Emergency Department Crowding and Thrombolysis Delays in Acute Myocardial Infarction

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See editorial, p. 586.

Study objective: We estimate the effect of emergency department (ED) crowding on door-to-needle time for patients given intravenous thrombolysis for suspected acute myocardial infarction.

Methods: This was a retrospective observational study of patients thrombolyzed in the ED for suspected acute myocardial infarction in 1998 to 2000 in 25 community and teaching hospital EDs in Ontario. EDs located close together and sharing a common ambulance diversion system were grouped into networks consisting of 2 to 5 hospitals each. At patient registration in an ED, the ambulance diversion status of all EDs in the network was determined. Network crowding was calculated as the percentage of EDs that were diverting ambulances on patient registration, categorized as none (0%), moderate (<60%), and high (≥60%). Door-to-needle time was defined as time from ED registration to drug administration. Multivariable quantile regression and logistic regression were carried out; covariates included age, sex, ECG characteristics, previous acute myocardial infarction, vital signs, time of presentation, and hospital type.

Results: A total of 3,452 thrombolysis patients were included: mean age was 62.9 years, and 73% were male patients. Overall median door-to-needle time was 43 minutes (interquartile ratio 27 to 80). Median door-to-needle time was 40, 45, and 47 minutes in conditions of none, moderate, and high network crowding, respectively (P<.001). The adjusted odds ratios for door-to-needle time delay (>30 minutes) and major delay (>60 minutes) were 1.32 (95% confidence interval [CI] 0.98 to 1.79) and 1.40 (95% CI 1.12 to 1.75), respectively, for high network crowding compared with none, and 1.21 (95% CI 0.89 to 1.63) and 1.06 (95% CI 0.86 to 1.29), respectively, for moderate crowding compared with none. In multivariate analyses, moderate and high crowding conditions were associated with increased median door-to-needle time (3.0 minutes [95% CI 0.1 to 6.0] and 5.8 minutes [95% CI 2.7 to 9.0], respectively).

Conclusion: ED crowding is associated with increased door-to-needle times for patients with suspected acute myocardial infarction and may represent a barrier to improving cardiac care in EDs.

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Editor's Capsule Summary

What is already known on this topic

Emergency department (ED) crowding is a widespread problem that is believed to impact the ability of emergency physicians to provide optimal care in the ED.

What question this study addressed

Whether ED crowding, as assessed by ambulance diversion within a local system, results in a delay in fibrinolytic treatment for patients with suspected acute myocardial infarction.

What this study adds to our knowledge

In 3,452 thrombolysis patients, those who went to EDs experiencing moderate to high crowding had longer median door-to-needle times (45 and 47 minutes, respectively) than those who experienced no crowding (40 minutes).

How this might change clinical practice

Crowding was shown to have a real impact on median time to thrombolysis. Well-done studies demonstrating a clear adverse impact of ED crowding on important medical outcomes might ultimately lead to positive change in the health care system.

INTRODUCTION

Emergency department (ED) crowding has been described as "the most serious issue confronting emergency departments in the developed world,"[1] largely because of concerns that the problem may compromise patient care and outcomes.[1-3] However, there exists little published evidence of adverse effects on quality of care.[4] One important indicator of quality of care in the ED that may be adversely affected is the time from patient arrival to delivery of thrombolysis in acute myocardial infarction, the so-called door-to-needle time.[5-8]

Numerous ED-based programs have been put in place in recent years in an effort to reduce door-to-needle time.[9-14] Nonetheless, recent reports suggest that delays in thrombolysis still occur in many jurisdictions and that target times are not being met for most patients.[7,15,16] In part, this failure may be because worsened ED crowding limited the potential for these programs to reduce thrombolysis times.

Factors that have been found to influence door-to-needle time include patient characteristics and clinical status,[17] physician factors,[15,16] hospital characteristics,[15,16] and policies such as restricted access to thrombolytics[10] or the use of chest pain protocols.[11,12] However, no study has examined how dynamic changes in the ED environment, such as those that occur with crowding, affect door-to-needle time. We sought to evaluate the effect of crowding within an ED network linked by an ambulance diversion system on door-to-needle time, hypothesizing that worsened crowding would be associated with greater delays in suspected acute myocardial infarction.

MATERIALS AND METHODS

Theoretical Model of the Problem

Previous studies of ED crowding and out-of-hospital delays for cardiac patients found that delays occurred only when multiple neighboring EDs were crowded simultaneously,[18] reflecting the use of ambulance diversion systems to control crowding.[18] These systems help manage ambulance traffic by temporarily slowing the influx of new patients to crowded EDs and diverting them to other ones nearby. EDs not on diversion receive these patients in addition to their usual ambulance load; hence, diversion systems make EDs sensitive to the crowding conditions at other hospitals. Other factors that may affect door-to-needle time include patient characteristics (age, sex, vital signs, medical history), ECG characteristics (diagnostic first ECG, bundle branch blocks), physician factors (choice of thrombolytic, emergency physician or consultant administering drug), contextual factors (day of week, time of day), out-of-hospital factors (out-of-hospital ECGs and thrombolysis, advance notification), and hospital factors (type, use of chest pain policies/protocols).

