

Special Article

THE ASSOCIATION BETWEEN HOSPITAL VOLUME AND SURVIVAL AFTER ACUTE MYOCARDIAL INFARCTION IN ELDERLY PATIENTS

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ABSTRACT

Background Patients with chest pain thought to be due to acute coronary ischemia are typically taken by ambulance to the nearest hospital. The potential benefit of field triage directly to a hospital that treats a large number of patients with myocardial infarction is unknown.

Methods We conducted a retrospective cohort study of the relation between the number of Medicare patients with myocardial infarction that each hospital in the study treated (hospital volume) and long-term survival among 98,898 Medicare patients 65 years of age or older. We used proportional-hazards methods to adjust for clinical, demographic, and health-system–related variables, including the availability of invasive procedures, the specialty of the attending physician, and the area of residence of the patient (rural, urban, or metropolitan).

Results The patients in the quartile admitted to hospitals with the lowest volume were 17 percent more likely to die within 30 days after admission than patients in the quartile admitted to hospitals with the highest volume (hazard ratio, 1.17; 95 percent confidence interval, 1.09 to 1.26; $P < 0.001$), which resulted in 2.3 more deaths per 100 patients. The crude mortality rate at one year was 29.8 percent among the patients admitted to the lowest-volume hospitals, as compared with 27.0 percent among those admitted to the highest-volume hospitals. There was a continuous inverse dose–response relation between hospital volume and the risk of death. In an analysis of subgroups defined according to age, history of cardiac disease, Killip class of infarction, presence or absence of contraindications to thrombolytic therapy, and time from the onset of symptoms, survival at high-volume hospitals was consistently better than at low-volume hospitals. The availability of technology for angioplasty and bypass surgery was not independently associated with overall mortality.

Conclusions Patients with acute myocardial infarction who are admitted directly to hospitals that have more experience treating myocardial infarction, as reflected by their case volume, are more likely to survive than are patients admitted to low-volume hospitals. (N Engl J Med 1999;340:1640-8.)

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IN most of the United States, patients with chest pain thought to be due to acute coronary ischemia are taken by ambulance to the nearest hospital rather than to tertiary centers that treat a large number (high volume) of patients with acute myocardial infarction. The destination is determined by proximity alone, both for efficient operation of the emergency medical transportation system and because time is deemed paramount.

The importance of experience on the part of the hospital and physician as a determinant of the patient's survival has been increasingly recognized for various specialties and procedures.¹⁻⁹ To determine whether hospital volume influences mortality among patients with acute myocardial infarction, we performed a retrospective cohort study, using data from the Cooperative Cardiovascular Project (CCP), which was conducted by the Health Care Financing Administration (HCFA). This cohort was uniquely suited for the analysis of the effects of aspects of the health care delivery system: the nationwide sample comprised nearly 100 percent of elderly patients with myocardial infarction who had fee-for-service insurance coverage, and the study had extensive clinical data, blinded data abstraction, and reliable long-term follow-up.

METHODS

The methods of the CCP are described fully elsewhere.¹⁰⁻¹² For each acute care hospital in the United States, HCFA identified all Medicare fee-for-service beneficiaries with the principal-discharge-diagnosis code 410.xx (acute myocardial infarction), excluding codes 410.x2 (subsequent care), of the *International Classification of Diseases, 9th Revision, Clinical Modification* (ICD-9-CM), during a continuous eight-month sampling period that fell between February 1994 and July 1995. Using photocopied medical-record charts, research abstracters entered pertinent historical, clinical, and demographic variables into an electronic data base.

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Patients

By virtue of geography and the policy of the emergency medical system, most patients with acute myocardial infarction are taken to the nearest hospital. To reduce potential biases in selection and referral of patients, we limited the analysis to patients 65 years of age or older who were admitted from home with a verified infarction that was present on admission. We excluded duplicate admissions, interhospital transfers, and admissions from nursing and retirement homes. We also excluded patients whose infarctions occurred after admission, those referred from physicians' offices and free-standing clinics, and patients with coma on arrival or with pre-existing dementia or terminal illness. We excluded patients from five states (Alabama, Connecticut, Iowa, Minnesota, and Wisconsin)

because of intentional undersampling related to other CCP research projects. We obtained demographic data for the county of residence by linking the postal ZIP codes of the patients to governmental data bases.¹³⁻¹⁶ Data on long-term survival, obtained from the enrollment data base of the Social Security Administration, were assigned to the initial admitting hospital regardless of subsequent transfer.

Myocardial infarction was deemed present if patients had a creatine kinase MB fraction greater than 0.05 or at least two of the following three criteria: chest pain, a serum creatine kinase level at least two times the upper limit of normal, or diagnostic electrocardiographic findings. We used dummy variables to code missing values for categorical variables and for continuous variables with

TABLE 1. CHARACTERISTICS AND OUTCOMES OF THE STUDY PATIENTS, BY QUARTILE, ACCORDING TO THE HOSPITAL'S VOLUME OF PATIENTS WITH ACUTE MYOCARDIAL INFARCTION.

