The Risk of Missed Diagnosis of Acute Myocardial Infarction Associated With Emergency Department Volume

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Study objective: Missed diagnosis of acute myocardial infarction is associated with adverse clinical outcomes and more dollars recovered in malpractice suits than any other condition. The rate of missed diagnosis varies between emergency departments (EDs); we hypothesized that it is associated with the volume of acute myocardial infarction patients treated in an ED and that the association can be explained by other hospital characteristics.

Methods: We linked the records of all acute myocardial infarction patients admitted to an Ontario hospital in 2002 to 2003 to their ED visit records in the 7 days preceding admission. Acute myocardial infarctions were defined as missed if the diagnosis on the previous visit matched a list of cardiac symptoms and illnesses. We assessed whether annual volume of admitted acute myocardial infarction patients treated in the ED (grouped as 0 to 49; 50 to 99; 100 to 199; 200 to 299; and ≥300) was associated with missed acute myocardial infarction, adjusting for age, sex, teaching hospital status, and acute myocardial infarction severity. In a secondary analysis, we used data from a survey of Ontario EDs to assess whether hospital characteristics (triage practices, use of diagnostic tests, and consultant availability) explained the volume association.

Results: Of 19,663 acute myocardial infarction patients, mean age (68.3 years), sex (63% men), and predicted 1-year mortality (mean 0.21; SD 0.18) were similar across volume groups. The rate of missed acute myocardial infarction was 2.1% (95% confidence interval [CI] 1.9% to 2.3%) and varied from 0% to 29% across EDs. Compared with very high-volume EDs, the adjusted odds ratio of missed acute myocardial infarction was 2.0 in very low- (95% CI 1.5 to 2.7) and 1.6 in low- (95% CI 1.1 to 2.3) volume EDs. Consultant availability partially explained the volume effect.

Conclusion: Lower-volume EDs have up to 2-fold higher odds of missed acute myocardial infarctions compared with highest-volume ones after controlling for patient factors. Many current technologies designed to increase diagnostic sensitivity are feasible only in higher-volume centers. Efforts to reduce overall rates of missed acute myocardial infarctions should instead focus on simpler solutions appropriate for lower-volume EDs, such as telemedicine to improve access to consultant expertise. [Ann Emerg Med. 2006;48:647-655.]

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SEE EDITORIAL, P. 657.

INTRODUCTION

Background

Patients with symptoms suggestive of acute myocardial infarction should promptly seek medical evaluation, yet the diagnosis is missed in about 2% to 3% of acute myocardial infarction patients presenting to emergency departments (EDs) in the United States[1] and Canada[2] and about 6% of patients in the United Kingdom.[3] Failure to accurately diagnose an acute myocardial infarction leads to delays in the initiation of appropriate treatments, may increase mortality,[1,3,4] and is responsible for more dollars recovered in malpractice suits than any other condition.[3,5–7]

Importance

Studies to identify predictors of missed acute myocardial infarction have focused on patient-level factors.[1,8] However, predictors that have been identified, such as nonwhite race and a normal ECG,[1] are of limited clinical utility and lack specificity. Interventions designed to reduce the risk, such as specialized

Editor's Capsule Summary

What is already known on this topic

Volume-outcome relationships have been noted for many conditions and have been suspected but not well documented in emergency medicine.

What question this study addressed

This administrative data-based study defined a missed myocardial infarction visit as a previous emergency department (ED) visit for a chief complaint suggestive of myocardial ischemia within 7 days before admission for documented infarction. The fundamental objective of the study was to assess the association of ED volume with the probability of a missed diagnosis while controlling for other possible confounding factors.

What this study adds to our knowledge

The study of nearly 20,000 cases found that lower volume was associated with a higher rate of missed infarction and that the odds of a missed diagnosis in very low-volume EDs was about twice that in the highest-volume EDs.

How this might change clinical practice

Misdiagnosis has traditionally been considered a problem that lies between the physician's ears; this study suggests that external, systemic factors play a role in determining performance and, by implication, that remedies solely for the physician might be misguided.