Data on acute myocardial infarction patients were drawn from Managing Acute Coronary Syndromes–A Tracking Project (MACSTRAK), an ongoing, prospective registry developed by clinicians principally for use as a hospital continuous quality improvement tool. Trained health care professionals at the bedside collect data on demographics, presentation, treatment, and outcome for all patients admitted to the coronary care unit at participating hospitals. A 1-page form is forwarded to a central project office at the University Health Network, Toronto, where each case report is screened for inconsistencies, errors, and omissions, and queries are then sent back to the local registry coordinators for resolution. Data are reported back to each hospital at regular intervals, with appropriate benchmarking from the aggregate data set for local use in quality assurance projects. Form counts are correlated with a standardized unit logbook to document capture rates. Approval of the data collection was provided by the institutional ethics review boards or the hospital administration, as dictated by local policies of the participating hospital. Data on the ambulance diversion status of EDs were obtained from Ontario's CritiCall

service, which monitors and maintains the province's ambulance diversion systems. From the MACSTRAK registry, we selected data from all EDs (n=25) that used a CritiCall ambulance diversion system during the study period. We included only patients who were admitted directly to a MACSTRAK hospital and who received intravenous thrombolysis in the ED for suspected acute myocardial infarction. We excluded patients if the ED arrival date or time was missing or if the ambulance diversion status of any network ED was missing. The study was approved by the research ethics board of the Sunnybrook and Women's Hospital.

Outcome Measures

The primary outcomes were median door-to-needle time, defined as the time from registration in the ED until intravenous administration of a thrombolytic agent, and 2 categorical outcomes: (1) the proportion of patients with "delayed" door-to-needle time (ie, between 30 and 60 minutes after registration); and (2) the proportion of patients with "major delay" in door-to-needle time (ie, >60 minutes after registration). These outcomes were based on consensus recommendations that set a target time of less than 30 minutes from ED arrival to thrombolysis.[19,20]

We defined EDs to be crowded when they were diverting ambulances.[4,21-25] We assigned each ED to a network consisting of all neighboring hospitals sharing a common ambulance dispatch and diversion system. Ten networks were created, consisting of 2 to 5 hospitals in each, and in most communities this represented all of the EDs in the city. The one exception was Toronto, the largest city in the study, which was divided into 4 networks corresponding to the 4 geographic quadrants used for ambulance dispatch purposes. For each patient, we determined the degree of crowding in the network on the basis of the ambulance diversion status of the all EDs (including the treating ED) in the network at the time of patient registration. Network crowding was calculated as the percentage of EDs diverting ambulances at patient registration and was categorized (according to prespecified criteria) as none (0%), moderate (<60%), or high (≥60%).

An Ontario Ministry of Health standard governed the criteria by which hospitals' decisions were made to divert ambulances (Appendix).[26] The attending emergency physician and the ED charge nurse determined the ambulance diversion condition on the basis of degree of ED crowding, in accordance with standard criteria. The decision was guided by these criteria and by individual physician judgment. The criteria were established for all hospitals by the Ontario Ministry of Health, and the use of ambulance diversion by EDs is monitored by the government.[27] ED staff relayed their ambulance diversion status to the central ambulance dispatch center in real-time through the Internet whenever required. The ambulance diversion status automatically expired after a maximum 2-hour period, although the ED could renew, upgrade, or downgrade its status at any time. There were no restrictions on simultaneous diversion at multiple EDs within a network.

The following potential confounders were controlled for in multivariate analyses: (1) patient age and sex; (2) clinical presentation (systolic blood pressure [<100, 100 to 160, 161 to 190, >190 mm Hg], pulse rate [<80, 80 to 100, >100 beats/min], shortness of breath [none/mild or moderate/severe]); (3) ECG findings (diagnostic first ECG [yes or no], ST elevation on diagnostic ECG [anterior, inferior, other, none (eg, left bundle-branch block, paced rhythm, or normal variant)]); (4) medical history (history of myocardial infarction, history of coronary artery bypass graft surgery or angioplasty); (5) thrombolytic used (streptokinase, tissue plasminogen activator, other); and (6) setting (hospital type [<120 beds, 120 to 300 beds, >300 beds, cardiac catheterization onsite], admission year [1998, 1999, 2000], day of week [weekday or weekend], time of day [day, evening or night]).