CHARACTERISTIC	HOSPITAL VOLUME			
	<1.4 PATIENTS/WK (N=24,829)	1.4-2.5 PATIENTS/WK (N=24,743)	2.6-4.4 PATIENTS/WK (N=24,648)	>4.4 PATIENTS/WK (N=24,678)
Demographic				
Mean age (yr)	76.0	75.8	75.7	75.8
Male sex (%)	51.9	51.9	52.5	54.4
White race (%)	88.1	89.2	91.0	92.6
County of residence (%)*				
Rural	48.5	22.3	14.8	7.4
Urban	22.3	30.2	32.5	39.3
Metropolitan	29.2	47.6	52.7	53.3
Clinical				
Diabetes mellitus (%)	31.0	30.7	30.7	30.8
Prior congestive heart failure (%)	19.9	19.4	19.8	19.0
Prior myocardial infarction (%)	28.0	29.4	31.0	32.2
Prior angioplasty (%)	5.2	6.4	7.5	9.0
Prior bypass surgery (%)	11.0	12.2	13.2	15.8
Mean heart rate (beats/min)	87.3	87.1	87.5	86.8
Mean arterial pressure (mm Hg)	105.2	104.1	104.1	102.6
Anterior infarction (%)	32.7	31.2	30.1	30.1
Killip class (%)				
1	53.1	52.1	51.3	51.3
2	17.3	17.3	17.6	17.6
3	28.2	29.0	29.5	29.3
4	1.4	1.6	1.6	1.8
Hospital- and physician-related				
Availability of invasive procedures (%)				
No angiography	78.5	38.1	14.6	3.5
Angiography only	17.9	38.2	38.6	19.7
Angioplasty and bypass surgery	3.6	23.7	46.8	76.8
Specialty of attending physician (%)				
Internal medicine	39.6	38.2	36.7	33.1
Cardiology	15.4	30.5	34.4	39.6
Family practice	26.4	14.5	11.3	8.8
General practice	7.6	3.8	3.2	2.2
Other	11.0	13.0	14.4	16.3
Mortality				
Death within 30 days after admission (%)				
Observed	16.7	15.3	14.7	14.4
Predicted	12.7	12.6	12.4	12.7
Death within 1 yr after admission (%)				
Observed	29.8	27.9	27.7	27.0
Predicted	25.5	25.4	25.3	25.7

*Urban counties were defined as those located within a metropolitan statistical area with a population of 50,000 to 1,000,000, and metropolitan counties as those in areas with a population of more than 1,000,000. Because of rounding, not all percentages total 100.

a rate of missing values greater than 5 percent. The results were unchanged in several alternative analyses that did not include dummy variables.

Data on Hospitals and Physicians

Our unit of analysis was an individual patient from the CCP. For each patient, we constructed a variable for the total number of CCP patients at the admitting hospital. We determined the availability of invasive procedures at each hospital according to the capability for coronary angiography or revascularization (no angiography, angiography only, or angioplasty and bypass surgery), assuming that hospitals billing for more than four procedures during the study had on-site capability. We obtained information on the other characteristics of the hospitals from the data base of the American Hospital Association.¹⁷

We determined the specialty of the physician by matching the unique physician identification numbers of CCP attending physicians to a HCFA data base of self-reported specialties. We limited the analysis of specialists to cardiologists, internists, family practitioners, and general practitioners, who were the attending physicians for 82.3 percent of the patients in the study.

Statistical Analysis

Our multivariate model, adapted from models for the assessment of 30-day mortality after myocardial infarction reported by Normand et al.¹⁸ and Lee et al.,¹⁹ included clinical, historical, and health-system-related variables. To the published models we added variables for hospital volume and availability of invasive procedures, specialty of the attending physician, presence or absence of electrocardiographic ST-segment elevation, presence or absence of contraindications to thrombolytic therapy, area of residence of the patient (rural, urban, or metropolitan), and geographic region (northeast, south, midwest, and west). Each clinical variable was significant at the level of $P < 0.001$, with the exception of a third heart sound (S_3) on admission ($P = 0.01$). None of the independent variables were collinear (Spearman correlations, < 0.5).

We divided the patient population into quartiles according to the case volume of the hospitals to which they were admitted and used Kaplan–Meier curves to compare unadjusted survival. To determine whether there was a selection bias, we used logistic regression to calculate a predicted one-year mortality rate²⁰ for each quartile of hospital volume and for each physician specialty. We used data on covariates for each patient from the proportional-hazards model while neutralizing the effects of hospital-related variables by standardizing them to the lowest-mortality groups. Thus, hospital volume was standardized to the median of the highest-volume quartile, the specialty of cardiology, the availability of bypass surgery, the patient's residence in a major metropolitan county, and the northeastern geographic region. We excluded the possibility that within-hospital clustering might affect the results, because the results of logistic regression,²¹ the generalized estimating equation,^{22,23} and the Cox proportional-hazards survival analysis²⁴ were virtually identical. Hospital volume was scaled to the difference between the medians of the lowest and highest quartiles (5.5 Medicare patients with myocardial infarction per week), approximating the maximal potential benefit of field triage for patients with myocardial infarction.

