Heart failure (HF) is common after acute myocardial infarction (MI),1–4 which is considered to be one of its major precursors,5–7 and has been associated with excess mortality.4,8–15 The magnitude of this excess risk was reported to be unchanged during the 1980s and 1990s.16,17 However, important changes in the epidemiology of MI have taken place over the last decades, characterized by an increased proportion of non–ST-segment–elevation MI, improved acute treatment and secondary prevention measures, reduced short-term case fatality rates, and an increasing burden of morbidity and mortality from noncardiovascular causes.18–22 These complex changes in key determinants of the incidence and prognosis of HF after MI point to the need to evaluate its current prognostic role. Indeed, previous estimates based on well-defined clinical cohorts are now outdated4,8,9,12,13,16 because they do not reflect the aforementioned changes in the epidemiology of MI, and HF complicating MI, in the population. More recent studies have not applied standardized methods of MI and HF ascertainment11,14 or were limited to HF developing during the index MI hospitalization only.10,15 Including HF after hospital discharge is important, however.

Background—Contemporary data are lacking on the prognostic importance of heart failure (HF) after myocardial infarction (MI). We evaluated the prognostic impact of HF post MI according to preserved/reduced ejection fraction and the timing of its occurrence.

Methods and Results—All Olmsted County, Minnesota, residents (n=2596) with incident MI diagnosed in 1990 to 2010 and no prior HF were followed through March 2013. Cox models were used to examine (1) the hazard ratios for death associated with HF type and timing and (2) secular trends in survival by HF status. During a mean follow-up of 7.6 years, there were 1116 deaths, 634 in the 902 patients who developed HF (70%) and 482 in the 1694 patients who did not develop HF (28%). After adjustment for age and sex, HF as a time-dependent variable was strongly associated with mortality (hazard ratio =3.31, 95% confidence interval: 2.93–3.75), particularly from cardiovascular causes (hazard ratio =4.20, 95% confidence interval: 3.50–5.03). Further adjustment for MI severity and comorbidity, acute treatment, and recurrent MI moderately attenuated these associations (hazard ratio =2.49 and 2.94 for all-cause and cardiovascular mortality, respectively). Mortality did not differ by ejection fraction, but was higher for delayed- versus early-onset HF (P for heterogeneity =0.002). The age- and sex-adjusted 5-year survival estimates in 2001 to 2010 versus 1990 to 2000 were 82% and 81% among HF-free and 61% and 54% among HF patients, respectively (P for heterogeneity of trends =0.05).

Conclusions—HF markedly increases the risk of death after MI. This excess risk is similar regardless of ejection fraction but greater for delayed- versus early-onset HF. Mortality after MI declined over time, primarily as a result of improved HF survival. (Circ Heart Fail. 2016;9:e002460. DOI: 10.1161/CIRCHEARTFAILURE.115.002460.)

Key Words: cohort studies ■ ejection fraction ■ epidemiology ■ heart failure ■ mortality ■ myocardial infarction ■ secondary prevention ■ trends

Heart failure (HF) is common after acute myocardial infarction (MI),1–4 which is considered to be one of its major precursors,5–7 and has been associated with excess mortality.8–15 The magnitude of this excess risk was reported to be unchanged during the 1980s and 1990s.16,17 However, important changes in the epidemiology of MI have taken place over the last decades, characterized by an increased proportion of non–ST-segment–elevation MI, improved acute treatment and secondary prevention measures, reduced short-term case fatality rates, and an increasing burden of morbidity and mortality from noncardiovascular causes.18–22 These have likely influenced the already complex and multifaceted association between HF after MI and mortality. Changes in the epidemiology of HF after MI occurred as well, with a decline in its incidence3,15,23 and a change in the case mix according to left ventricular dysfunction, characterized by an increasing proportion of HF cases presenting with preserved ejection fraction (EF),1 for which treatment benefits are less established.24,25 These complex changes in key determinants of the incidence and prognosis of HF after MI point to the need to evaluate its current prognostic role. Indeed, previous estimates based on well-defined clinical cohorts are now outdated because they do not reflect the aforementioned changes in the epidemiology of MI, and HF complicating MI, in the population. More recent studies have not applied standardized methods of MI and HF ascertainment or were limited to HF developing during the index MI hospitalization only. Including HF after hospital discharge is important, however,

See Clinical Perspective
because evidence suggests that these cases face poor prognosis.\textsuperscript{8,11,14} Hence, existing results are predictably conflicting, with mortality hazard ratios (HRs) associated with incident HF ranging from <2-fold\textsuperscript{15} to >10-fold.\textsuperscript{8} Most importantly, reports classifying HF by reduced (HFrEF) or preserved (HFrPEF) EF are rare, and no data are available evaluating the association with cause-specific death. This is critical in light of the reported shift in deaths after HF toward noncardiovascular causes, particularly among patients with HFrPEF.\textsuperscript{26}

The purpose of this study, using a population-based approach with robust, standardized methods of MI and HF ascertainment, was to determine (1) the impact of HF complicating MI on all-cause and cause-specific mortality; (2) whether these associations differ according to EF and timing of HF onset after MI; and (3) changes over a 20-year study period (1990–2010) in relative and absolute survival by HF status.

