EMA Emergency Medicine Australasia

Emergency Medicine Australasia (2021) **33**, 655–664 doi: 10.1111/1742-6723.13699

ORIGINAL RESEARCH

Emergency department crowding and mortality for patients presenting to emergency departments in New Zealand

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Abstract

Objective: The association between ED crowding and mortality has been established internationally, but not in New Zealand. The aim was to determine which measures of crowding were associated with mortality for new patients presenting to New Zealand EDs. The primary outcome was mortality for patients within 7 days of arrival in the ED.

Methods: This was a retrospective cohort study, using administrative data from 2006 to 2012. The crowding conditions at the time of presentation of each patient were recreated. Multivariable Cox proportional hazard modelling was used to determine the probability of death within 7 days of the presentation to ED. Each crowding measure was added independently to the optimum mortality model to determine how each crowding metric influenced the model.

Results: Twenty-five of 28 (89%) eligible acute hospitals in New Zealand were included, with 5 793 767 ED visits by 2 214 865 individuals. Seven-day mortality was higher for patients arriving at times when there was more than 10% hospital access block (hazard ratio [HR] 1.10, 95% confidence interval [CI] 1.05, 1.17) or non-compliance with the 4-h emergency access target (HR 1.07, 95% CI 1.01, 1.12). ED occupancy did not influence the model importantly, while the number of arrivals in the previous 6 h was associated with lower mortality (HR 0.90, 95% CI 0.84, 0.97).

Conclusion: Access block had the strongest association with 7-day mortality. That ED occupancy and the number of arrivals were not associated with increased mortality suggests that system issues related to long ED stays may be most important in the link between ED crowding and mortality.

Key words: *access block, crowding, emergency service, hospital, mortality.*

Key findings

- Access block was the crowding measure with the strongest association with increased mortality for patients presenting to EDs. New patients presenting to EDs had a 10% relative increase in mortality when more than 10% of current patients waiting for admission were suffering access block.
- Not meeting ED LOS targets was also associated with increased mortality for new arrivals, while ED occupancy and number of arrivals were not associated with increased mortality.

Introduction

Previous studies have shown the association between high ED occupancy based on total patient time under treatment per shift[1] or the combination of access block for admission and high hospital occupancy[2] and mortality for patients admitted to hospital from the ED in Australia. These studies found that the relative risk of inpatient death approximately 30% higher for patients presenting at times of crowding.[2] Prior research in New Zealand has found that introduction of a time target performance measure for ED was associated with reductions in ED length of stay (LOS), access block and mortality for patients in the ED.[3] However, due to a pre-target trend towards falling inpatient mortality, the further slight reduction in in-hospital mortality observed in the present study post-target was not statistically significant.[3] To date, no studies have demonstrated that access block or any other measure of ED crowding is associated with excess mortality for acute patients in the New Zealand setting. The aim of the current study was to determine which measure(s) of ED crowding were associated with mortality for new patients presenting to the New Zealand EDs. The primary outcome was mortality for patients within 7 days of arrival in the ED.

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Accepted 27 November 2020

Methods

This was a retrospective cohort study, using administrative data from patients presenting to EDs throughout New Zealand from 2006 to 2012. The association between measures of crowding and mortality were tested, after adjusting for patient and system-level covariates also thought to be associated with mortality.

Setting

Twenty-five of 28 (89%) eligible acute hospitals in New Zealand were included, for the years 2006 to 2012 inclusive. There were four Australasian College for Emergency Medicine (ACEM) Level 1, 11 Level 2, four Level 3 and six Level 4 hospitals.[4] The included hospitals provide acute care for 91% of New Zealand's population and had an annual census of approximately 1 million visits in 2012.[3]

Data sources

Selection of hospitals

Of 34 potentially eligible public hospitals in New Zealand with an ED, six did not staff the ED on-site 24 h a day, and these were excluded. Of the 28 eligible hospitals, three were unable to supply data for technical reasons and these were also excluded (two were Level 2 (15% of Level 2) and one Level 4 (14% of Level 4).