Research we'd like to see

The mechanisms that might explain these observations are obscure, but an understanding of why the miss rates differ in different settings is necessary before an intervention to try to improve performance.

chest pain observation units, are not widely used outside the United States[9–12] and may be practical only in larger EDs.[9,13,14]

Goals of This Investigation

Although previous studies have assumed that patient factors predominantly predict the risk of missed acute myocardial infarction, physician and hospital characteristics may also be important. For example, high-volume surgical centers are known to have lower perioperative mortality than low-volume centers,[15–17] and physician decisionmaking varies for acute cardiac patients, depending on the availability of hospital resources.[18] Small hospital EDs have been found to have missed acute myocardial infarction rates that were substantially higher than those of teaching hospital EDs.[19] We hypothesized that high-volume EDs have lower rates of missed acute myocardial infarction than centers that treat fewer acute myocardial infarctions. We also explored whether ED factors such as triage procedures and the availability of consultants and diagnostic resources are associated with missed acute myocardial infarction risk. Finally, we assessed whether missed acute myocardial infarction was associated with increased mortality.

MATERIALS AND METHODS

Theoretical Model of the Problem

Patient outcomes may be determined by characteristics inherent to the patient, the care provider, and the context in which the care is provided. The risk of missed acute myocardial infarction diagnosis may be influenced by a patient's age, sex, and clinical features, including ECG and laboratory findings. Provider characteristics could include ED nurse and physician experience and training. Finally, contextual factors include the type of hospital, its experience as a whole with acute myocardial infarction patients, and the relevant practices (such as quality of triage) and resources (such as the availability of advanced diagnostic testing or cardiology consultants) present there.

Study Design and Setting

This was a retrospective cohort study of acute myocardial infarction patients admitted to hospital in Ontario from April 1, 2002, to March 31, 2003. Ontario is Canada's largest province, with a population of 12 million.

Selection of Participants

The study population comprised all Ontario residents aged 20 to 95 years, with a valid health insurance number, admitted to hospital through an ED with a most responsible diagnosis (the diagnosis responsible for the majority of the hospital length of stay) of acute myocardial infarction (*International Classification of Diseases, 10th Revision, Canada* [ICD-10-CA] codes I21.0 to I21.9). Patient records were identified from the Discharge Abstract Database and the National Ambulatory Care Reporting System, administrative health databases that contain abstracts for all hospital admissions and ED visits in Ontario, respectively. For patients with multiple acute myocardial infarction admissions during the study period, only the first admission was retained. Participants were excluded who were admitted for an acute myocardial infarction in the previous year according to *International Classification of Diseases, Ninth Revision (ICD-9)* codes 410.00 to 410.92 because acute myocardial infarction may be more readily suspected therein, and such persons may be more likely to attend larger hospitals for subsequent cardiac care. All Ontario hospitals were mandated to switch from *ICD-9* to *ICD-10-CA* coding as of April 1, 2002.

Methods of Measurement

The hospital admission records of acute myocardial infarction patients were linked to records of their ED visit(s) with an anonymous unique identifier. We first identified the ED visit that resulted in hospital admission for acute myocardial infarction, designated as the index visit, and then identified all previous ED visits in the 7 days before hospital admission.

When a patient was transferred directly from one ED to another before admission, the visit to the first ED was considered the index visit. An acute myocardial infarction was defined as "missed" if, on a previous ED visit, the ED discharge diagnosis matched a prespecified list as follows: chest pain (*ICD-10-CA* R07.1 to R07.4), angina (*ICD-10-CA* I20), shortness of breath or congestive heart failure (*ICD-10-CA* R06.0, R06.8, I50, or J81), abdominal pain (*ICD-10-CA* R10.1, R10.3, or R10.4), heartburn, esophagitis, or gastritis (*ICD-10-CA* R12, R13, K20, K21, K22.9, K23.8, K29, or K30), or syncope/malaise (*ICD-10-CA* R42, R53, or R55) and the patient was also not admitted to hospital during the ED visit. These conditions were chosen because they may represent the typical or atypical presentation and alternative diagnoses to acute myocardial infarction.[2,20,21] Both 30-day and 1-year mortality data were obtained through linkage to the Ontario Registered Persons Database, which documents mortality statistics for the province. The primary exposure variable was the annual acute myocardial infarction volume in each ED, defined as the total number of visits among acute myocardial infarction patients admitted from or initially assessed in the ED. Index and all previous related ED visits by acute myocardial infarction patients were counted when the number of acute myocardial infarctions treated in an ED was determined. We defined 5 categories of annual acute myocardial infarction volume (very low [1 to 49], low [50 to 99], medium [100 to 199], high [200 to 299], and very high [≥300]) that were reasonable reflections of ED size, given that the effect of volume on outcome may be nonlinear. These were established without reference to the missed acute myocardial infarction rates to avoid selections that could maximize volume-outcome associations.