Methods

Study Design and Setting

This research was conducted in Olmsted County, Minnesota, a location ideally suited for epidemiological studies because of its relative isolation from other urban centers and because comprehensive medical records from all sources of care for the local population are indexed and linked via the Rochester Epidemiology Project.\textsuperscript{27} As virtually all Olmsted County residents are represented in this system, this data source provides a nearly complete enumeration of the source population for many decades.\textsuperscript{28} After approval as minimal-risk study by the Mayo Clinic and Olmsted Medical Center Institutional Review Boards, a follow-up study was performed using the above-mentioned resources. All persons included in the study provided authorization.

Cohort Identification and Validation

Residents admitted to Olmsted County hospitals with possible MI from 1990 to 2010 were identified using methods previously described.\textsuperscript{19} Briefly, all events with International Classification of Diseases, 9th revision code 410 (acute MI) were reviewed. In addition, events with code 411 (other ischemic heart disease) were reviewed in a 50% random sample until 1998, a 10% random sample from 1999 to 2002, and a 100% sample from 2003 to 2010. Additional codes were not included because of their low yield.

MIs were validated using standard epidemiological criteria.\textsuperscript{19} Patients diagnosed with MI before 1990 were excluded so that only incident (first-ever) cases were included. The diagnosis of MI was verified based on the presence of 2 of the following: cardiac pain, elevated biomarkers, and ECG changes. Biomarkers used in clinical practice included creatine kinase (CK) and its MB fraction (CK-MB) until 2000 and troponin thereafter. However, CK-MB was measured until the end of the period as part of a surveillance study. Troponin T, CK, and CK-MB were measured with a sandwich electrochemiluminescence immunoassay on the Elecsys 2010 (Roche Diagnostics Corp, Indianapolis, IN) in the Laboratories of the Department of Medicine and Pathology at Mayo Clinic.

Main Exposure Measure

The primary exposure was incident HF. Participants were followed through March 2013 using their complete inpatient and outpatient medical records in the community from index MI date to HF incidence, death, or the most recent clinical contact. Participants diagnosed with HF by International Classification of Diseases, 9th revision code 428 were identified. Abstractors then reviewed records to validate HF using the Framingham criteria. These criteria require the presence of at least 2 major criteria, or 1 major criterion in addition to 2 minor criteria, to confirm HF.\textsuperscript{29} This approach was applied previously, showing minimal missing data and excellent interobserver agreement.\textsuperscript{30}

The type of HF was defined according to echocardiographic measurement as HFrEF (EF<50%) and HFrPEF (EF≥50%). EF was measured using an approach that was recently described.\textsuperscript{31} The EF measurement that was closest to the HF diagnosis (applying a predefined maximum period of 60 days) was recorded for each participant; the median (25th, 75th percentile) time from EF measurement to HF was −1 (−2, 0) days and did not change over the study period (P=0.07). The cutoff of 50% to define preserved/reduced EF was selected according to the guidelines.\textsuperscript{32} Time of HF onset was classified as early onset (≤3 days after MI) and delayed onset (>3 days) based on median length of hospital stay after MI during the 2000s.

Outcome Measures

The primary outcomes were time to all-cause and cause-specific death. Using the medical record, follow-up began at the time of the index MI and continued through March 2013. In addition to death noted in clinical care, the Mayo Clinic registration office records obituaries and local death notices, and death data are obtained quarterly from the State of Minnesota Department of Vital and Health Statistics. Information on the date of death and its underlying cause was obtained, through which deaths were classified as cardiovascular (International Classification of Diseases, 9th revision 390–459) and noncardiovascular.\textsuperscript{33}

Additional Clinical Data

The medical record was reviewed to ascertain cardiovascular risk factors, comorbidities, MI characteristics, and acute treatment variables at the index date or at the closest time before hospital admission. Smoking was classified as current versus noncurrent smoking. Body mass index (kg/m\textsuperscript{2}) was calculated using the current height and earliest adult height. Clinical definitions were used to assess hypertension, diabetes mellitus, and hyperlipidemia. Overall comorbidity burden was assessed by the Charlson comorbidity index.\textsuperscript{34} The Modification of Diet in Renal Disease equation was used to estimate glomerular filtration rate, with <60 mL/min per 1.73 m\textsuperscript{2} regarded as impaired renal function.\textsuperscript{35} MI presentation according to ST-segment elevation, Q-wave, and anterior location was determined, as well as Killip class. The latter was assessed within 24 hours of the index MI and analyzed as a categorical variable (class >1 versus class 1). Revascularization procedures during the index hospitalization included coronary artery bypass grafting and percutaneous coronary intervention (PCI). Recurrent MI (occurrence and date) was recorded on the basis of clinical diagnoses.

