78–0.92)
Male	—	1.34 (1.27–1.42)
Teaching hospital	—	0.95 (0.88–1.03)
Admitted from a skilled nursing facility	—	1.17 (0.97–1.41)
Urgent admission	—	2.07 (1.92–2.24)
Emergent admission	—	2.64 (2.46–2.83)
Diabetes mellitus	—	1.00 (0.95–1.07)
History of stroke	—	1.23 (1.16–1.31)
Hypertension	—	0.87 (0.82–0.93)
Chronic obstructive pulmonary disease	—	1.35 (1.28–1.42)
Renal disease	—	1.62 (1.51–1.74)
Peripheral vascular disease	—	1.22 (1.14–1.30)
Dementia	—	1.48 (1.38–1.60)
30-Day readmission		
Heart failure group *vs.* comparison group	1.90 (1.83–1.98)	1.51 (1.45–1.58)
Coronary artery disease group *vs.* comparison group	1.27 (1.22–1.32)	1.16 (1.12–1.20)
Heart failure group *vs.* coronary artery disease group	1.50 (1.44–1.56)	1.30 (1.25–1.36)
Age (5-yr increment)	—	1.08 (1.07–1.10)
Race, nonwhite	—	1.06 (1.01–1.11)
Male	—	1.10 (1.06–1.13)
Teaching hospital	—	1.06 (1.01–1.11)
Admitted from a skilled nursing facility	—	1.28 (1.10–1.50)
Urgent admission	—	1.30 (1.24–1.36)
Emergent admission	—	1.42 (1.36–1.48)
Diabetes mellitus	—	1.13 (1.09–1.17)
History of stroke	—	1.14 (1.10–1.19)
Hypertension	—	1.05 (1.01–1.10)
Chronic obstructive pulmonary disease	—	1.19 (1.15–1.23)
Renal disease	—	1.23 (1.17–1.30)
Peripheral vascular disease	—	1.13 (1.09–1.18)
Dementia	—	1.27 (1.20–1.35)

Values are expressed as hazard ratio (95% confidence interval).

* Unadjusted model includes indicators for disease group and type of procedure. † Adjusted model includes indicators for disease group, type of procedure, age, sex, race, admission characteristics, comorbidities, and hospital teaching status.

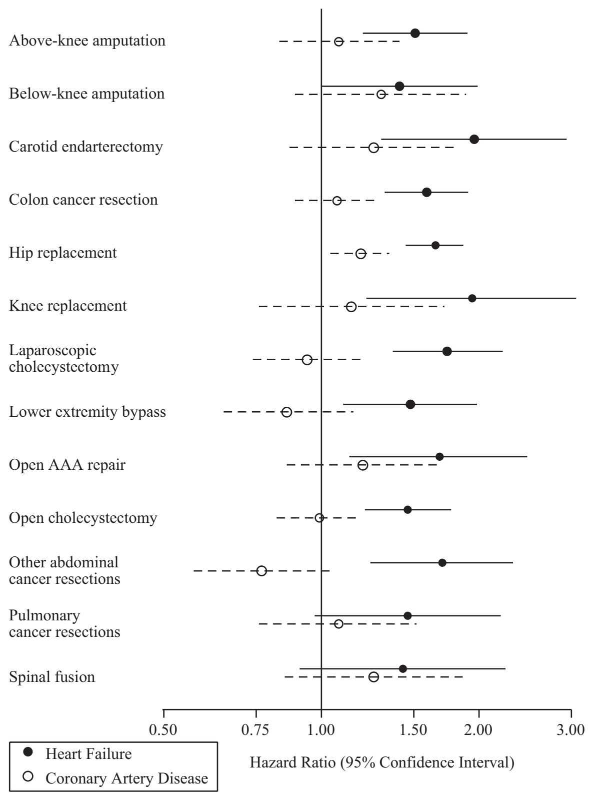

Fig. 1. Effects of heart failure and coronary artery disease, compared to neither, on operative mortality by procedure. Procedure-specific models include indicators for disease group, age, sex, race, admission characteristics, comorbidities, and hospital teaching status. AAA = abdominal aortic aneurysm.