All analyses were conducted using Stata software (version 7, StataCorp, College Station, TX). Univariate analysis (median tests) of non–normally distributed time intervals was carried out. Crude and adjusted median quantile regression models were used to determine the association between network crowding and door-to-needle time (in minutes). Standard errors were calculated using bootstrap resampling to ensure robust variance estimates.[28] We evaluated collinearity by examining the correlation among the regression coefficients and set a threshold of 0.80 for the correlation coefficient to determine whether variables should be excluded from the model. We tested the assumptions of the model by inspecting the plot of the residual values against the predicted values. In a sensitivity analysis, we compared these results with those obtained using linear regression with robust standard errors. Logistic regression analysis was used to examine the adjusted and unadjusted association between crowding and door-to-needle time of greater than 30 minutes and 60 minutes, respectively; model fit was assessed using the Hosmer-Lemeshow goodness-of-fit test. For both linear and logistic regression analyses, we used Stata's robust estimator of variance with the cluster option to obtain standard errors that accounted

for potential clustering of door-to-needle times within institutions.

RESULTS

We initially identified 3,702 patients who were in the linked CritiCall and MACSTRAK data sets and were admitted to hospitals that were part of a network. Five patients were excluded because the ambulance diversion status of the hospital at the time of patient registration was unknown, 165 patients because the ambulance diversion status of 1 or more network hospitals was unknown, and 80 patients because of missing time of arrival at the ED, leaving 3,452 patients. The number of included patients at each of the 25 admitting hospital sites ranged from 22 to 254.

Table 1 shows the characteristics of patients included in the study. Men accounted for 72.7% of patients, and the mean age was 62.9 years. Fewer patients were part of the registry in 1998 (15%) than in 1999 and 2000 (45.9% and 39.1%, respectively). Patients were principally derived from large hospitals without cardiac catheterization facilities (57.3%) and from medium-sized hospitals (26.9%). The first ECG was diagnostic in 84.1% of cases, and the majority of patients had inferior or anterior ST elevation (47.0% and 41.4%). Intravenous recombinant tissue plasminogen activator was the thrombolytic agent used in 70.3% of patients.

Most (58.2%) patients presented to an ED network experiencing crowding at the time of registration (28.9% moderate and 29.2% high network crowding) versus 1,443 (41.8%) patients who presented to ED networks with no crowding. Crowding changed little from 1998 to 2000, with 66.1% of patients exposed to moderate or high network crowding in 1998 versus 53.0% in 1999 and 61.3% in 2000.

Overall, median door-to-needle time was 43 minutes (interquartile ratio 27 to 80 minutes). The target door-to-needle time of less than 30 minutes was achieved in 29.2% of patients, with a further 35.9% of patients receiving delayed thrombolysis (30 to 60 minutes) and 34.9% of patients experiencing a major delay (>60 minutes). During the 3 years, there was a 3-minute improvement in median door-to-needle time, from 46 minutes in 1998 to 43 minutes in 2000.

In univariate analysis of network crowding and thrombolysis time, median door-to-needle time increased significantly from 40 minutes (95% confidence interval [CI] 39 to 42 minutes) to 45 minutes (95% CI 41 to 46 minutes) and 47 minutes (95% CI 44 to 50 minutes) as network crowding increased from none to moderate and high, respectively. In adjusted quantile regression analyses, moderate and high network crowding were associated with statistically significant 3.0-minute (95% CI 0.1 to 6.0 minutes) and 5.8-minute (95% CI 2.7 to 9.0 minutes) increases in median door-to-needle time. Other statisti-

Table 1.
Characteristics of 3,452 ED patients thrombolyzed for suspected acute myocardial infarction.

Characteristic	No. (%)
Demographic	
Male, No. (%)	2,492 (72.7)
Age, y, mean (SD)	62.9 (13.2)
Setting	
Admission year	
1998	517 (15.0)
1999	1,585 (45.9)
2000	1,350 (39.1)
Admission time	
Day	1,444 (41.8)
Evening	1,113 (32.2)
Night	895 (25.9)
Day of week	
Weekday	2,376 (68.8)
Hospital size	
Small	135 (3.9)
Medium	928 (26.9)
Large (without catheterization)	1,979 (57.3)
Large (with catheterization)	410 (11.9)
Electrocardiograph	
First ECG diagnostic	2,904 (84.1)
ST elevation	
Anterior	1,402 (41.4)
Inferior	1,593 (47.0)
Other	131 (3.9)
Not diagnostic	261 (7.7)
Clinical status	
Symptom onset >24 h	128 (3.7)
Moderate or severe dyspnea	188 (5.7)
Pulse rate, beats/min	
<80	1,953 (59.7)
80–100	989 (30.2)
>100	331 (10.1)
Systolic blood pressure, mm Hg	
<100	355 (10.7)
101–160	2,359 (70.8)
161–190	470 (14.1)
>190	150 (4.5)
Cardiac history	
Previous CABG/PTCA	201 (6.0)
Previous acute myocardial infarction	977 (29.3)
Treatment	
Thrombolytic agent	
Streptokinase	782 (22.7)
rtPA	2,480 (71.9)
Other	187 (5.4)

CABG, Coronary artery bypass graft surgery; **PTCA,** percutaneous transluminal coronary angioplasty; **rtPA,** recombinant tissue plasminogen activator.