Statistical Analysis

Baseline characteristics, overall and by HF status, during follow-up are presented as mean and standard deviations for continuous variables and as frequencies for categorical variables. Death rates with person-time denominators were calculated for HF and HF-free categories and compared with Fisher’s exact test. Person-time at risk for the HF-free category was accumulated from the index MI until HF diagnosis, death, or end of follow-up. For the HF category, person-time at risk was accumulated from HF validation date until death or end of follow-up. Cox proportional hazards models were constructed to estimate the HRs and 95% confidence intervals (CIs) for all-cause, cardiovascular, and noncardiovascular disease mortality associated with HF. HF was modeled as a time-dependent variable, allowing subjects to transfer from one exposure group to another during follow-up. Initial adjustment was made for age (as a linear term) and sex (base model). Subsequently, Charlson comorbidity index, Killip class, PCI, and recurrent MI (modeled as a time-dependent covariate) were further adjusted for (multivariable-adjusted model). The selection of variables for the multivariable model was based on the percent change in the age- and sex-adjusted regression coefficient for HF (regressed on time to death) on inclusion of individual candidate confounding variables, applying a 5% threshold.\textsuperscript{36,37} Models were repeated with HF defined according to type (HFrEF versus HFrPEF) and
Mortality Associated With HF After MI

3 Gerber et al

timing (early- versus delayed-onset HF), with the same set of covariates used to enhance comparability across analyses. The proportional hazards assumption was tested by examining the Schoenfeld residuals (applying the cox.zph function in R), with no violations detected.

Temporal trends in the association between HF and mortality (overall and by cardiovascular/noncardiovascular causes) were assessed using Cox models, adjusting for the aforementioned sets of covariates. Four groups were defined according to year of entry into the cohort (1990–2000 versus 2001–2010) and HF status (modeled as a time-dependent variable). Both HR and absolute risk reduction estimates were calculated, with the direct adjustment method used for the latter.

EF was missing in 19% of the cases, necessitating multiple imputations. Data sets were created with missing values replaced by imputed values based on a model incorporating various demographic and clinical variables and an indicator for HF along with the cumulative baseline hazard of HF approximated by the Nelson–Aalen estimator. The results of these data sets were then combined using Rubin’s rules. Analyses were performed using SAS statistical software, version 9.3 (SAS Institute Inc, Cary, NC) and R, version 2.14.0 (The R Foundation for Statistical Computing). Heterogeneity tests for differences across strata were done with WINPEPI, version 11.23.

Results

Between January 1990 and December 2010, 2943 residents of Olmsted County, Minnesota, were hospitalized with first MI, representing the entire experience of a community. Among these, 347 patients had a history of prior HF and were excluded, leaving 2596 participants in the present study (mean age, 67 years; 60% men).

During a mean (SD) follow-up of 7.6 (5.8) years (1990–2000 versus 2001–2010) and HF status (modeled as a time-dependent variable). Both HR and absolute risk reduction estimates were calculated, with the direct adjustment method used for the latter.

EF was missing in 19% of the cases, necessitating multiple imputations. Data sets were created with missing values replaced by imputed values based on a model incorporating various demographic and clinical variables and an indicator for HF along with the cumulative baseline hazard of HF approximated by the Nelson–Aalen estimator. The results of these data sets were then combined using Rubin’s rules. Analyses were performed using SAS statistical software, version 9.3 (SAS Institute Inc, Cary, NC) and R, version 2.14.0 (The R Foundation for Statistical Computing). Heterogeneity tests for differences across strata were done with WINPEPI, version 11.23.

Changes in patient characteristics and acute management occurred between 1990 to 2000 and 2001 to 2010, including lower Killip class, more comorbidities, and greater utilization of reperfusion/revascularization therapy. Among HF cases, patients in the more recent era were older and had a worse cardiovascular profile, but were more likely to undergo PCI and HF patients in the earlier era (Table 3). The risk of recurrent MI during follow-up declined, as did the risk of incident HF (both P<0.001 from the log-rank test). The incidence rates of HF per 100 person-years (truncating follow-up at 5 years) were 10.2 in 1990 to 2000 and 7.9 in 2001 to 2010 (P=0.001). Among HF patients, the proportion of HFrEF decreased, whereas the median time from index MI to HF diagnosis remained unchanged (Table 3). A summary of deaths within 2 years after the MI stratified by HF status and time period, overall and by HF type and timing, is provided in Table 4. To include all follow-up on patients and account for censoring, age- and sex-adjusted survival estimates were calculated for the 2 time periods and compared. The age- and sex-adjusted 5-year survival estimates (95% CIs) in 2001 to 2010 versus 1990 to 2000 were 82% (80%–84%) and 81% (79%–83%) among HF-free subjects, compared with 61% (57%–64%) and 54% (51%–57%) among incident HF patients, respectively (P for heterogeneity in trends =0.05; Figure 1). This translates into an absolute risk reduction estimate from 1990 to 2000 to 2001 to 2010 of 1.3 deaths per 100 patients (95% CI 1.5 to 4.2) for HF-free subjects compared with 6.5 deaths per 100 patients (95% CI 2.1–10.9) for HF cases, adjusted for age and sex. Further adjustment for Charlson comorbidity index, Killip class, PCI, and recurrent MI (modeled as a time-dependent covariate) did not appreciably change the results. In relative terms, the age- and sex-adjusted HR for mortality in 2001 to 2010 versus 1990 to 2000 was 0.77 (95% CI 0.65–0.92). Multivariable-adjusted all-cause and cause-specific mortality HRs according to index MI type and timing were similar to those observed for all-cause mortality (Table 2).