RESULTS

Characteristics of the Patients

The original data set contained information on 234,769 admissions. We excluded admissions from the five undersampled states (4.2 percent); admissions after the index admission (11.0 percent); patients admitted from places other than home (25.0 percent); patients who did not have a verified infarction on admission (10.0 percent); patients admitted to hospi-

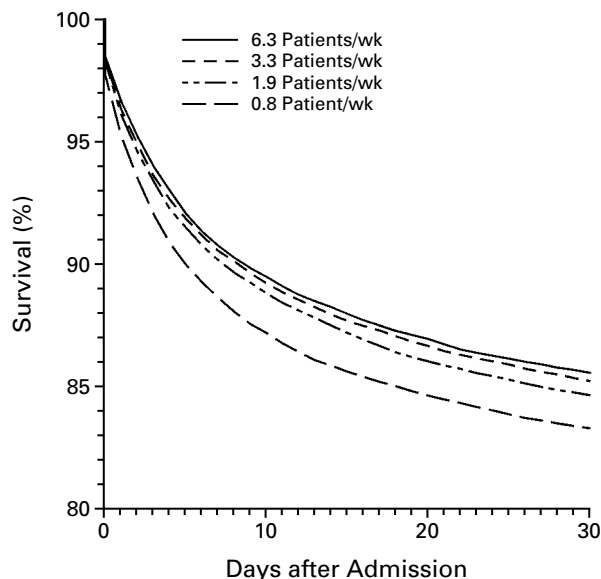


Figure 1. Crude Kaplan–Meier 30-Day Survival Curves, by Quartile, According to Hospital Volume of Medicare Patients with Acute Myocardial Infarction.

For each quartile, the median hospital volume of Medicare patients with myocardial infarction per week is shown.

tals that were able to provide emergency angioplasty without bypass surgery (2.7 percent); and patients younger than 65 years (5.0 percent).

Overall, 98,898 patients met the criteria for the study. Data on 3713 (3.8 percent) of these patients were excluded from the multivariate analysis because of missing information. The rates of missing information for variables describing clinical characteristics were less than 5 percent with the exception of the rates for serum albumin (27.0 percent) and chest radiographs (6.0 percent). Analyses that included the physician's specialty excluded 750 patients (0.8 percent) for whom information on the specialty was not available. The median follow-up period for survivors was 910 days.

Demographic and clinical characteristics of the patients in the study, by quartile, according to hospital volume, are shown in Table 1. Most differences were significant at the level of $P < 0.001$, but their magnitude and clinical significance were small, with predictable exceptions. A higher proportion of patients at low-volume hospitals had rural ZIP codes, patients at high-volume hospitals tended to be city dwellers, and high-volume hospitals were more likely to offer treatment by cardiologists as well as coronary angiography and revascularization.

Survival

Unadjusted Kaplan–Meier survival curves for quartiles of hospital volume (Fig. 1) showed an early survival advantage at high-volume hospitals. Thirty days

TABLE 2. ADJUSTED HAZARD RATIOS FOR DEATH ASSOCIATED WITH VARIABLES PERTAINING TO THE HOSPITALS AND PHYSICIANS.*

VARIABLE	DEATH WITHIN 30 DAYS AFTER ADMISSION (N=84,920)	DEATH MORE THAN 30 DAYS AFTER ADMISSION (N=71,838)	LONG-TERM MORTALITY (N=84,920)†
	hazard ratio (95% CI)		
Hospital volume (per decrease of 5.5 patients/wk)‡	1.10 (1.05–1.16)§	1.03 (1.00–1.07)	1.05 (1.02–1.08)§
Availability of invasive procedures			
No angiography	1.02 (0.96–1.08)	1.02 (0.98–1.07)	1.03 (0.99–1.07)
Angiography only	1.00 (0.95–1.05)	1.00 (0.96–1.04)	1.01 (0.97–1.04)
Angioplasty and bypass surgery¶	1.00	1.00	1.00
Specialty of attending physician			
General practice	1.09 (1.00–1.17)	1.06 (0.99–1.13)	1.07 (1.02–1.12)
Family practice	0.98 (0.94–1.03)	1.02 (0.98–1.06)	1.00 (0.97–1.04)
Cardiology	1.04 (1.00–1.09)	0.93 (0.90–0.96)	0.97 (0.94–1.00)
Internal medicine¶	1.00	1.00	1.00