Table 2.
Network ED crowding and door-to-needle time performance.

Network Crowding Level	Door-to-Needle Time, No. (%)			
	0–29 Min	30–60 Min	>60 Min	χ^2 (*P* Value)
None	456 (32.3)	507 (35.9)	451 (31.9)	<.001
Moderate	272 (27.8)	366 (37.5)	339 (34.7)	
High	260 (26.3)	340 (34.4)	389 (39.3)	

cally significant predictors of median door-to-needle time were the presence of a diagnostic first ECG (−63.1 minutes; 95% CI −71.7 to −54.4 minutes), male sex (−6.8 minutes; 95% CI −10.0 to −3.70 minutes), large hospital size without a catheterization laboratory (4.05 minutes; 95% CI 1.4 to 6.7 minutes), anterior ST elevation myocardial infarction (3.20 minutes; 95% CI 0.6 to 5.8 minutes), myocardial infarction without ST elevation (31.2 minutes; 95% CI 15.4 to 47.0 minutes), and thrombolytic drug used (streptokinase 7.7 minutes [95% CI 3.5 to 12.0 minutes] and drugs other than recombinant tissue plasminogen activator 9.6 minutes [95% CI 4.7 to 14.4 minutes]).

Table 2 and the Figure present univariate analyses of target door-to-needle time performance, demonstrating that it steadily worsened with increasing network crowding. The proportion of patients thrombolyzed within the target time of less than 30 minutes declined from 32.3% to 26.3% when network crowding increased from none to high, whereas the proportion of patients experiencing major delays increased from 31.9% to 39.3% (Figure). The results of the logistic regression analyses are shown in Table 3. In unadjusted analyses, high network crowding was a statistically significant predictor of door-to-needle time delay (odds ratio [OR] 1.38; 95% CI 1.07 to 1.77) and major delay (OR 1.38; 95% CI 1.13 to 1.69). In adjusted analyses, high network crowding was associated with major delay (OR 1.40; 95% CI 1.12 to 1.75) and a trend toward missed door-to-needle time target (Table 3). In both unadjusted and adjusted analyses, moderate crowding was associated with trends toward door-to-needle time delay and major delay.

To ensure that our results were consistent regardless of the statistic used to measure door-to-needle time,[29] we repeated the analysis with mean door-to-needle time as outcome, using a robust linear regression analysis. We found an independent association between high network crowding and mean door-to-needle time (11.3 minutes, 95% CI 2.5 to 20.1 minutes), but only a trend with moderate crowding (8.0 minutes, 95% CI −0.7 to 16.6 minutes). We also evaluated the effect of restricting our analysis to the crowding status of the treating ED only and ignoring the situation at other EDs in the network. In multivariable analyses, crowding at the treating ED only was associated with a statistically significant increase in median door-to-needle time (3.6 minutes, 95% CI 0.1 to 7.0 minutes) and trends toward increased odds of door-to-needle time delay (OR 1.23, 95% CI 0.93 to 1.62) and major delay (OR 1.23, 95% CI 0.96 to 1.59).

LIMITATIONS

We may have underestimated the association between ED crowding and door-to-needle time because we could not

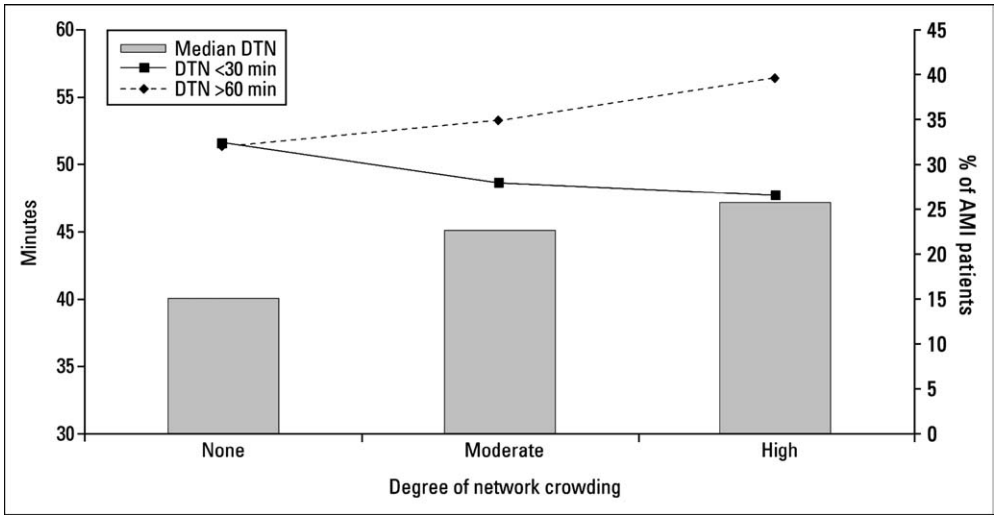

Figure.
Degree of network crowding and median door-to-needle times (columns, left y axis) and percentage of acute myocardial infarction patients with door-to-needle time of less than 30 minutes or greater than 60 minutes (lines, right y axis). ***DTN****, Door-to-needle time;* ***AMI****, acute myocardial infarction.*