More than half (n=634, 57%) of the deaths during follow-up occurred among patients with preceding HF. The incidence densities of mortality per 1000 person-years were 150 and 31 among patients with and without HF, respectively (P<0.001). After adjusting for age and sex, HF as a time-dependent variable was strongly associated with all-cause mortality (HR=3.31; 95% CI: 2.93–3.75, compared with HF-free status). Mortality did not differ by HF type (HR=3.45 for HFrEF versus 3.07 for HFpEF; P for heterogeneity =0.31), but was substantially higher for delayed- than for early-onset HF (HR=4.02 versus 2.81, respectively; P for heterogeneity =0.001). Further adjustment for indicators of MI severity and comorbidity burden, acute intervention, and recurrent MI moderately attenuated the HRs (2.49 overall; 2.55 for HFrEF versus 2.37 for HFpEF [P for heterogeneity =0.56]; 2.93 for delayed-onset versus 2.03 for early-onset HF [P for heterogeneity =0.002]; Table 2). Approximately 50% of the deaths were ascribed to cardiovascular causes (541 of a total of 1075 deaths classified). The HF–mortality association was stronger for cardiovascular than for noncardiovascular causes. Patterns seen in the associations between HF type and between HF timing were similar to those observed for all-cause mortality (Table 2).

More than half (n=634, 57%) of the deaths during follow-up occurred among patients with preceding HF. The incidence densities of mortality per 1000 person-years were 150 and 31 among patients with and without HF, respectively (P<0.001). After adjusting for age and sex, HF as a time-dependent variable was strongly associated with all-cause mortality (HR=3.31; 95% CI: 2.93–3.75, compared with HF-free status). Mortality did not differ by HF type (HR=3.45 for HFrEF versus 3.07 for HFpEF; P for heterogeneity =0.31), but was substantially higher for delayed- than for early-onset HF (HR=4.02 versus 2.81, respectively; P for heterogeneity =0.001). Further adjustment for indicators of MI severity and comorbidity burden, acute intervention, and recurrent MI moderately attenuated the HRs (2.49 overall; 2.55 for HFrEF versus 2.37 for HFpEF [P for heterogeneity =0.56]; 2.93 for delayed-onset versus 2.03 for early-onset HF [P for heterogeneity =0.002]; Table 2). Approximately 50% of the deaths were ascribed to cardiovascular causes (541 of a total of 1075 deaths classified). The HF–mortality association was stronger for cardiovascular than for noncardiovascular causes. Patterns seen in the associations between HF type and between HF timing were similar to those observed for all-cause mortality (Table 2).
to 2010 (67% to 56%; P=0.001). A temporal decline was observed for all-cause mortality in patients with HFpEF, driven by a 50% reduction in cardiovascular mortality. No statistically significant reduction was observed in mortality for patients with HFpEF. Regarding trends by timing of HF onset, the proportion of early-onset HF out of all HF cases diagnosed within 5 years after MI did not change between 1990 to 2000 and 2001 to 2010 (58% and 59%, respectively; P=0.99). Similarly, among delayed-onset HF cases diagnosed within 5 years after MI, no significant differences in the time from index MI to HF diagnosis were detected (mean [SD], 522 [621] versus 455 [555] days in 1990–2000 and 2001–2010, respectively; P=0.33). There was a substantial decline over calendar year in all-cause mortality associated with early-onset HF (HR=0.63; 95% CI 0.50–0.81, adjusted for age, sex, Charlson comorbidity index, Killip class, PCI, and recurrent MI), whereas no decline was evident for delayed-onset HF (HR=1.02; 95% CI 0.79–1.31). The temporal decline in mortality in patients with early-onset HF was primarily attributable to a reduction in cardiovascular mortality (adjusted HR=0.58; 95% CI 0.42–0.80), whereas less of a reduction was observed in noncardiovascular mortality (adjusted HR=0.71; 95% CI 0.49–1.02). For all temporal trends analyses, similar trends were observed with year of index MI modeled as a continuous variable, indicating a linear temporal trend.

### Discussion

#### Summary of Findings

This population-based cohort study provides contemporary quantification of the survival impact of HF complicating MI. After MI, HF strongly increases the risk of all-cause death, cardiovascular death, and noncardiovascular death independently of key confounders, including MI severity, comorbidity, and acute treatment. Patients with HFpEF and HFpEF share a similar prognosis, whereas HF developing >3 days after MI confers a worse prognosis than HF occurring concurrently with the index MI or shortly after.