To assess the influence of specific ED processes or resources on the relationship between ED volume and the risk of missed acute myocardial infarction, we combined our administrative data with data obtained from a survey of all Ontario EDs mailed in March 2005. The specific ED processes and resources we examined focused on triage (using administrative data) and laboratory testing and the availability of consultants (using survey data). Triage is a key process at the initial point of patient contact with an ED triage nurse; patient priority and acuity are determined, tests including blood evaluations and an ECG can be carried out, and a decision is made about whether the patient will be treated in a high- or low-intensity area of the ED. We assessed ED triage according to 2 factors: (1) quality, in terms of the average rate of low-urgency triage scores given to acute myocardial infarction patients, defined as a Canadian Triage Acuity score of either 4 ("less urgent") or 5 ("nonurgent"); and (2) completeness, by determining whether the first ECG was routinely done at triage.[22] Patients with suspected acute cardiac problems should be assigned high-urgency triage scores of 1 to 3,[23] and an ECG should be carried out as soon as possible.[7] We also examined 2 specific ED resources: (1) laboratory cardiac troponin T or I testing, coded as either routinely available 24 hours a day or less than 24 hours a day; and (2) the availability of cardiology or internal medicine specialist consultation in the ED, coded as either available in the ED or available only after a patient is transferred from the ED to another facility.

Primary Data Analysis

We used logistic regression to examine the relationship between missed acute myocardial infarction and hospital acute myocardial infarction volume. All models controlled for patient age (20 to 49, 50 to 64, 65 to 74, and 75 years or older), sex, socioeconomic status (neighborhood income quintile), history of acute myocardial infarction, the number of visits to the same ED in the previous year, teaching hospital status, day of week, time of day, and acute myocardial infarction severity index. The latter index predicts the risk of 1-year mortality after hospital admission for acute myocardial infarction according to comorbidities present at admission. It is derived from data in the hospital discharge database and has been validated as a predictor of acute myocardial infarction severity.[24]

Because patients at the same ED may have correlated outcomes, we adjusted for clustering of patients within EDs by using generalized estimating equations.[25] This adjustment had little effect on the standard errors. We first analyzed the logarithm of ED acute myocardial infarction volume as a continuous variable to establish the presence of a relationship. In subsequent models, ED acute myocardial infarction volume was analyzed using categorical variables, with the very high-volume ED group as the reference category. As a secondary analysis, we added ED-level process and resource factors to the model to determine whether they altered the volume-outcome association, thereby helping to explain the mechanisms by which EDs may miss more acute myocardial infarctions. This method has been used to disentangle the relative importance of surgeon and hospital volume in explaining volume-outcome relationships in complex surgery.[26] An ED factor was determined to be influential a priori if its addition to the model attenuated the odds ratio (OR) by at least 20% or it caused the OR to become statistically nonsignificant.[26] To evaluate trend in the ED-level variables, we used linear regression with the logarithm of ED acute myocardial infarction volume as the dependent variable. All *P* values were 2-sided at a significance level of 0.05. All statistical analyses were performed using SAS for UNIX, version 8.02 (SAS Institute, Inc., Cary, NC). All databases were linked anonymously with encrypted individual health card numbers, and the study was approved by the ethics review board of Sunnybrook Health Sciences Centre.

Sensitivity Analyses

We conducted 2 sensitivity analyses. First, we made the definition of missed acute myocardial infarction more specific by restricting it to only previous ED visits with a final diagnosis of chest pain or angina. Second, we made our definition more sensitive by extending the look-back period for previous ED visits to 14 days preceding acute myocardial infarction admission.

Table 1. Characteristics of acute myocardial infarction patients according to whether the diagnosis was missed in the ED.