*In addition to hospital volume, availability of invasive procedures, and physician's specialty, the model included the following variables: age, race, duration of symptoms, heart rate, mean arterial pressure, respiratory rate, presence of a third heart sound (S₃) on admission, cardiopulmonary resuscitation within 48 hours before admission, cardiomegaly as evidenced by chest film on admission, radiographic evidence of congestive heart failure on admission, shock within 48 hours before admission, albumin level, serum urea nitrogen level, serum creatinine level, ST-segment elevation, electrocardiographic evidence of a conduction abnormality (including atrial fibrillation, left or right bundle-branch block, second- or third-degree heart block, and ventricular tachycardia), electrocardiographic location of myocardial infarction, non-Q-wave myocardial infarction, mobility status (able to walk independently, able to walk with assistance, or unable to walk), contraindications to thrombolytic therapy, characteristics of county of residence (rural, urban, or metropolitan), and geographic region of the United States. The model also included a clinical history of congestive heart failure, coronary-artery bypass surgery, myocardial infarction, cigarette smoking, diabetes mellitus, chronic obstructive pulmonary disease, peripheral vascular disease, and stroke. CI denotes confidence interval.

†The median follow-up period for survivors was 910 days.

‡The analysis does not include patients for whom the physician's specialty was unavailable (750 patients) or was other than the four specialties listed (13,228 patients). The findings for hospital volume were unchanged in a model that omitted the physician's specialty and included all patients. The numbers of patients for whom data were complete are as follows: survival within 30 days after admission, 81,728; survival more than 30 days after admission, 69,424; and overall survival, 81,728.

§P<0.001.

¶This was the reference category.

||P=0.01.

after discharge, the unadjusted mortality rate was 16.7 percent at the lowest-volume centers, as compared with 14.4 percent at the highest-volume centers, with a progressive dose-response effect. The association between higher mortality and admission to hospitals treating a small number of patients with myocardial infarction (low volume) remained significant in a proportional-hazards analysis (Table 2): a decrease of 5.5 Medicare patients per week was associated with a hazard ratio for death at 30 days of 1.10 (95 percent confidence interval, 1.05 to 1.16; P<0.001) and a long-term hazard ratio for death of 1.05 (95 percent confidence interval, 1.02 to 1.08; P<0.001).

In an otherwise identical model that treated hospital volume as an ordinal variable according to quartile, the hazard ratio for 30-day survival among patients in the lowest versus the highest hospital-volume quartile was 1.17 (95 percent confidence interval, 1.09 to 1.26; P<0.001); for the second quartile the ratio was 1.07

(95 percent confidence interval, 1.01 to 1.13; P=0.02); and for the third quartile the ratio was 1.05 (95 percent confidence interval, 0.99 to 1.10; P=0.11). By comparison, the hazard ratio for 30-day survival was 1.09 for patients who had had prior bypass surgery and 1.18 for patients with a history of diabetes mellitus. The risk of death was disproportionately high at low-volume hospitals, but hospital volume as a continuous variable remained significant when the analysis was limited to the two highest-volume quartiles.

The association between hospital volume and mortality was not due to imbalances among the quartiles in coexisting conditions or the severity of the illness. The predicted 30-day and 1-year mortality rates, which neutralize the effects of health-system factors (Table 1), were essentially identical in all quartiles of hospital volume. Subgroup analyses according to the demographic and clinical characteristics of the patients at presentation (Table 3) showed that survival at

TABLE 3. THIRTY-DAY MORTALITY RATES AND ADJUSTED HAZARD RATIOS FOR DEATH AT 30 DAYS, ACCORDING TO CLINICAL CHARACTERISTICS OF PATIENTS AT PRESENTATION.*