Using data spanning over 20 years, we demonstrated herein, with strong evidence, an improvement in survival after MI. Nevertheless, survival varied considerably by HF status. From 1990 to 2000 to 2001 to 2010, the adjusted absolute risk reduction estimates (fewer deaths per 100 patients) at 5 years of follow-up were 7 and 1 in MI patients with and without HF, respectively. Among the latter group, some improvement over time in cardiovascular survival was offset by a greater risk of noncardiovascular death, resulting in an overall plateau. In contrast, a sizable decline was evident among patients with HF, primarily because of a large decrease in the risk of cardiovascular death. Over time, the proportion of HFpEF increased, with its prognosis improving more clearly than that of HFrEF. The mortality trends diverged markedly between early-onset and delayed-onset HF, with a considerable decline in the former category and none in the latter.

#### Interpretation of Study Findings

Several studies have shown an association between HF complicating MI and mortality. Yet, because many of these studies were based on cohorts assembled during the 1980s and 1990s, the relevance of their findings to contemporary practice is questionable. Indeed, remarkable changes...
were documented during the past decades in the epidemiology and management of MI that dramatically affected clinical presentation, treatment, and outcomes.\textsuperscript{19,20,22} These advances probably had a beneficial impact on the incidence of HF and deaths attributable to HF complicating MI.\textsuperscript{11} Moreover, the increasing use of more sensitive biomarkers has resulted in detection of smaller MIs,\textsuperscript{23,22} likely contributing to reduced risk of subsequent HF\textsuperscript{23,43} and potentially to decreased severity of HF and improved prognosis.\textsuperscript{11} In a previous study of the cohort analyzed herein,\textsuperscript{3} we observed a notable decline in the incidence of HF after first MI between 1990 and 2010. Stratified by type, this decline was limited to HFrEF, with no detectable change in the rate of HFpEF, resulting in a change in the case mix of HF. Stratified by timing of occurrence, a decline in incidence was shown in both early-onset and delayed-onset HF; with temporal changes in MI presentation and acute management affecting mostly the former patient group. To this end, however, no change in the survival impact of HF after MI was observed during the 1980s and 1990s,\textsuperscript{16,17} whereas mixed trends were reported between 1998 and 2010 in a study involving Medicare beneficiaries.\textsuperscript{23} Yet, the latter study did not distinguish incident from prevalent HF cases and, like many other recent studies on this topic,\textsuperscript{4,10,11,14} used administrative data and did not apply standardized methods of MI and HF ascertainment. As such, its data may have uncertain validity because of evolving coding practices\textsuperscript{44,45} and incomplete capture of HF cases because of the shift of care toward outpatient settings (which typically involve less severe cases).\textsuperscript{46}

The present study demonstrates a strong association between HF after MI and mortality, but also suggests a decline in this association from 1990 to 2010. Moreover, HF after MI was also associated with noncardiovascular death over the entire study period. The precise mechanism for the latter association is yet to be determined, but may involve frailty, an age-related syndrome of increasing vulnerability and decreasing resistance to stressors, which was shown to be both overrepresented in HF patients and predictive of death.\textsuperscript{47} It was previously proposed that HF after MI not only increases mortality, but also augments the associated risk of other prognostic factors, such as cancer, diabetes mellitus, and chronic renal failure.\textsuperscript{4} Interestingly, we have recently linked incident HF to subsequent cancer risk in a prospective cohort of patients with MI.\textsuperscript{48} Regardless of the mechanisms involved in the latter association, an increasing body of evidence supports the concept of HF as a sentinel condition which might reflect end-stage chronic diseases.\textsuperscript{4} Indeed, the present report, which is in line with previous findings,\textsuperscript{4,11} shows that most deaths among MI patients occur in the context of a preceding HF. Importantly, we found the survival gains over the past 2 decades to be primarily attributable to HF cases, compared with no major change in HF-free MI survival. This extends the findings of Mc Manus et al,\textsuperscript{15} examining in-hospital survival after MI. The improved survival of patients with HFpEF over the study period is intriguing considering the lack of specific effective treatment for this syndrome. This raises the question about the relative importance of secondary prevention versus therapy of HF. In this context, a recent Scandinavian study suggested that an observed temporal improvement in short-term survival of post-MI HF patients was only partly attributable to changes in interventional and pharmacological treatment.\textsuperscript{49}

One can argue that earlier detection of HF, resulting perhaps from increased awareness, may result in the appearance of prolonged survival, akin to lead time bias. This is an unlikely explanation, however, for the diverging temporal trends in the survival of patients with and without HF because most cases of HF are diagnosed soon after MI,\textsuperscript{3,11} and the proportion of patients with early-onset HF did not change over the study period as reported herein.