Data

This was a secondary analysis of data collected for the shorter stays in ED National Research project which spanned the years 2006–2012.[3] A database was created by linking all ED visits for the study years identified from the National Non-Admitted Patient Collection[5] and the National Minimum Dataset,[6] which are maintained by the Ministry of Health in New Zealand and contain event-based information for all ED and hospital admissions respectively. A unique presentation date and time to the ED defined a visit in the database. Visit dates and demographic data were extracted and linked via a unique patient identifier, the National Health Index number,[7] to local District Health Board (DHB) databases containing detailed time stamps of the ED patient journey (presentation time, triage, assessment, admission and discharge times) in each hospital for each event. Duplicate events were identified and removed. To account for multiple events within a single hospital visit (which may be done for administrative reasons at DHB level) events relating to a single visit were merged. A complete description of the data definitions for each variable and the data collection process has previously been published[8] and the list of variables is provided in Appendix S1.

The number of beds for each ED was sourced from surveys of ED point occupancy conducted in all EDs in the country bi-annually for the years 2010–2012.[9] Where data was not available for the years 2006–2009, the first value available in 2010 was imputed.

Hospital Level was determined from the ACEM survey of Clinical Directors in 2014 and for non-ACEM accredited hospitals by the authors based on the hospital location, number of presentations, staffing and function. The hospitals were numbered randomly within Level to preserve anonymity.

Exposure variables

All visits were included in the calculation for the crowding variables. To reveal the crowding conditions faced by each patient on arrival at ED, the database was imported into a relational database for data management (PostgreSQL V10.0). This was held on a secure server (Nectar Cloud) via a University of Auckland subscription. Variables were created in the PostgreSQL database directly or using statistical software R V3.5.1 (64 bit) with the R Studio V1.1.456 interface (http://r-project.org; R Foundation, Auckland, New Zealand). Table 1 shows the names and descriptions of the crowding exposure variables.

Covariates

Potential confounders included as covariates in the model were selected *a-priori* due to their possible likely association with either the exposure or outcome variables (Table 2).

Outcome variable

Mortality was determined by the date of death and discharge type. This information is collected at a national level from data provided to the registry of births deaths and marriages by funeral directors based on death certificates which are completed by medical practitioners at or soon after the time of death. Data for deaths held in the National Collections according to a patient's unique National Health Index is updated monthly and is considered reliable (Appendix S1).

The unit of analysis was the patient rather than the visit. Only the first visit by each person during the study period was counted in the survival analysis to maintain the assumption of independence. This approach identifies the lower bound of events per visit, but closely approximates the true rate (Appendix S1).

Sample size

As this data contained more than 90% of the population available to study and included over 2 million individuals, a sample size calculation was not necessary. With large data sets, there is a danger of finding clinically unimportant differences statistically significant. The clinically important difference in mortality was determined prior to undertaking the analysis as a 10% relative difference.[3]

Statistical analysis

Categorical data were described using proportions and 95% confidence intervals (CIs). Continuous data were categorised into clinically meaningful groups after exploring their underlying distributions (Appendix S1).

Survival (time to event) analysis was used as both the exposure[10] and outcome variables may be time dependent.[11] When this is the case, survival analysis is thought to be more appropriate than logistic regression at a single point in time to estimate the effect of crowding on an outcome.[10] Kaplan Meier curves were constructed for each exposure