account for out-of-hospital transport delays caused by ambulance diversion[18,30] and could not measure the delay between arrival in an ED waiting area and patient registration. Also, given the voluntary nature of MACSTRAK, data on some acute myocardial infarction patients may not be submitted to the registry. Although the capture rate at hospitals in this study during data collection was 97.1% and the accuracy of MACSTRAK data was confirmed in a study that compared it with Ministry of Health administrative databases,[31] any missing data may be more likely to be that of acute myocardial infarction patients with extreme door-to-needle times because one purpose of the registry is to monitor thrombolysis performance. There is no single standard definition of ED crowding; however, ambulance diversion was endorsed as a proxy measure by the US General Accounting Office,[21] is widely used,[23-25,32-34] and is important because it reflects an inability to provide rapid medical care to acutely ill patients.[33,35] Also, standard Ministry of Health criteria governed the indications for ambulance diversion across Ontario,[26] and its use is monitored by hospitals and the Ministry. We did not have data on some potential confounders such as race, presenting symptoms, or use of hospital chest pain policies. However, we included year of patients' treatment as a proxy measure for the latter factor because such policies have become more common at most EDs. None of the ambulance systems in our study had out-of-hospital ECGs or administered thrombolytics. Although we did account for clustering of door-to-needle times within institutions in the logistic and linear regression analyses, we could not do so in the quantile regression analysis of median door-to-needle time because there is no well-accepted method to do so. Finally, we could not assess for other adverse effects of crowding such as the inappropriate or incorrect use of thrombolysis, the inappropriate withholding of thrombolysis because of prolonged ED delays, or the failure to administer other acute myocardial infarction therapies such as acetylsalicylic acid.

Table 3.
*Logistic regression analyses of network ED crowding and door-to-needle time performance.**

Outcome	Network Crowding	OR (95% CI) Unadjusted	OR (95% CI) Adjusted†
Door-to-needle time delay (>30 min)	None	Reference	Reference
	Moderate	1.27 (0.97–1.66)	1.21 (0.89–1.63)
	High	1.38 (1.07–1.77)	1.32 (0.98–1.79)
Major door-to-needle time delay (>60 min)	None	Reference	Reference
	Moderate	1.12 (0.93–1.36)	1.06 (0.86–1.29)
	High	1.38 (1.13–1.69)	1.40 (1.12–1.75)

*Estimated with robust standard errors to account for clustering within admitting hospital.
†Adjusted analyses controlled for age, sex, ECG characteristics, vital signs, cardiac history, symptom onset, thrombolytic drug used, hospital size, day of week, time of day, and year of admission.

DISCUSSION

We found that crowding in EDs is associated with time-to-thrombolysis delays for patients with suspected acute myocardial infarctions. In adjusted analyses, high network crowding was associated with a 40% (95% CI 12% to 75%) increase in the odds of a major door-to-needle time delay (>60 minutes) and a 5.8-minute (95% CI 2.7 to 9.0 minutes) increase in the median door-to-needle time compared with conditions of no network crowding. Moderate network crowding was associated with an increase of 3.0 minutes (95% CI 0.1 to 6.0 minutes) in median door-to-needle time compared with no crowding and was associated with a trend toward increased odds of door-to-needle time delay and major delay. These analyses controlled for patient factors, type of acute myocardial infarction, and hospital and treatment factors.

Time to thrombolysis is considered a core hospital performance measure in the United States,[20,36] Canada,[6] and the United Kingdom.[7,37] Studies of thrombolysis in acute myocardial infarction have demonstrated that shorter door-to-needle times are associated with lower mortality,[37-41] with the benefit increasing nonlinearly the earlier it is given.[14,37,42] Indeed, one jurisdiction has recently lowered their door-to-needle time target to 20 minutes from 30 minutes,[14] and studies suggest that a 60-minute delay in door-to-needle time is associated with the loss of 69 lives per 1,000 patients treated (95% CI 16 to 144).[14,42]

These estimates allow us to express the delays we observed associated with ED crowding in terms of excess mortality. Because a 60-minute door-to-needle time delay for 1,000 patients treated results in 69 lives lost (95% CI 16 to 144),[14,42] we can estimate that a 1-minute delay results in 1.15 lives lost (95% CI 0.3 to 2.4). The acute myocardial infarction patients in our study exposed to moderate and high network crowding groups had increased median door-to-needle times of 3.0 and 5.8 minutes, respectively. The delay associated with high network crowding would therefore be expected to result

in 7 additional deaths (95% CI 2 to 14) per 1,000 patients treated, and the 3-minute median delay with moderate network crowding would be expected to result in 3 additional deaths (95% CI 1 to 7) per 1,000 patients treated. Therefore, among the 989 acute myocardial infarction patients exposed to high and 977 patients exposed to moderate network crowding in our study, we can estimate that there were an additional 10 deaths (95% CI 3 to 21) associated with crowding.