CLINICAL CHARACTERISTIC	NO. OF PATIENTS (% OF TOTAL)	MORTALITY WITHIN 30 DAYS AFTER ADMISSION (%)	MULTIVARIATE MODEL WITH HOSPITAL VOLUME ALONE (N=95,185)	MULTIVARIATE MODEL WITH HOSPITAL VOLUME, INVASIVE PROCEDURE, AND PHYSICIAN'S SPECIALTY (N=81,728)		
			DECREASING HOSPITAL VOLUME†	DECREASING HOSPITAL VOLUME‡	NO ANGIOGRAPHY AVAILABLE AT HOSPITAL‡	ONLY ANGIOGRAPHY AVAILABLE AT HOSPITAL‡
adjusted hazard ratio (95% CI)						
Age						
65–69 yr	21,938 (22.2)	8.5	1.19 (1.07–1.33)§	1.20 (1.04–1.38)¶	0.98 (0.83–1.16)	1.00 (0.86–1.15)
70–74 yr	24,867 (25.1)	11.7	1.13 (1.04–1.23)§	1.16 (1.04–1.30)¶	1.00 (0.87–1.15)	0.97 (0.86–1.09)
75–79 yr	21,751 (22.0)	15.6	1.14 (1.06–1.23)**	1.12 (1.01–1.24)	1.04 (0.92–1.17)	1.04 (0.93–1.15)
80–84 yr	17,384 (17.6)	20.0	1.09 (1.01–1.17)	1.09 (0.98–1.20)	1.01 (0.90–1.14)	0.92 (0.83–1.03)
≥85 yr	12,958 (13.1)	26.9	1.00 (0.93–1.08)	1.00 (0.91–1.11)	1.02 (0.90–1.15)	1.05 (0.95–1.17)
History of cardiac disease						
None	61,623 (62.3)	15.2	1.12 (1.06–1.17)**	1.08 (1.01–1.15)	1.09 (1.01–1.17)	1.05 (0.98–1.12)
Prior myocardial infarction, angioplasty, or bypass surgery	37,275 (37.7)	15.5	1.09 (1.03–1.15)§	1.13 (1.05–1.22)**	0.93 (0.84–1.01)	0.93 (0.86–1.01)
Killip class of myocardial infarction						
1	51,395 (52.0)	10.2	1.09 (1.03–1.16)§	1.02 (0.94–1.11)	1.12 (1.02–1.24)	1.08 (0.99–1.18)
2	17,252 (17.4)	16.1	1.11 (1.02–1.21)	1.12 (1.00–1.25)	1.04 (0.91–1.19)	1.00 (0.89–1.13)
3	28,673 (29.0)	21.7	1.09 (1.03–1.15)§	1.15 (1.06–1.23)**	0.91 (0.84–1.00)	0.93 (0.86–1.01)
4	1,578 (1.6)	56.3	1.29 (1.10–1.53)§	1.25 (1.01–1.55)	1.23 (0.95–1.59)	1.05 (0.83–1.34)
Results of electrocardiography on admission††						
No ST-segment elevation	51,444 (54.4)	13.5	1.12 (1.07–1.18)**	1.17 (1.09–1.26)**	0.95 (0.88–1.04)	0.95 (0.88–1.02)
ST-segment elevation or left bundle-branch block	43,091 (45.6)	17.2	1.09 (1.03–1.15)§	1.05 (0.98–1.12)	1.08 (0.99–1.17)	1.05 (0.98–1.13)
Contraindications to thrombolytic therapy						
Absolute contraindications	12,069 (12.2)	21.5	1.16 (1.06–1.27)§	1.15 (1.01–1.29)	1.00 (0.87–1.15)	0.96 (0.85–1.09)
Relative contraindications	42,947 (43.4)	13.3	1.10 (1.04–1.16)§	1.08 (1.00–1.16)	1.05 (0.96–1.16)	1.09 (1.00–1.18)
No contraindications	43,882 (44.4)	15.5	1.10 (1.04–1.16)**	1.12 (1.04–1.20)§	0.99 (0.91–1.08)	0.94 (0.88–1.02)
Time from onset of angina to presentation						
<6 hr	58,847 (59.5)	12.8	1.09 (1.04–1.15)**	1.08 (1.01–1.16)	1.06 (0.97–1.14)	1.00 (0.93–1.07)
6–12 hr	9,296 (9.4)	16.1	1.10 (0.98–1.23)	1.12 (0.96–1.31)	1.06 (0.88–1.27)	1.00 (0.85–1.18)
>12 hr	13,024 (13.2)	17.7	1.20 (1.09–1.32)**	1.16 (1.02–1.32)	1.08 (0.93–1.26)	1.04 (0.91–1.19)
Unknown or unable to be determined	17,731 (17.9)	21.3	1.08 (1.01–1.16)	1.10 (1.00–1.21)	0.92 (0.82–1.03)	1.01 (0.91–1.12)

*The crude rates of demographic variables and mortality rates include all study patients. Two multivariate models are shown. The first model, of the effect of hospital volume alone, includes the entire study cohort and all variables described for Table 2 except invasive procedure and the physician's specialty, thus combining for policy analysis the effects of volume and of specialty and technology (which are associated with volume, as shown in Table 1). The second model includes all patients and variables described for Table 2. In the overall model, there were no significant interactions between hospital volume or invasive procedure and clinical characteristics except for age (P=0.02 for the interaction with hospital volume). CI denotes confidence interval.

†The decrease in hospital volume is assessed in increments of 5.5 patients with myocardial infarction per week.

‡The reference category (hazard ratio, 1.00) for invasive procedures is hospitals that offer angioplasty and bypass surgery.

§P<0.005.

¶P=0.01.

||P<0.01.