The categorization of early versus delayed HF is by necessity arbitrary, and the Framingham criteria were designed

![Table 2. Mortality Associated With Heart Failure After Myocardial Infarction Modeled as a Time-Dependent Variable](https://circheartfailure.ahajournals.org/content/6/3/573.t2)

<table>
<thead>
<tr>
<th>Hazard Ratio (95% Confidence Interval)</th>
<th>All HF</th>
<th>Reduced EF</th>
<th>Preserved EF</th>
<th>HF Type</th>
<th>Early Onset</th>
<th>Delayed Onset</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Did Not Develop HF</td>
<td>Developed HF</td>
<td>(n=1694)</td>
<td>HC</td>
<td>Developed HF</td>
<td>(n=902)</td>
</tr>
<tr>
<td>All-cause mortality</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of events</td>
<td>482</td>
<td>634</td>
<td>412</td>
<td>222</td>
<td>299</td>
<td>335</td>
</tr>
<tr>
<td>Basic adjusted model*</td>
<td>1.0 (referent)</td>
<td>3.31 (2.93–3.75)</td>
<td>3.45 (3.00–3.96)</td>
<td>3.07 (2.58–3.66)</td>
<td>2.81 (2.42–3.26)</td>
<td>4.02 (3.46–4.66)</td>
</tr>
<tr>
<td>Multivariable-adjusted model†</td>
<td>1.0 (referent)</td>
<td>2.49 (2.18–2.85)</td>
<td>2.55 (2.19–2.97)</td>
<td>2.37 (1.96–2.87)</td>
<td>2.03 (1.72–2.41)</td>
<td>2.93 (2.51–3.42)</td>
</tr>
<tr>
<td>Cardiovascular mortality</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of events</td>
<td>206</td>
<td>335</td>
<td>228</td>
<td>107</td>
<td>168</td>
<td>167</td>
</tr>
<tr>
<td>Basic adjusted model*</td>
<td>1.0 (referent)</td>
<td>4.20 (3.50–5.03)</td>
<td>4.51 (3.71–5.49)</td>
<td>3.62 (2.82–4.66)</td>
<td>3.43 (2.78–4.29)</td>
<td>5.66 (4.53–7.07)</td>
</tr>
<tr>
<td>Multivariable-adjusted model†</td>
<td>1.0 (referent)</td>
<td>2.94 (2.41–3.58)</td>
<td>3.09 (2.49–3.84)</td>
<td>2.65 (2.02–3.49)</td>
<td>2.30 (1.81–2.92)</td>
<td>3.74 (2.97–4.71)</td>
</tr>
<tr>
<td>Noncardiovascular mortality</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of events</td>
<td>250</td>
<td>284</td>
<td>176</td>
<td>108</td>
<td>128</td>
<td>156</td>
</tr>
<tr>
<td>Basic adjusted model*</td>
<td>1.0 (referent)</td>
<td>2.71 (2.27–3.24)</td>
<td>2.74 (2.24–3.35)</td>
<td>2.66 (2.08–3.41)</td>
<td>2.35 (1.89–2.92)</td>
<td>3.13 (2.53–3.87)</td>
</tr>
<tr>
<td>Multivariable-adjusted model†</td>
<td>1.0 (referent)</td>
<td>2.10 (1.74–2.55)</td>
<td>2.09 (1.68–2.60)</td>
<td>2.12 (1.64–2.74)</td>
<td>1.74 (1.35–2.26)</td>
<td>2.40 (1.94–2.98)</td>
</tr>
</tbody>
</table>

\*Adjusted for age and sex.
†Further adjusted for Charlson comorbidity index, Killip class, percutaneous coronary intervention, and recurrent MI (modeled as a time-dependent covariate).
to evaluate HF in a chronic situation. The time difference between the echocardiogram and the clinical diagnosis could impact the categorization of the type of HF. Hence, we cannot exclude some degree of misclassification of the diagnosis or categorization of HF. However, there was no statistically significant difference for the time from EF measurement to HF over the study period such that it is unlikely that misclassification would be differential over time. As our study focuses on secular trends, it is unlikely that such putative misclassification would bias our results.

The reasons for the divergence in mortality trends in patients with early-onset and delayed-onset HF are yet to be determined and may include greater treatment opportunities for HF developing in direct relation to the MI. Different mechanisms according to HF timing are also important in this regard. Conceptually, early-onset HF after MI reflects

Table 3. Changes in Baseline Characteristics from 1990 to 2000 to 2001 to 2010 by Heart Failure Status at Follow-Up