Figure 1 shows the results of procedure-specific operative mortality regression models that control for demographic and admission characteristics and comorbidities. The adjusted effect of heart failure, with the comparison group as the reference, was consistent across procedures and was statistically significant for all but two procedures: spinal fusion and pulmonary cancer resections. The risk of operative mortality due to heart failure was also consistently higher than the risk due to CAD.

We reran the regression models after dividing the heart failure group into two subgroups: patients with CAD and patients without CAD (table 5). For operative mortality, there was no significant difference between the groups in either the unadjusted or the adjusted models. For 30-day readmission, adjusting only for procedure type, patients with both heart failure and CAD were significantly more likely to be readmitted than patients with heart failure alone; however, after adding other confounders to the model, this difference disappeared.

We also limited the analysis to the 64% of patients who had an elective admission. Controlling for confounders, the risk of mortality among patients with an elective admission in the heart failure group was 87% higher than in the comparison group (hazard ratio, 1.87; 95% CI, 1.64–2.12). This effect was stronger than that observed in the overall study population. The mortality risk among patients with an elective admission in the CAD group was not significantly different than in the comparison group (hazard ratio, 1.11; 95% CI, 0.98–1.25). In the 30-day readmission model, the magnitude and statistical significance of the effects of heart failure and CAD, controlling for potential confounders, were essentially unchanged, compared with the results in the overall study population.

Among the 93,689 patients without diabetes mellitus, history of stroke, or renal disease, the adjusted risk of mortality (hazard ratio, 1.65; 95% CI, 1.50–1.82) and the adjusted risk of readmission (hazard ratio, 1.52; 95% CI, 1.42–1.61) due to heart failure remained substantial and significant. Similarly, the adjusted risk of mortality (hazard ratio, 1.15; 95% CI, 1.05–1.27) and the adjusted risk of readmission (hazard ratio, 1.18; 95% CI, 1.12–1.24) due to CAD were similar to those found in the main analysis.

Average 30-day mortality was 1.6% in the general Medicare population of patients with heart failure, 0.5% for patients with CAD, and 0.3% for patients with neither condition. The 30-day inpatient admission rate was 9.9% for elderly patients with heart failure, 3.8% for patients with CAD, and 1.6% for patients with neither condition. Using the average mortality observed in this study, the excess mortality above these rates was 6.4% for the heart failure group, 2.6% for the CAD group, and 2.1% for the

Table 5. Regression Models of Operative Mortality and 30-Day Readmission for Heart Failure Groups with or without Coronary Artery Disease

Effect	Unadjusted*	Adjusted†
Operative mortality		
Heart failure group with coronary artery disease *vs.* comparison group	2.52 (2.36–2.70)	1.60 (1.49–1.72)
Heart failure group without coronary artery disease *vs.* comparison group	2.57 (2.33–2.85)	1.74 (1.57–1.92)
P value‡	0.69	0.11
30-Day readmission		
Heart failure group with coronary artery disease *vs.* comparison group	1.94 (1.86–2.02)	1.53 (1.46–1.60)
Heart failure group without coronary artery disease *vs.* comparison group	1.72 (1.59–1.85)	1.43 (1.33–1.54)
P value‡	0.001	0.08

Values are expressed as hazard ratio (95% confidence interval) unless otherwise indicated.

* Unadjusted model includes indicators for disease group and type of procedure. † Adjusted model includes indicators for disease group, type of procedure, age, sex, race, admission characteristics, comorbidities, and hospital teaching status. ‡ *P* value tests for difference in effect magnitude between heart failure groups.

comparison group. Similarly, the excess readmission rate observed above these rates was 7.2% for the heart failure group, 7.0% for the CAD group, and 6.5% for the comparison group.