**P<0.001.

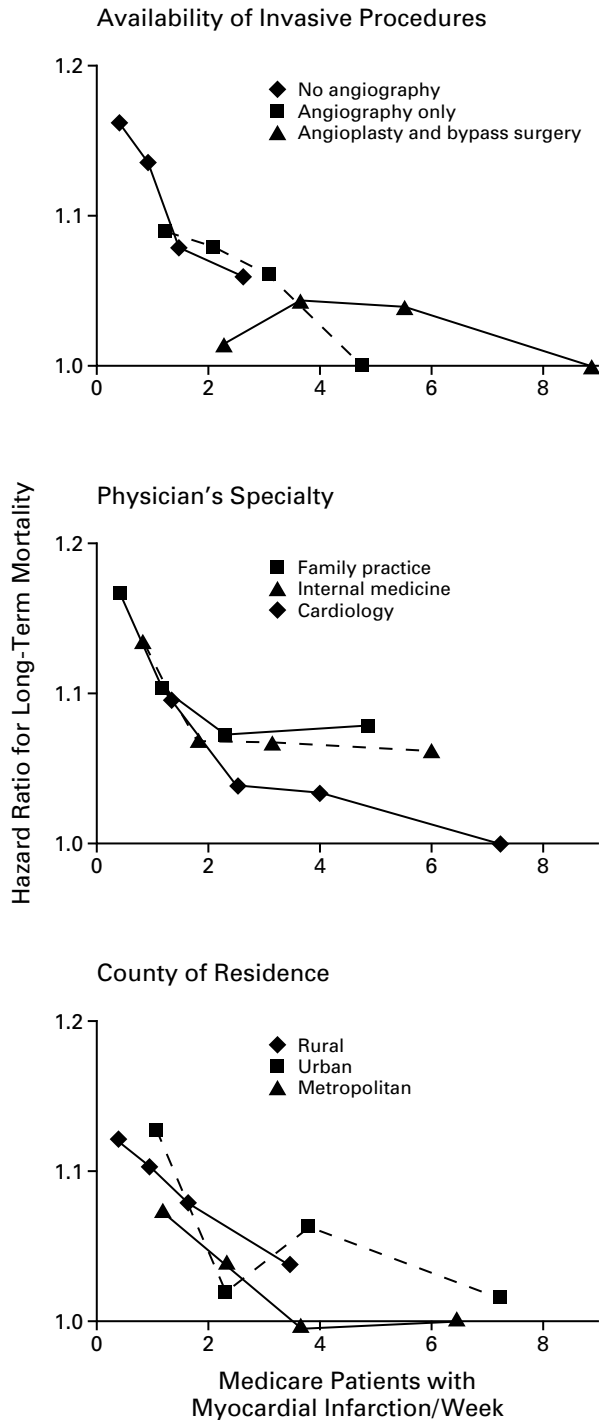
††Data were not available for some patients.

low-volume hospitals was consistently worse than at high-volume hospitals.

Availability of Invasive Procedures, Physician Specialty, and Rural Residence

The availability of invasive procedures, after adjustment for hospital volume and the physician's specialty, was not associated with a significant survival advantage. For each type of hospital invasive procedure, there was a dose-response relation between

hospital volume of patients with myocardial infarction and long-term survival (Fig. 2, top). When hospital volume was treated as a continuous variable, the dose-response relation for survival within 30 days after admission was highly significant at hospitals that did not offer angiography (hazard ratio, 1.38 for a decrease of 5.5 patients with myocardial infarction per week; 95 percent confidence interval, 1.16 to 1.63; P<0.001) and at hospitals that offered only angiography (hazard ratio, 1.19; 95 percent confidence inter-



val, 1.06 to 1.34; $P < 0.01$). The hazard ratio for volume plateaued among hospitals that offered bypass surgery and angioplasty, with borderline statistical significance (hazard ratio, 1.07; 95 percent confidence interval, 1.01 to 1.13; $P = 0.02$). Figure 2 (top) confirms that no significant survival advantage can be attributed to hospital invasive procedures alone, because there was a substantial overlap of hazard ratios for long-term mortality among hospitals with different technological capability but equivalent volume, a finding confirmed by statistical analysis of interaction. After adjustment for volume, there was no significant association between survival and the hospital's number of beds or teaching status.

Altogether, 30.0 percent of the patients had cardiologists as attending physicians, 37.0 percent had internists, and 15.3 percent had family practitioners. The patients treated by cardiologists were considerably healthier than the patients treated by other specialists, with a logistic predicted one-year mortality of 23.0 percent, as compared with 26.9 percent for patients treated by internists, a trend found previously.²⁵ There was a small long-term survival advantage for patients of cardiologists, with a long-term hazard ratio for death of 0.97 (95 percent confidence interval, 0.94 to 1.00; $P = 0.02$). The specialty of the attending physician did not affect the association between hospital volume and survival, which had a dose-response relation for patients of each type of specialist (Fig. 2, middle). The benefit of having a cardiologist as an attending physician was essentially the same among hospitals that could not provide angiography, those that could provide only angiography, and those that could provide angioplasty and bypass surgery. During the eight-month sampling period, each cardiologist treated a median of six Medicare patients with myocardial infarction, as compared with a median of three for each internist, and a median of two for each family practitioner and

Figure 2. Stratified Proportional-Hazards Ratios for Long-Term Mortality According to Potentially Confounding Factors Pertaining to the Health System.