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Overall (n=2596)</th>
<th>Developed HF (n=902)</th>
<th>Did Not Develop HF (n=1694)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, y</td>
<td>67.0 (14.2)*</td>
<td>66.2 (14.5)*</td>
<td>72.2 (12.6)*</td>
</tr>
<tr>
<td>Male</td>
<td>689 (57)</td>
<td>877 (63)</td>
<td>255 (47)</td>
</tr>
<tr>
<td>Male BMI, kg/m²</td>
<td>27.9 (5.7)*</td>
<td>28.9 (6.0)*</td>
<td>28.2 (6.0)*</td>
</tr>
<tr>
<td>Hypertension</td>
<td>657 (54)</td>
<td>914 (66)</td>
<td>357 (66)</td>
</tr>
<tr>
<td>Hyperlipidemia</td>
<td>468 (39)</td>
<td>833 (64)</td>
<td>210 (39)</td>
</tr>
<tr>
<td>Current smoking</td>
<td>350 (29)</td>
<td>320 (23)</td>
<td>128 (24)</td>
</tr>
<tr>
<td>Diabetes mellitus</td>
<td>229 (19)</td>
<td>305 (22)</td>
<td>138 (26)</td>
</tr>
<tr>
<td>Charlson comorbidity index</td>
<td>1 (0, 2)†</td>
<td>1 (0, 2)†</td>
<td>1 (0, 2)†</td>
</tr>
<tr>
<td>Killip &gt;1</td>
<td>349 (29)</td>
<td>297 (22)</td>
<td>228 (43)</td>
</tr>
<tr>
<td>ST-elevation MI</td>
<td>458 (39)</td>
<td>366 (27)</td>
<td>188 (36)</td>
</tr>
<tr>
<td>Anterior MI</td>
<td>444 (38)</td>
<td>463 (34)</td>
<td>218 (41)</td>
</tr>
<tr>
<td>Q-wave MI</td>
<td>638 (56)</td>
<td>667 (52)</td>
<td>306 (60)</td>
</tr>
<tr>
<td>PCI</td>
<td>530 (44)</td>
<td>872 (63)</td>
<td>200 (37)</td>
</tr>
<tr>
<td>CABG</td>
<td>124 (10)</td>
<td>115 (8)</td>
<td>63 (12)</td>
</tr>
<tr>
<td>Atrial fibrillation</td>
<td>145 (12)</td>
<td>135 (10)</td>
<td>95 (18)</td>
</tr>
<tr>
<td>Estimated GFR, &lt;60 mL/min per 1.73 m²</td>
<td>627 (52)</td>
<td>576 (42)</td>
<td>339 (63)</td>
</tr>
</tbody>
</table>

BMI indicates body mass index; CABG, coronary artery bypass graft surgery; GFR, glomerular filtration rate; HF, heart failure; HFrEF, heart failure with reduced ejection fraction; MI, myocardial infarction; PCI, percutaneous coronary intervention; and SD, standard deviation.

Values expressed as n (% of nonmissing values) unless otherwise noted.

*Value expressed as mean (SD).
†Value expressed as median (25th, 75th percentiles).
‡Follow-up restricted to 5 y after MI (385 patients developed HF from 1990 to 2000; 342 patients developed HF from 2001 to 2010).

Table 4. Number of Deaths* Within 2 Years of MI Stratified by Time Period

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N Deaths Within 2 y, N (%)</td>
<td>N Deaths Within 2 y, N (%)</td>
</tr>
<tr>
<td>All HF</td>
<td>670 (96 (14.3))</td>
<td>1024 (96 (9.4))</td>
</tr>
<tr>
<td>Developed HF</td>
<td>541 (127 (23.5))</td>
<td>361 (84 (23.3))</td>
</tr>
<tr>
<td>Reduced EF</td>
<td>363 (94 (26.0))</td>
<td>200† (50 (25.1))</td>
</tr>
<tr>
<td>Preserved EF</td>
<td>178 (33 (18.3))</td>
<td>161‡ (34 (21.0))</td>
</tr>
<tr>
<td>Early onset</td>
<td>225 (102 (45.3))</td>
<td>200‡ (51 (25.5))</td>
</tr>
<tr>
<td>Delayed onset</td>
<td>316 (25 (7.9))</td>
<td>161‡ (33 (20.5))</td>
</tr>
</tbody>
</table>

EF indicates ejection fraction; HF, heart failure; and MI, myocardial infarction.

*These results do not take into account the censoring of some subjects.
† and ‡ are not the same persons.
extensive myocardial damage and is thus related to infarct characteristics, including location and size and time to reperfusion. In contrast, delayed-onset HF has been linked to other mechanisms, such as progressive remodeling, recurrent MI, and subclinical ischemia. As most patients with incident HF in this cohort did not experience a recurrent MI, remodeling is more likely to play a role as the underlying mechanism of delayed-onset HF.

After MI, it is often assumed that systolic dysfunction is the typical HF presentation. Nonetheless, we have recently shown a temporal change in the case mix of HF after MI, with an increasing proportion of HfpEF. The worse survival associated with HFrEF compared with HFpEF after MI could be hypothesized to attenuate the strength of an association between HF after MI and mortality over time. However, herein, the prognosis of HFrEF and HFpEF was similar and, unlike previous reports, EF measurements were not limited to those obtained at the index MI date.