Characteristic*	Characteristic Level	AMI Not Missed, N=19,244 (%)	Missed AMI, N=419 (%)
Mean (SD) age, y		68.4 (14.0)	65.0 (14.6)
Men		12,191 (63.3)	284 (67.8)
Income quintile (Q)†	Q1 (lowest)	4,203 (21.8)	105 (25.1)
	Q2	4,142 (21.5)	94 (22.4)
	Q3	3,606 (18.7)	64 (15.3)
	Q4	3,306 (17.2)	69 (16.5)
	Q5	3,165 (16.4)	59 (14.1)
Triage acuity	Resuscitation	967 (5.0)	≤5 (0.2)
	Emergency	10,022 (52.1)	132 (31.5)
	Urgent	7,415 (38.5)	228 (54.4)
	Less urgent	696 (3.6)	48 (11.5)
	Nonurgent	144 (0.7)	10 (2.4)
Time of registration in ED	Daytime	8,270 (43.0)	190 (45.3)
	Evening	7,222 (37.5)	166 (39.6)
	Nighttime	3,752 (19.5)	63 (15.0)
Day of registration in ED	Weekend	5,398 (28.1)	98 (23.4)
	Weekday	13,846 (71.9)	321 (76.6)
Mean (SD) visits to same ED in previous year		0.62 (1.74)	1.13 (2.22)
Hospital type	Community	15,163 (78.8)	321 (76.6)
	Small centre	1,116 (5.8)	45 (10.7)
	Teaching centre	2,965 (15.4)	53 (12.6)
History of AMI		2,721 (14.1)	65 (15.5)
Comorbidity at admission	Shock	406 (2.1)	6 (1.4)
	Diabetes mellitus	771 (4.0)	8 (1.9)
	Heart failure	4,065 (21.1)	57 (13.6)
	Cancer	439 (2.3)	9 (2.1)
	Stroke	517 (2.7)	6 (1.4)
	Pulmonary edema	219 (1.1)	≤5 (1.2)
	Acute renal failure	760 (3.9)	17 (4.1)
	Chronic renal failure	1,013 (5.3)	21 (5.0)
	Dysrhythmia	2,775 (14.4)	45 (10.7)
Mortality	30-Day	2,342 (12.2)	38 (9.1)
	1-y	3,991 (20.7)	73 (17.4)
Predicted 1-year mortality	Mean (SD), %	20.8 (18.4)	16.9 (16.7)
ED discharge diagnosis at previous ED visit	Chest pain/angina	N/A	275 (65.6)
	Heart failure/dyspnea	N/A	47 (11.2)
	Abdominal/esophageal pain	N/A	70 (16.7)
	Other	N/A	27 (6.4)

AMI, Acute myocardial infarction; N/A, not applicable.
*All data are presented as No. (%) unless otherwise specified.
†Unknown for 850 persons (4.3%).

RESULTS

We identified 19,663 patients admitted to hospital for an acute myocardial infarction who were treated at 171 EDs in the province (17 teaching hospitals and 154 community hospitals); 63.4% of patients were men, and their mean age was 68.3 years. The largest proportion of patients arrived in the ED in the daytime (43.0%), and 14.2% of patients had a history of acute myocardial infarction. Comorbidities present at the time of admission and known to be associated with acute myocardial infarction mortality[24] are listed inTable 1. Demographic characteristics and acute myocardial infarction severity based on average predicted mortality were similar in study participants across ED volume groups (Table 2).

A total of 419 acute myocardial infarction patients, or 2.1% (95% confidence interval [CI] 1.9-2.3), met our definition of missed acute myocardial infarction. The rate varied from 0% to 29% across EDs. The mean (SD) delay between previous related ED visit and acute myocardial infarction admission was 2.3 (1.9) days. In 17% of cases, the hospital of the previous related visit differed from the admitting hospital. Almost 2 of 3 missed acute myocardial infarction patients had an ED diagnosis of chest pain or angina at their previous related visits (Table 1). Missed acute myocardial infarction patients were less likely to have comorbid illnesses at admission than were other acute myocardial infarction patients and had lower predicted and actual mortality. Thirty-day mortality was 9.1% among missed

Table 2. Characteristics of participants with acute myocardial infarction according to annual volume of ED visits.