During the study period, the overall median door-to-needle time was 44 minutes, which is higher than the 38-minute median door-to-needle time reported by the US National Registry of Myocardial Infarction in 1999[43] but lower than that reported in a Quebec registry.[15] Simply reducing the overall median door-to-needle time in any hospital system toward the target of less than 30 minutes would save lives, and indeed a more recent report showed that median door-to-needle time had declined to 37 minutes in several Ontario hospitals.[16] However, substantial improvements in door-to-needle time have been achieved in both the United States[43] and Canada[16] in the past several years, and further incremental improvements will likely become ever more difficult to achieve. Further success may require a better understanding of the systemic factors leading to delays and the design of appropriate strategies to deal with them.

Our results suggest that ED crowding is one such factor leading to delay. Furthermore, they suggest that crowding affects EDs at an ecologic level within networks of nearby hospitals. We found that the increase in median door-to-needle time and the odds of delay and major delay were all greater under conditions of high network crowding (5.8 minutes; OR 1.32 and OR 1.40, respectively) than they were when we restricted our analysis to crowding at the treating hospital only (3.6 minutes; OR 1.23 and OR 1.23, respectively). This suggests that, as crowding worsened at one hospital, it gradually spread to others within a network of hospital EDs, perhaps as a result of ambulance diversion systems redistributing patient load. Therefore, efforts to reduce crowding at one hospital may have limited success if other network hospitals are not making similar efforts at their sites. Interventions to reduce crowding are likely to have the greatest impact if they are coordinated across a hospital network or community as opposed to ad hoc efforts in individual hospitals. Solutions implemented at only 1 hospital (eg, increased use of ambulance diversion) might temporarily improve its situation but would worsen the situation at neighboring ones, which, our results suggest, would be counterproductive for all EDs in the network. An alternative solution might be coordinated efforts across the community or hospital network to address root causes of crowding, such as improving primary and ambulatory care services for elderly patients with chronic illnesses, exacerbations of which frequently lead to hospitalization and ED crowding,[25,44-46] or increasing capacity and efficiency across the network for patients admitted from EDs.[25]

ED crowding has received substantial attention in recent years in scientific publications[1,4,5,22,24,30,47-49] and the popular media,[50-55] but there has been little systematic evidence of deleterious effects on patients.[34] Our results demonstrate that crowding is more than just a nuisance and may have adverse consequences for patients. Furthermore, they suggest that hospitals will have difficulty isolating themselves from conditions prevalent at neighboring institutions, and that solutions need to be coordinated within networks of hospitals to improve quality of care for all patients.

Author contributions: MJS originated the hypothesis, designed the study, and had main responsibility for interpreting the results and writing the manuscript. MV helped design the study, conducted data analyses, and helped interpret the results and write the manuscript. GS collected data, organized a database, conducted data analyses, and edited the manuscript. LM helped design the study, interpret the results, and edit the manuscript. PD provided the MACSTRAK data and helped design the analysis, interpret the data, and edit the manuscript. MJS takes responsibility for the paper as a whole.

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REFERENCES

1. Fatovich DM. Emergency medicine. *BMJ.* 2002;324:958-962.
2. Derlet RW, Richards JR. Emergency department overcrowding in Florida, New York, and Texas. *South Med J.* 2002;95:846-849.
3. Derlet RW, Richards JR, Kravitz RL. Frequent overcrowding in US emergency departments. *Acad Emerg Med.* 2001;8:151-155.
4. Asplin BR. Does ambulance diversion matter? *Ann Emerg Med.* 2003;41:477-480.
5. Derlet RW, Richards JR. Overcrowding in the nation's emergency departments: complex causes and disturbing effects. *Ann Emerg Med.* 2000;35:63-68.