**Limitations and Strengths**

Some limitations should be acknowledged in interpreting these data. These results emanate from a single community and thus may not be applicable to other populations. Yet, comparisons of previous population-based studies of various chronic diseases in Olmsted County with those from other communities in the United States indicate that the results for the population of this area can be extrapolated to a large part of the population of the country. Although HF was validated with the use of Framingham criteria, no data were available on its severity. Also, it is possible that heightened surveillance during the index MI hospitalization could contribute to a higher diagnosis rate of HF during this time. Echocardiograms were missing in 19% of the HF cases, necessitating the use of multiple imputations in the analysis of HF type. The lack of routine data on prognostic factors and interventions at the time of HF, and on secondary prevention measures afterward, precludes assessment of the relative importance of secondary prevention versus therapy in HF survival. Changes in clinical practice, healthcare policy, and recording of relevant variables over time should be considered when interpreting the results of secular trend analyses.

This study has several strengths. Community-wide studies, which monitor population trends in disease incidence and outcomes, are well-suited to evaluate the prognostic impact of HF after MI. Their data are more generalizable to the broader spectrum of patients seen in day-to-day practice and provide a representative and contemporary picture of the natural history of
Mortality Associated With HF After MI

this clinical syndrome. The comprehensive population-based approach provided by the Rochester Epidemiology Project, along with a rigorous ascertainment of incident MI and the access to complete inpatient and outpatient data in the process of HF validation, offers a unique opportunity to conduct robust surveillance. This surveillance system enables capture of long-term nonfatal clinical events that occur after the initial hospitalization, a distinctive strength that allows the integration of intercurrent clinical events after MI in the prediction of death, which has important implications for risk stratification. Echocardiographic data were routinely obtained allowing the analysis of HFREF and HFP EF, a crucial element in understanding the contemporary burden of HF complicating MI.

Conclusions and Implications

HF developing after MI is a strong risk factor for all-cause, cardiovascular, and noncardiovascular mortality. Although this finding, based on more contemporary data, supports earlier reports, our data further document and quantify the association and identify more vulnerable subgroups and specific times of higher risk. Furthermore, these data demonstrate important secular trends. The magnitude of the excess risk attributable to HF is similar between HFREF and HFP EF but greater for delayed-onset than for early-onset HF. Mortality after MI declined over the past 2 decades, primarily as a result of improved HF survival. However, the survival benefit was limited to early-onset HF. As most deaths after MI still occur in patients who developed HF, future survival gains will likely be achieved through improved treatment strategies among MI patients at risk for HF, specifically enhanced secondary prevention. Such efforts should be deployed to target delayed-onset HF, for which no improvement in prognosis was evident.

Sources of Funding

This study was supported by the National Institutes of Health (R01 HL59205, R01 HL72435, and R01 HL120907) and made possible by the Rochester Epidemiology Project (R01 AG034676 from the National Institute on Aging). The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health.

Disclosures

None.

References

Mortality Associated With HF After MI


CLINICAL PERSPECTIVE

Major changes in the epidemiology of myocardial infarction (MI) have taken place over the last decades and have likely influenced the already complex and multifaceted association between heart failure (HF) after MI and mortality. However, contemporary data on the prognostic importance of HF after MI are lacking. In this population-based cohort of patients with a first-ever MI from 1990 to 2010, we found that HF was strongly associated with mortality, particularly from cardiovascular causes. This excess risk is similar regardless of ejection fraction but greater for late- versus early-onset HF. Mortality after MI declined over time, primarily as a result of improved HF survival. There are important clinical implications of these data. As most deaths after MI occur in patients who develop HF, future survival gains will most likely be achieved through improved treatment strategies among MI patients at risk for HF. Such efforts should be deployed to target late-onset HF, for which no improvement in prognosis was evident. Furthermore, these data demonstrate important secular trends.
Mortality Associated With Heart Failure After Myocardial Infarction: A Contemporary Community Perspective

Yariv Gerber, Susan A. Weston, Maurice Enriquez-Sarano, Cecilia Berardi, Alanna M. Chamberlain, Sheila M. Manemann, Ruoxiang Jiang, Shannon M. Dunlay and Véronique L. Roger

Circ Heart Fail. 2016;9:e002460
doi: 10.1161/CIRCHEARTFAILURE.115.002460

Circulation: Heart Failure is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
Copyright © 2015 American Heart Association, Inc. All rights reserved.
Print ISSN: 1941-3289. Online ISSN: 1941-3297

The online version of this article, along with updated information and services, is located on the World Wide Web at:
http://circheartfailure.ahajournals.org/content/9/1/e002460

Permissions: Requests for permissions to reproduce figures, tables, or portions of articles originally published in Circulation: Heart Failure can be obtained via RightsLink, a service of the Copyright Clearance Center, not the Editorial Office. Once the online version of the published article for which permission is being requested is located, click Request Permissions in the middle column of the Web page under Services. Further information about this process is available in the Permissions and Rights Question and Answer document.

Reprints: Information about reprints can be found online at:
http://www.lww.com/reprints

Subscriptions: Information about subscribing to Circulation: Heart Failure is online at:
http://circheartfailure.ahajournals.org//subscriptions/