		Annual Number of ED Visits for AMI				
Characteristic	**Characteristic Level**	**Very Low (0–49) (n=1675)**	**Low (50–99) (n=1663)**	**Medium (100–199) (n=3794)**	**High (200–299) (n=6462)**	**Very High (≥300) (n=6069)**
Mean (SD) ED visits		30.4 (11.1)	71.7 (16.0)	144.2 (29.1)	256.8 (28.3)	370.7 (51.5)
No. EDs represented		75	25	28	26	17
Men, %		1,077 (64.3%)	1,064 (64.0%)	2,327 (61.3%)	4,053 (62.7%)	3,954 (65.2%)
Mean (SD) age, y		68.5 (13.8)	67.2 (13.9)	69.1 (13.9)	68.6 (14.0)	67.9 (14.0)
Income quintile (Q), No. (%)	Q1 (lowest)	382 (22.8)	320 (19.2)	864 (22.8)	1,411 (21.8)	1,331 (21.9)
	Q2	367 (21.9)	377 (22.7)	791 (20.8)	1,409 (21.8)	1,292 (21.3)
	Q3	295 (17.6)	304 (18.3)	694 (18.3)	1,173 (18.2)	1,204 (19.8)
	Q4	298 (17.8)	309 (18.6)	691 (18.2)	1,065 (16.5)	1,012 (16.7)
	Q5	227 (13.6)	250 (15.0)	611 (16.1)	1,149 (17.8)	987 (16.3)
Comorbidity at Admission, No. (%)	Shock	27 (1.6)	14 (0.8)	82 (2.2)	138 (2.1)	151 (2.5)
	Diabetes mellitus	43 (2.6)	38 (2.3)	140 (3.7)	279 (4.3)	279 (4.6)
	Heart failure	325 (19.4)	307 (18.5)	760 (20.0)	1,414 (21.9)	1,316 (21.7)
	Cancer	27 (1.6)	32 (1.9)	102 (2.7)	139 (2.2)	148 (2.4)
	Stroke	43 (2.6)	41 (2.5)	108 (2.8)	177 (2.7)	154 (2.5)
	Pulmonary edema	18 (1.1)	19 (1.1)	42 (1.1)	67 (1.0)	78 (1.3)
	Acute renal failure	42 (2.5)	40 (2.4)	163 (4.3)	288 (4.5)	244 (4.0)
	Chronic renal failure	36 (2.1)	47 (2.8)	196 (5.2)	407 (6.3)	348 (5.7)
	Dysrhythmia	196 (11.7)	213 (12.8)	528 (13.9)	1,046 (16.2)	837 (13.8)
Delay from previous related ED visit to AMI admission, No. (%)	≤1 Day	35 (2.1)	23 (1.4)	25 (0.7)	52 (0.8)	46 (0.8)
	2 Days	≤5 (0.2)	8 (0.5)	16 (0.4)	25 (0.4)	27 (0.4)
	3+ Days	21 (1.3)	16 (1.0)	42 (1.1)	46 (0.7)	33 (0.5)
Predicted 1-y mortality, %*	Mean (SD)	19.2 (16.8)	17.9 (16.0)	21.3 (18.4)	21.3 (18.8)	20.7 (19.0)
Predicted 1-y mortality grouping, No. (%)*	<10	591 (35.3)	654 (39.3)	1,271 (33.5)	2,251 (34.8)	2,218 (36.5)
	11-20	373 (22.3)	379 (22.8)	731 (19.3)	1,209 (18.7)	1,203 (19.8)
	≥20	711 (42.4)	630 (37.9)	1,792 (47.2)	3,002 (46.5)	2,648 (43.6)

*Based on the AMI severity score.

acute myocardial infarction patients and 12.2% among other acute myocardial infarction patients.

Table 2 compares acute myocardial infarction patients across acute myocardial infarction volume groupings. Overall, acute myocardial infarction patients in different ED acute myocardial infarction volume groupings were similar in terms of their distributions of age, sex, socioeconomic status, and comorbidity, as well as acute myocardial infarction severity based on predicted 1-year mortality. For missed acute myocardial infarction patients, the delay between previous related ED visit and the acute myocardial infarction admission was also similar.