Discussion

This is the largest study of patients with heart failure undergoing major noncardiac surgery in the United States. We found a substantial risk of operative mortality and 30-day all-cause readmission among patients with heart failure compared with patients with CAD and patients with neither heart failure nor CAD. Although professional guidelines have provided uniform, evidence-based approaches to the care of patients undergoing major noncardiac procedures, improvements in the care of patients with heart failure in this setting are greatly needed. Our analysis of outcomes from surgical procedures of varying risk provides evidence that elderly patients with heart failure remain at significantly higher risk for major morbidity and mortality, even after adjusting for other factors.

Professional guidelines and previous studies have generally focused on ischemic heart disease rather than heart failure.[21–25] Our study shows that heart failure is present in almost 20% of cases of common surgical procedures performed in the elderly. Previous studies suggested that heart failure was less prevalent in the surgical population, with estimates ranging from less than 5% to 12% of cases.[21–25] Many of these studies were limited by small sample sizes or a small number of study centers. In these limited samples, it is difficult to fully understand the impact of heart failure in the perioperative setting.

Although usual care for patients with heart failure has improved substantially since the pivotal studies in perioperative risk assessment were completed,[15] heart failure remains an important factor in postoperative outcomes.[11–13,21,25,26] We observed a 63% greater risk of operative mortality and a 51% greater risk of 30-day all-cause readmission among patients with heart failure, compared with patients without heart failure or CAD, after adjusting for demographic characteristics, comorbidities, and hospital and admission factors. To put the risk due to heart failure in context, only nonelective admission status and renal disease conferred higher risks of mortality to patients; and no other covariates, including admission urgency, were as important as heart failure for explaining readmission. There was no additional risk of mortality or readmission for patients with both heart failure and CAD, compared with patients with heart failure alone, suggesting that a diagnosis of heart failure is most relevant to these patients. Similar to previous reports, patients with CAD also had increased risk of mortality and morbidity compared with patients without CAD, but the risk was much smaller than the risk for patients with heart failure.

There are two important factors relevant to surgical outcomes that we could not directly measure. One is the severity of the underlying surgical disease. The other is the severity of the underlying heart failure or CAD. To address the first issue, we restricted the analysis to the subset of elective admissions. Among these admissions, the surgical disease severity should be more homogeneous among the three groups. Even in this pool of patients, those with heart failure had nearly double the risk of mortality compared with patients with neither CAD nor heart failure. More work is needed to identify when a patient with heart failure is in optimal shape for surgery. In addition, there is a significant need for interventions that can improve the outcomes of these patients in the perioperative period.

To address the second issue, we tried to ascertain how much excess 30-day mortality and readmission was observed in this study above what would be expected in similar populations of elderly Medicare beneficiaries. Although this is a rudimentary comparison, we note that the excess mortality in this study is differentially higher for the heart failure group compared with the other two groups. One interpretation is that the observed differences for mortality between groups is not explained by the underlying likelihood of mortality for each of the groups. The remaining differences are more likely attributable to the procedure. Readmission rates were similar between groups, suggesting that the observed differences in readmission rates reflect the underlying likelihood of inpatient admission for each group.

The impact of comorbidities in patients with heart failure should also be considered. We found that these patients frequently have additional comorbid conditions that contribute to mortality and readmission rates. Previous epidemiologic studies of heart failure have also shown that age and comorbid conditions contribute to shorter life expectancy and limit the effectiveness of some therapies.[27] However, even after adjustment for and in the absence of important comorbid conditions, heart failure remained a significant predictor of adverse outcomes.