6. Lindsay P, Schull M, Bronskill S, et al. The development of indicators to measure the quality of clinical care in emergency departments following a modified-Delphi approach. *Acad Emerg Med.* 2002;9:1131-1139.
7. Clinical Effectiveness and Evaluation Unit, Royal College of Physicians. *How Hospitals Manage Heart Attacks: First Public Report of the Myocardial Infarction National Audit Project*. London, United Kingdom: Royal College of Physicians, Myocardial Infarction National Audit Project; 2002, 1–11.
8. Ryan TJ, Anderson JL, Antman EM, et al. ACC/AHA guidelines for the management of patients with acute myocardial infarction: executive summary: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (Committee on Management of Acute Myocardial Infarction). *Circulation.* 1996;94:2341-2350.
9. National Heart Attack Alert Coordinating Committee. Emergency department: rapid identification and treatment of patients with acute myocardial infarction. *Ann Emerg Med.* 1994;23:311-329.
10. Pell A, Miller H, Robertson C. Effect of "fast-track" admission for acute myocardial infarction on delay to thrombolysis. *BMJ.* 1992;304:83-87.
11. Maxey C. A case map reduces time to administration of thrombolytic therapy in patients experiencing an acute myocardial infarction. *Nurs Case Manage.* 1997;2: 229-237.
12. Lambrew CT, Bowlby LJ, Rogers WJ, et al. Factors influencing the time to thrombolysis in acute myocardial infarction: Time to Thrombolysis Substudy of the National Registry of Myocardial Infarction-1. *Arch Intern Med.* 1997;157:2577-2582.
13. Hand M, Brown C, Horan M, et al. The National Heart Attack Alert Program: progress at 5 years in educating providers, patients, and the public and future directions. *J Thromb Thrombol.* 1998;6:9-17.
14. Department of Health, UK Government. *Review of Early Thrombolysis: Faster and Better Treatment for Heart Attack Patients*. London, United Kingdom: Department of Health, UK Government; 2003, 1-17.
15. Brophy JM, Diodati JG, Bogaty P, et al. The delay to thrombolysis: an analysis of hospital and patient characteristics. Quebec Acute Coronary Care Working Group. *CMAJ.* 1998;158:475-480.
16. Tu JV, Donovan LR, Lee DS, et al. *Quality of Cardiac Care in Ontario*. Toronto, Ontario, Canada: ICES; 2004:1-37.
17. Davis LL, Evans JJ, Strickland JD, et al. Delays in thrombolytic therapy for acute myocardial infarction: association with mode of transportation to the hospital, age, sex, and race. *Am J Crit Care.* 2001;10:35-42.
18. Schull MJ, Morrison LJ, Vermeulen M, et al. Emergency department gridlock and out-of-hospital delays for cardiac patients. *Acad Emerg Med.* 2003;10:709-716.
19. The Heart and Stroke Foundation of Canada. Canadian Cardiovascular Society, Canadian Association of Emergency Physicians, Emergency Cardiac Care Coalition. Recommendations for ensuring early thrombolytic therapy for acute myocardial infarction. *CMAJ.* 1996;154:483-487.
20. Joint Commission on Accreditation of Healthcare Organizations. *Acute Myocardial Infarction Core Performance Measures: Specifications Manual for National Implementation of Hospital Core Measures*. Oakbrook Terrace, IL: Joint Commission on Accreditation of Healthcare Organizations; 2002.
21. United States General Accounting Office. *Hospital Emergency Departments: Crowded Conditions Vary Among Hospitals and Communities*. Washington, DC: United States General Accounting Office; 2003:1-65. Publication GAO-03-460.
22. Asplin BR, Magid DJ, Rhodes KV, et al. A conceptual model of emergency department crowding. *Ann Emerg Med.* 2003;42:173-180.
23. Scheulen JJ, Li G, Kelen GD. Impact of ambulance diversion policies in urban, suburban, and rural areas of central Maryland. *Acad Emerg Med.* 2001;8:36-40.
24. Schull MJ, Szalai J, Schwartz B, et al. Emergency department overcrowding following systematic hospital restructuring: trends at twenty hospitals over ten years. *Acad Emerg Med.* 2001;8:1037-1043.
25. Schull M, Lazier K, Vermeulen M, et al. Emergency department contributors to ambulance diversion: a quantitative analysis. *Ann Emerg Med.* 2003;41:467-476.
26. Sapsford RT. *Standards for Ontario Hospital Emergency Units Providing Ambulance Access*. Toronto, Ontario, Canada: Ministry of Health of Ontario; 1999.
27. Ontario Hospital Association and Ministry of Health. *OHA Region 3: Emergency Services Working Group: Final Report*. Toronto, Ontario, Canada: Ontario Hospital Association; 1998.
28. Gould WW. *Quantile Regression With Bootstrapped Standard Errors*. College Station, TX: Stata Corporation; 1992:167-176.
29. Austin PA, Schull MJ. Quantile regression: a statistical tool for pre-hospital research. *Acad Emerg Med.* 2003;10:789-797.
30. Schull MJ, Morrison LJ, Vermeulen M, et al. Emergency department overcrowding and ambulance transport delays for patients with chest pain. *CMAJ.* 2003;168:277-283.