When the risk of missed acute myocardial infarction was compared across ED volume groups, a higher annual ED acute myocardial infarction log volume was related to a lower risk of missed acute myocardial infarction ($P<.0001$). The rate of missed acute myocardial infarction across ED volume groups was inversely related to the annual number of ED visits for acute myocardial infarction (Figure). The adjusted risk of missed acute myocardial infarction was significantly higher in EDs with 0 to 49 (OR 2.0; 95% CI 1.5 to 2.7) or 50 to 99 (OR 1.6; 95% CI 1.1 to 2.3) annual acute myocardial infarction visits relative to those with 300 or more (Table 3). Older age was associated with a lower risk of missed acute myocardial infarction (50 to 64 years and ≥75 years compared with those aged 20 to 49 years, with a similar trend for those aged 65 to 74 years), as was diabetes and congestive heart failure, whereas presenting on weekdays was associated with higher risk.

We varied the definition of missed acute myocardial infarction in 2 sensitivity analyses, one to make it more sensitive by extending the look-back period for previous ED visits to 14 days and second, to make it more specific by restricting it to only previous ED visits with a final diagnosis of chest pain or angina. In both analyses, the volume-outcome relationship was similar.

A total of 153 of the 171 EDs in our sample returned the survey, an 89% response rate. Table 4 compares ED process and resource factors by volume group. Acute myocardial infarction patients were assigned low-urgency triage scores more often in lower-volume EDs ($P<.001$). Onsite consultants, around-the-clock troponin results, and ECGs at triage were more common in higher-volume EDs ($P<.001$). Although it was not itself significantly associated with missed acute myocardial infarctions, the addition of on-site consultant availability to the model significantly attenuated the OR for very low-volume EDs, making it nonsignificant (1.57; 95% CI 0.91 to 2.69; $P=.10$); the OR for low-volume EDs did not change substantially (1.49; 95% CI 1.03 to 2.15; $P=.04$). No other ED-level factor produced significant changes when added to the

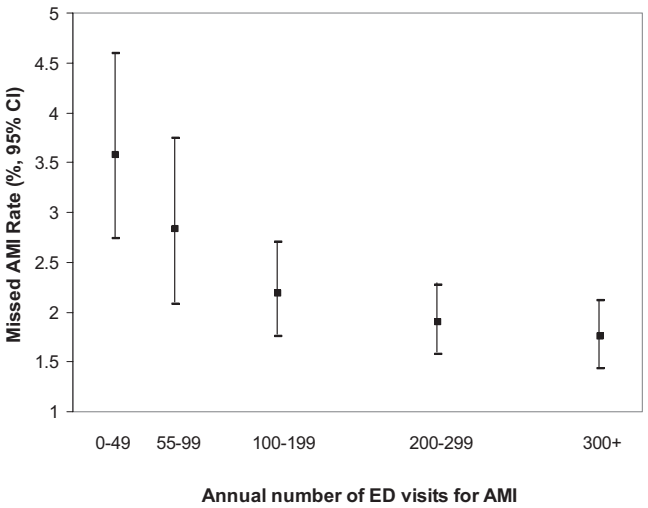

Figure. Rate of missed acute myocardial infarction according to the annual number of ED visits for acute myocardial infarction.

Table 3. Association between annual number of ED visits for acute myocardial infarction and the risk of missed acute myocardial infarction.

Variable	Level	OR	95% CI
ED AMI volume group	Very low	1.96	1.39–2.76
	Low	1.57	1.10–2.25
	Medium	1.33	0.98–1.82
	High	1.20	0.89–1.63
	Very high	1.00	Reference
Age group, y	20–49	1.00	Reference
	50–64	0.65	0.49–0.88
	65–74	0.75	0.57–1.00
	75+	0.53	0.37–0.75
Male sex vs female		1.08	0.91–1.30
Income quintile (Q)	Q1 (lowest)	1.31	0.89–1.91
	Q2	1.19	0.84–1.68
	Q3	0.95	0.66–1.36
	Q4	1.08	0.74–1.57
	Q5	1.00	Reference
History of AMI vs none		1.23	0.93–1.62
Visits to same ED in previous year, per visit		1.05	0.93–1.19
Weekday vs weekend		1.26	1.01–1.58
Time of day	Day	1.00	Reference
	Evening	1.01	0.79–1.30
	Night	0.76	0.57–1.02
Teaching hospital vs community		0.91	0.59–1.40
AMI severity index	Shock	0.88	0.42–1.83
	Diabetes	0.37	0.19–0.76
	Congestive heart failure	0.67	0.51–0.90
	Cancer	0.97	0.46–2.05
	Stroke	0.67	0.31–1.44
	Pulmonary edema	1.35	0.60–3.04
	Acute renal failure	1.43	0.90–2.29
	Chronic renal failure	1.26	0.82–1.96
	Dysrhythmia	0.84	0.62–1.13

main model. Missed acute myocardial infarction was not associated with increased risk of mortality at 30 days (OR 0.9; 95% CI 0.6 to 1.3) or 1 year (OR 1.03; 95% CI 0.8 to 1.3).