The risk estimates for heart failure that we observed are lower than previously reported.[14,24,25,28] There are several possible explanations for these differences. First, previous studies predated major changes in the routine care of patients with heart failure, such as angiotensin-converting enzyme inhibitors and β-blockers, which the American College of Cardiology and the American Heart Association have elevated to class I recommendations.[15] It is likely, however, that routine care for patients with CAD and for patients without CAD or heart failure has also evolved. Second, the study population and case mix likely differ from those in earlier studies. In a previous analysis of Medicare data, we used diagnosis related group codes to identify broad classes of procedures for analysis.[14] This approach resulted in the selection of many procedures not included in the current analysis and may also have resulted in a different procedure mix within each diagnosis related group for each disease group. Third, improvements in the quality of surgical, anesthesia, and postoperative care may have evolved for patients with and without heart failure or CAD over the past decade.[17,29–31] Finally, there may have been previous diagnosis of heart failure and CAD in recent years due either to lower thresholds for imaging or to recent diagnostic methods such as natriuretic peptide testing.

Limitations

The use of administrative data means that our ability to characterize patients' comorbidities at the time of surgery was limited to diagnoses associated with claims. In general, ICD-9-CM diagnosis codes have low sensitivity and high specificity.[19] Unlike other Medicare analyses, we used information from outpatient and physician claims to augment information on diagnoses in the inpatient data. We also used multiple years of data from before the index hospitalization to determine patients' heart failure and CAD status. These measures should have helped to limit misclassification bias. Even so, it is more likely that patients with heart failure or CAD were misclassified to the comparison group than *vice versa*. This pattern would lead to a conservative bias of the resulting estimates.

For patients in the heart failure group, we lack details on the nature of the disease. We do not have clinical data such as ejection fraction that would enable us to determine whether patients had systolic or diastolic heart failure. We also do not have information on the etiology of disease. We are unable, therefore, to describe differences in surgical outcomes by these heart failure characteristics.

We also do not know what medical therapies patients were on at the time of surgery. Patients in both the heart failure and CAD groups on β-blockers or angiotensin-converting enzyme inhibitors may have had better outcomes than similar but untreated patients. Future studies should assess the impact of preoperative treatment patterns on surgical outcomes.

Conclusion

Patients with heart failure undergoing common surgical procedures have a substantially higher risk of operative mortality and hospital readmission than other patients, including those with coronary disease, admitted for the same procedures. Despite improvements in perioperative care and care for chronic heart failure, improvements are needed for the growing population of patients with heart failure undergoing major noncardiac surgery.

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Appendix: Procedure Selection Criteria

Procedure	Selection Criteria*
Carotid endarterectomy	Procedure code 38.12
Lower extremity bypass	Procedure code 39.29 (but excluding diagnosis code 444.21)
Open abdominal aortic aneurysm repair	Procedure codes 38.44 and 39.25; diagnosis codes 441.4, 441.7, and 441.9
Hip replacement	Procedure codes 81.51, 81.52, and 81.53
Knee replacement	Procedure codes 81.54 and 81.55
Spinal fusion	Procedure code 81.0x
Above-knee amputation	Procedure code 84.17
Below-knee amputation	Procedure codes 84.12, 84.14, and 84.15
Open cholecystectomy	Procedure codes 51.21 and 51.22
Laparoscopic cholecystectomy	Procedure codes 51.23 and 51.24
Colon cancer resection	
Colectomy	Procedure codes 45.73–45.76; diagnosis codes 153–154.0
Other abdominal cancer resections	
Gastrectomy	Procedure codes 43.5–43.99; diagnosis codes 151–151.9
Pancreatic resection	Procedure codes 52.51, 52.53, and 52.7; diagnosis codes 152–152.9 and 156–157.9
Nephrectomy	Procedure code 55.51; diagnosis codes 189–189.9
Cystectomy	Procedure codes 57.70–57.79; diagnosis codes 188–189.9
Pulmonary cancer resections	
Lobectomy	Procedure code 32.4; diagnosis codes 162–165.9
Pneumonectomy	Procedure code 32.5; diagnosis codes 162–165.9

* Procedure and diagnosis codes are from *International Classification of Diseases*, 9th Revision, Clinical Modification.

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