The top panel shows the ratios according to the availability of invasive procedures; middle panel, according to the residence of the patient (rural, urban, or metropolitan). In each panel, the study population is stratified according to the factor of interest and then divided into quartiles within each stratum according to hospital volume (the median number of patients per week). The proportional-hazards model uses the variables described for Table 2. The reference category (relative hazard, 1.00) for invasive procedures is the highest-volume quartile of patients at hospitals that provide angioplasty and bypass surgery; for physician's specialty, the highest-volume quartile of patients with cardiologists as attending physicians; and for county of residence, the highest-volume quartile of patients who reside in metropolitan areas that have a population greater than 1 million. The median follow-up period for survivors was 910 days.

general practitioner. The number of patients treated by the attending physician was not significant in any of the analyses, which included the physician's specialty, excluded the specialty, or were restricted to a particular specialty.

Living in a less populous region as opposed to a metropolitan area was an independent risk factor for short- and long-term mortality (Fig. 2, bottom). Hazard ratios for death at 30 days were 1.11 for rural counties (95 percent confidence interval, 1.06 to 1.17; $P < 0.001$) and 1.06 for urban counties in metropolitan statistical areas with a population of 1 million or less (95 percent confidence interval, 1.02 to 1.11; $P = 0.005$). Population density did not affect the association between hospital volume and survival, which had a dose-response relation within each demographic subgroup.

Patterns of Hospital Practice

Only part of the survival advantage at high-volume hospitals was explained by measurable differences in the quality of care. When we added to our basic model separate variables for each patient's receipt of aspirin and thrombolytic medications on admission and beta-blockers and angiotensin-converting-enzyme inhibitors at discharge, the hazard ratio for death at 30 days associated with lower hospital volume at hospitals that did not offer on-site angiography decreased from 1.38 to 1.23 (95 percent confidence interval, 1.04 to 1.46; $P = 0.02$). At hospitals that offered angiography only, the hazard ratio, 1.17, was essentially unchanged (95 percent confidence interval, 1.04 to 1.31; $P = 0.008$). At hospitals that offered bypass surgery, the ratio decreased from 1.07 to 1.02 ($P = 0.60$). The diminution was due largely to the use of aspirin and beta-blockers, a finding consistent with the results of prior studies.^{11,26} The hazard ratio associated with lower hospital volume did not change when revascularization within 30 days (including angioplasty or bypass surgery at another hospital) was added to the model, despite considerable variation in revascularization rates: 24 percent at hospitals without angiography, 29 percent at hospitals with angiography only, and 42 percent at hospitals with angioplasty and bypass surgery.

DISCUSSION

We found that elderly patients with acute myocardial infarction have better outcomes when they are admitted directly to hospitals that treat a large number of patients with acute coronary syndromes than when they are admitted to hospitals that treat a small number of such patients. The crude difference in 30-day mortality between patients in the lowest and highest quartiles of hospital volume was 2.3 deaths per 100 patients. There was a consistent dose-response relation between hospital volume and survival. There was virtually no change in the mortality

differential after adjustment for clinical factors, the availability of invasive procedures, the physician's specialty, and the patient's county of residence.

Although the hazard associated with low hospital volume is smaller for patients with myocardial infarction than for patients undergoing surgical procedures,^{1,3-9} the mortality attributable to hospital volume is considerable, because the population at risk is large and because mortality from cardiac causes is high among the elderly. For nearly half the Medicare patients with myocardial infarction nationwide, the 30-day survival benefit at high-volume centers exceeds both a 1 percent absolute difference in mortality, the threshold generally applied to trials of thrombolytic drugs,²⁷ and the benefit found in landmark trials of medical therapy for acute myocardial infarction.²⁸ Equally important, the survival advantage at high-volume hospitals applies to all patients with acute myocardial infarction, not only to patients who are eligible for a particular therapy; the CCP is a nationwide study of actual clinical practice rather than a study of efficacy.

In our study, the availability of invasive procedures did not confer a significant survival benefit, a finding consistent with the results of prior studies.²⁹ The principal factor determining outcome in acute myocardial infarction thus may not be invasive procedures or the physician's specialty but the availability of an experienced health care team. For high-volume hospitals, distinctions between volume and the availability of invasive procedures are immaterial, because such hospitals typically offer angioplasty and bypass surgery. But for health system planners, this finding, from data collected in 1994 and 1995, when primary angioplasty for acute myocardial infarction was in its adolescence,^{30,31} raises questions about the benefit of the proliferation of technology at smaller hospitals.