LIMITATIONS

We relied on population-based administrative health databases to identify and characterize acute myocardial infarction patients, as has been done in previous acute myocardial infarction research.[27] This strategy had the advantage of greater numbers of cases but the disadvantage of less clinical detail than is typical in prospective studies, clinical registries, or medical record reviews. Carrying out a volume-outcome study that was sufficiently large by medical record review or clinical registry would have been impractical. Our definition of previous related ED visits to identify missed acute myocardial infarction has not been validated; however, the overall rate we found based on our definition is consistent with published rates of missed acute myocardial infarction in prospective studies from Canada and the United States.[1,28] Some cases defined as missed acute myocardial infarction may have represented patients with high-risk acute coronary syndromes, such as unstable angina, at their initial ED presentation who then went on to have an acute myocardial infarction. Nonetheless, admission of high-risk acute coronary syndrome patients is recommended,[29,30] though such cases might equally be termed *missed acute coronary syndrome*. We evaluated our missed acute myocardial infarction definition by conducting 2 sensitivity analyses with different definitions of previous related ED visit and found no change in our conclusions. Furthermore, any misclassification should not affect our volume-outcome analysis as long as it is similar across volume groups. The mortality analysis should be interpreted with caution because we cannot account for missed acute myocardial infarction patients sent home from an ED who died without being readmitted to a hospital.

DISCUSSION

The volume of acute myocardial infarction patients treated in an ED is an important predictor of the risk of missed acute myocardial infarction. Overall, 2.1% of acute myocardial infarction patients were missed during an ED visit in the previous 7 days before hospitalization. Very low-volume EDs exhibited about a doubling of the rate of a missed diagnosis of acute myocardial infarction compared with high-volume EDs, whereas those with low volume had about a 1.6 times higher odds. These results have broad implications because 100 of the 171 EDs in our study were either low- or very low-volume sites.

In studies of surgical volume-outcome relationships, better outcomes in higher-volume hospitals have been associated with surgeon and hospital factors.[15,16,26] We found that some acute myocardial infarction processes and resources differ in high- and low-volume EDs. Lower-volume EDs were more likely to assign low-acuity triage scores to acute myocardial infarction patients, were less likely to have troponin test results available around the

Table 4. Comparison of practices and resources for the assessment of suspected acute coronary syndrome patients in Ontario EDs.

ED Practice or Resource	Measure	Annual Volume of ED Visits for AMI					*P* Value
		Very Low (0–49) (n=64 EDs)	Low (50–99) (n=23 EDs)	Medium (100–199) (n=26 EDs)	High (200–299) (n=24 EDs)	Very High (≥300) (n=16 EDs)	
Low-urgency triage rate* for AMI	Mean (95% CI)	11.7 (11.2–12.2)	5.8 (5.6–6.1)	4.6 (4.4–4.7)	4.0 (3.9–4.1)	2.0 (1.9–2.0)	<.001
First ECG acquisition†	Routinely done at triage, % (95% CI)	49.1 (46.6–51.6)	47.1 (44.6–49.6)	44.6 (43.0–46.3)	38.9 (37.7–40.2)	56.2 (55.0–57.5)	<.001
Troponin testing	Available 24 hours/day, % (95% CI)	16.0 (14.1–17.8)	44.1 (41.6–46.5)	90.9 (90.0–91.9)	100.0	100.0	<.001
Specialist consultation in the ED‡	Available on site, % (95% CI)	20.0 (18.0–22.0)	78.5 (76.5–80.6)	100.0	100.0	100.0	<.001

*Percentage of all ED visits for AMI given a Canadian Triage and Acuity score of 4 or 5 according to data from the National Ambulatory Care Reporting System.
†Process for obtaining first ECG in patients with suspected acute coronary syndrome.
‡Cardiologist or general internist consultation for patients with suspected acute coronary syndrome.