31. Austin PC, Daly PA, Tu JV. A multicenter study of the coding accuracy of hospital discharge administrative data for patients admitted to cardiac care units in Ontario. *Am Heart J.* 2002;144:290-296.
32. Brown DF. Emergency department divert: an analysis of the contributions of ED volume, hospital occupancy, and internal medicine inpatient census [abstract]. *Acad Emerg Med.* 2001;8:575.
33. Crowding Resources Task Force, Franaszek JB, ed. *American College of Emergency Physicians. Responding to Emergency Department Crowding: A Guidebook for Chapters*. Dallas, TX: American College of Emergency Physicians; 2002:4-58.
34. Asplin B. Does ambulance diversion matter? *Ann Emerg Med.* 2003;41:477-480.
35. Dickinson G. Emergency department overcrowding. *CMAJ.* 1989;140:270-271.
36. 7th statement of work. Quality of care measure specifications: acute myocardial infarction (AMI). Center for Medicare and Medicaid Services (CMS). 1-8-2002.
37. Boland A, Dundar Y, Bagust A, et al. Early thrombolysis for the treatment of acute myocardial infarction: a systematic review and economic evaluation. *Health Technol Assess.* 2003;7(15):1-133.
38. ISIS-2 (Second International Study of Infarct Survival) Collaborative Group. Randomised trial of intravenous streptokinase, oral aspirin, both, or neither among 17,187 cases of suspected acute myocardial infarction: ISIS-2. *Lancet.* 1988;2:349-360.
39. Fibrinolytic Therapy Trialists' (FTT) Collaborative Group. Indications for fibrinolytic therapy in suspected acute myocardial infarction: collaborative overview of early mortality and major morbidity results from all randomised trials of more than 1,000 patients. *Lancet.* 1994;343:311-322.
40. The GUSTO Investigators. An international randomized trial comparing four thrombolytic strategies for acute myocardial infarction. *N Engl J Med.* 1993;329:673-682.
41. Gruppo Italiano per lo Studio della Streptochinasi nell'Infarto Miocardico (GISSI). Effectiveness of intravenous thrombolytic treatment in acute myocardial infarction. *Lancet.* 1986;1:397-402.
42. Rawles JM. Quantification of the benefit of earlier thrombolytic therapy: five-year results of the Grampian Region Early Anistreplase Trial (GREAT). *J Am Coll Cardiol.* 1997;30:1181-1186.
43. French WJ. Trends in acute myocardial infarction management: use of the National Registry of Myocardial Infarction in quality improvement. *Am J Cardiol.* 2000;85:5B-9B.
44. Upshur RE, Knight K, Goel V. Time-series analysis of the relation between influenza virus and hospital admissions of the elderly in Ontario, Canada, for pneumonia, chronic lung disease, and congestive heart failure. *Am J Epidemiol.* 1999;149:85-92.
45. Schull MJ, Mamdani M, Fang J. Community influenza outbreaks and emergency department ambulance diversion. *Ann Emerg Med.* 2004;44:61-67.
46. Nichol KL, Nordin J, Mullooly J, et al. Influenza vaccination and reduction in hospitalizations for cardiac disease and stroke among the elderly. *N Engl J Med.* 2003; 348:1322-1332.
47. Derlet RW, Richards JR, Kravitz RL. ED overcrowding: definition and magnitude [abstract]. *Acad Emerg Med.* 2000;7:544.
48. Gallagher EJ, Lynn SG. The etiology of medical gridlock: causes of emergency department overcrowding in New York City. *J Emerg Med.* 1990;8:785-790.
49. Redelmeier DA, Blair PJ, Collins WE. No place to unload: a preliminary analysis of the prevalence, risk factors, and consequences of ambulance diversion. *Ann Emerg Med.* 1994;23:43-47.
50. Shute N, Marcus MB. Code blue: crisis in the ER. *U.S. News and World Report.* October 9, 2001:54-68.
51. Code red. *Toronto Sun.* March 20, 2001:6.
52. American College of Emergency Physicians Web site. ED crowding makes national headlines. Available at: http://www.acep.org/1,2663,0.html. Accessed October 4, 2004.
53. Critical-care bypass may end. *Globe & Mail.* February 8, 2001:A5.
54. No critical patients will be turned away Health Minister says. *National Post.* March 20, 2001:A3.
55. Emergency room crisis likely to worsen. *Toronto Star.* June 8, 2001:A2.

APPENDIX.

Ontario Ministry of Health definitions of ambulance diversion status.[26]

Normal Status: A status that signifies that the emergency unit is able to accept all patients, including those arriving by ambulance.

Redirect Consideration: A status that signifies that the emergency unit is able to accept only critically ill or injured patients arriving by ambulance. All other ambulance patients should be referred by the ambulance dispatcher, where possible or feasible, to emergency units within the catchment area indicating a normal status.

Critical Care Bypass: A status that signifies that it is unsafe for the emergency unit to receive critically ill or injured patients by ambulance because patient care would be compromised. During critical care bypass, all ambulance patients will be redirected to emergency units within the catchment area indicating a normal status or, alternatively, redirect consideration status.