Our study showed a small survival advantage for patients treated by cardiologists: a long-term hazard ratio of 0.97 for death ($P = 0.02$), as compared with the risk ratio of 0.79 for death in the hospital reported by Nash et al.,³² the odds ratio of 0.83 for death in the hospital reported by Casale et al.,³³ and the hazard ratio of 0.88 for death at one year reported by Jollis et al.²⁵ One reason for the varying estimates of the effect of attending-physicians' specialties may be that the data from Medicare Part A do not necessarily indicate the admitting physician. About 14 percent of Medicare patients with myocardial infarction reportedly have cardiologists as attending physicians after initially being admitted by noncardiologists³⁴; such patients may have been considered at high risk and may thus have been referred to cardiologists. Another possible reason is selection bias. When we applied our proportional-hazards model to the entire CCP data set, excluding only duplicate admissions and transfers, and limited the model to variables used in the prior CCP analysis, the long-

term hazard ratio for patients who had cardiologists as attending physicians was 0.90. When we applied our exclusion criteria and used the full model in Table 2, the hazard ratio changed to 0.97. Such confounding suggests that any observational analysis of acute myocardial infarction according to the physician's specialty (including our own) may be inherently limited by selection bias, perhaps because a specialization in cardiology is often a prerequisite for performing initial therapies such as thrombolysis and primary angioplasty.

We could not identify a predominant mechanism for the survival advantage at high-volume hospitals. The use of aspirin, thrombolytic agents, beta-blockers, angiotensin-converting-enzyme inhibitors, and revascularization accounted for about one third of the survival benefit. Because the experience of a health care team is multifactorial, the absence of a more specific mechanism is not surprising and is consistent with the effects of volume in other fields.¹⁻⁹

From the standpoint of health policy, the existence of an effect of volume is as important as its mechanism, suggesting that field triage, with patients with myocardial infarction transported directly to high-volume centers designated for the treatment of cardiac disease, might improve survival after myocardial infarction. The possibility of field triage arouses concern about morbidity and mortality en route to hospitals and particularly about possible delays in thrombolysis for eligible patients. Published estimates of the effect of thrombolytic symptom-to-treatment delays range from 0.16 life saved per 100 patients treated per hour of earlier treatment³⁵ to 3.3 lives per 100 patients treated per hour within 1.6 hours after the onset of symptoms.³⁶ In any case, thrombolytic treatment is not the sole determinant of policy for the emergency medical system, because relatively few patients receive thrombolytic agents — only 19.3 percent of the CCP cohort. And even fewer patients present shortly after the onset of symptoms, when thrombolytic therapy has the greatest benefit. In the Global Utilization of Streptokinase and Tissue Plasminogen Activator for Occluded Coronary Arteries study, only one quarter of the patients presented within one hour after the onset of symptoms.³⁷ As a practical matter, minor transport delays might be clinically insignificant as compared with a benefit relating to hospital volume of more than 2 lives saved per 100 patients.

The actual effect of transport time on thrombolysis is an important issue that needs to be resolved by the development and validation of criteria for triage, clinical trials, and regional adjudication by policy makers for the emergency medical system. At high-volume hospitals, earlier administration of thrombolytic agents might compensate for short transport delays; in our CCP cohort, the median interval between arrival at the hospital and the administration of throm-

bolytic agents was five minutes shorter for the highest-volume quartile than for the lowest-volume quartile ($P < 0.001$). In addition, hospitals are often clustered so closely that triage would not involve appreciable transport delays, a common-sense observation supported by analysis with the use of ZIP codes as a marker for hospital proximity. Twenty-two percent of the CCP patients in metropolitan areas and 36 percent of the patients in urban areas were admitted to smaller hospitals (those treating fewer than four CCP patients with myocardial infarction per week) that had the same ZIP code as another hospital, and three quarters of such patients (74 percent and 78 percent, respectively) were treated at smaller hospitals within two ZIP-code integers of another hospital. In rural areas, field triage might be feasible in conjunction with prehospital thrombolysis, a combination that has proved effective in randomized trials.^{38,39}

The findings of any observational study must be interpreted cautiously. The possibility of confounding of hospital volume by unmeasured variables cannot be ruled out. Our study does not include patients in managed-care plans or patients younger than 65 years. Systematic differences in ICD-9-CM coding or documentation could create bias. Technical advances in interventional cardiology, such as intracoronary stents and glycoprotein IIB/IIIA receptor antagonists, might benefit hospitals with high-technology interventions, regardless of their volume of patients.

In conclusion, we found that in the initial hospital care of patients with acute myocardial infarction, the more experience the hospital had, the better the patient's chance for survival. After comprehensive adjustment for coexisting clinical conditions, the patients in the quartile admitted to the lowest-volume hospitals were 17 percent more likely to die within 30 days after admission than those in the highest-volume quartile ($P < 0.001$), a difference of 2.3 deaths per 100 patients. The capability of the hospitals to perform coronary angiography, angioplasty, and bypass surgery had no significant effect on survival beyond that associated with increasing volume. In regions with acceptable transport time, survival after acute myocardial infarction might be improved by the use of field triage to transport patients directly to high-volume centers designated for the treatment of cardiac disease.

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