clock, and were less likely to have specialist consultation available in the ED. In such circumstances, accessing a specialist opinion may require a patient transfer, which can represent a substantial barrier, especially in borderline cases. When consultant availability was controlled for in our model, the volume-outcome relationship was significantly attenuated for very low-volume EDs, suggesting that this may be a particularly important risk factor in these EDs. Other ED-level factors introduced into the model did not influence the volume-outcome relationship. Previous studies have shown that acute myocardial infarction mortality is lower when patients are treated by high-volume physicians[27,31] who are predominantly specialists.[27] Specialists may also be more experienced in interpreting diagnostic tests or may have more time to work through cases with subtle or atypical findings.

In higher-volume centers, even relatively small reductions in the rate of missed acute myocardial infarction could result in a large reduction in the number of misses in absolute terms; however, further reductions in the already very low rates at these centers may be difficult to achieve and potentially very costly. Accordingly, reducing the risk of missed acute myocardial infarction may depend on a strategy aimed at reducing that rate within lower-volume settings. Some complex surgeries are now limited to higher-volume centers as a result of better outcomes.[17] This approach is likely not appropriate for acute illnesses such as acute myocardial infarction, given the time-sensitive nature of their condition. Specialized chest pain observation units using advanced diagnostic testing may help reduce the risk,[11,32,33] but they have not been widely embraced outside of the United States[11,12,28] and may be impractical for lower-volume EDs.[9,13]

Our analysis does not permit us to determine whether individual patients were treated by a specialist, and the availability of specialists in an ED may be a proxy for other physician factors affecting the risk of missed acute myocardial infarction in lower-volume settings, such as a higher prevalence of part-time emergency physicians[34] and lower likelihood of training in emergency medicine among ED physicians[35] or ED factors such as the presence of specific chest pain diagnostic protocols. Triage nurse training and experience also vary between lower- and higher-volume EDs in Ontario,[36] and decisions by triage nurses may influence the initiation of diagnostic tests and subsequent decisions by other medical staff.[37,38] The Ontario Ministry of Health has mandated that all EDs in the province use the 5-level Canadian Triage and Acuity Scale; however, we found a more than 5-fold difference in the rate of low-urgency triage scores being given to acute myocardial infarction patients across ED volume groups, despite similar mean acute myocardial infarction severity scores. We found little difference, however, in protocols about ECG acquisition at triage. Neither of the ED factors relating to triage quality nor completeness influenced our volume-outcome analysis, suggesting that these factors have little influence on the odds of missed acute myocardial infarction diagnosis. Nonetheless, measures aimed at reducing differences in staff training between lower- and higher-volume EDs may be beneficial.

Differences in staff experience may be unavoidable because nurses and physicians in lower-volume EDs will by definition continue to treat fewer acute myocardial infarctions. What may be helpful in these settings is the adoption of a standard diagnostic protocol, beginning with standardized triage, serial ECG, and troponin testing.[39] Simple automated tools to aid in ECG interpretation could be incorporated and are known to be effective in lower-volume settings.[40] This approach would ensure an adequate evaluation, using appropriately timed diagnostic testing, and could reduce ECG misinterpretation, which contributes to acute myocardial infarction misdiagnosis.[1,39] Lower-volume sites could improve access to

specialist consultation through telemedicine links, which are now being used for the acute assessment of suspected ST-elevation acute myocardial infarction[41,42] and stroke.[43,44] Whether a brief return visit to the ED within 24 hours can enhance the detection of an emerging acute myocardial infarction is not known but should be considered an additional option.[3]

In summary, our results suggest that the risk of missed diagnosis of acute myocardial infarction depends on patient- and ED-level factors. Protocols designed to reduce the risk should be developed and implemented in lower-volume EDs, including appropriately timed and sensitive diagnostic tests and easier access to specialist consultation. Using population-based administrative data to identify acute myocardial infarction patients would allow for the monitoring of the impact of these interventions.

In Retrospect

Additional detail about the ED processes and resources that were utilized in the assessment of specific patients would have helped to better elucidate the mechanisms by which ED volume is associated with the risk of missed acute myocardial infarction. Such detail is likely only available from medical record data.

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