TABLE 1. *Exposure (crowding) variables*

Variable	Description and thresholds for categories
ED LOS	Exit time – presentation time. This is the median ED LOS of other patients in ED at the time of the index patient arrival. Thresholds were 2, 4, 6, 8 h
Total patient care time	Sum of ED LOS of other patients at time of index patient arrival. Thresholds are quartiles of total patient care time
Time target for ED LOS	Proportion of patients in ED with an ED LOS < threshold at the time of the index patient arrival. Thresholds are 90% <4 h and 95% <6 h
Access block	Proportion of patients with a decision to admit with ED LOS >8 h at the time of the index patient arrival
Boarding duration	Time spent in ED after the decision to admit. This is the median boarding duration of all other patients in ED at the time of the index patient arrival. Thresholds are 1, 2, 4 h
Time target for boarding duration	Proportion of patients in ED with a boarding duration < threshold at the time of the index patient arrival. Thresholds are quartiles of boarding duration target success. Thresholds were 2 and 4 h
Time to assessment	Assessment time – presentation time. This is the time of first sign on by a treating clinician of other patients at the time of arrival of the index patient. Thresholds are 30, 60, 90, 120 min
Triage time compliance	This is the proportion of patients already seen by a treating clinician within the ACEM recommended time from arrival according to their triage category (ATS). Thresholds are quartiles of triage time compliance
ED occupancy	Number of patients in ED at the time of the index patient arrival/number of beds. Thresholds are 85%, 100% and 120%
Boarder number	Number of patients in ED with a decision to admit to hospital at the time of the index patient arrival. Thresholds are quartiles of the number boarding
Arrivals in previous hour/6 h	The number of presentations to ED in the period prior to the index patient's presentation (does not count the index patient). Thresholds are quartiles of number of arrivals

ATS, Australasian Triage Scale: 1 = most urgent, 5 = least urgent; LOS, length of stay.

variable and the potential confounding variables and differences between the categories were tested with the log-rank test (Appendix S2). Multivariable Cox proportional hazard modelling was used to determine the probability of death within 7 days of the presentation to ED based on clinically relevant categories of each crowding metric in the unadjusted models. The potential confounding variables (covariates) were explored using Cox Proportional Mixed Effect models. This was done stepwise in order of association with the outcome variable to find the best fitting model based on the value of the Akaike information criterion (AIC).[12] The final model included triage category, age, arrival mode, trauma/non-trauma status, ethnicity, season, deprivation and day of the week. The addition of hospital level produced a competing model (AIC difference <2) at the cost of an extra variable, so this was not included.[12] Gender and shift of arrival did not improve the model, so these were also not included. Hospital and year were included in the model as separate random terms.

In the adjusted analysis, each crowding metric was added separately to the best fitting model of the confounding variables to determine whether the crowding term influenced the model. If the metric improved the model, then it was considered to impact on mortality. If the hazard ratio (HR) was less than one the association was a reduction in mortality and if the HR was greater than one the association was an increase in mortality. If the model was not improved with the addition of the metric then the metric was not considered to be associated with mortality.

Statistical software R V3.5.1 (64 bit) was used to analyse the data using R Studio V1.1.456 interface (http://r-project.org; R Foundation) with separate packages for the univariate analysis,[13] Kaplan Meier plots,[14] and multivariate analyses.[15] Statistical significance was taken at $P < 0.05$.

Ethics

The Northern-A Health and Disability Ethics Committee granted approval for the use of the data as an amendment to the original ethics approval for the Shorter Stays in ED National Research Project.[3] New Zealand Health and Disabilities Ethics Committees reference: MEC/10/06/060/AM06, 17 March 2017.

TABLE 2. *Covariates in the adjusted model*

Variable	Description	Rationale
Age	Calculated as date of presentation – date of birth continuous Categorical: <5/5, 14/15, 34/35, 64/65+	Mortality association
Gender	Categorical: male/female	Mortality association
Ethnicity	Categorical Māori/Pacific/European/Asian/Other	Mortality association
Deprivation†	Quintiles of deprivation based on geographic area of domicile: 1 = least deprived/5 = most deprived	Mortality association
Triage category	According to the ACEM categories of urgency to be seen: 1 = most urgent/ 5 = least urgent	Mortality association
Ambulance arrival	Categorical: Yes/No Whether the patient arrived by ambulance (including helicopter) or self presented	Mortality association
ACC status	Categorical; Yes/No In New Zealand this distinguishes between trauma/overdose and non-trauma cases; a crude approximation of type of condition	Mortality association
Hospital	Categorical	Different conditions and staffing
Year	Categorical 2006/2007/2008/2009/2010/2011/ 2012	Account for different patterns of disease and changes in practice in different years
Situation change	Categorical: Improving/Static/ Worsening according to the variables edor (occupancy) and TPCT (total patient care time) at time of arrival of index patient	Account for changing situation at times of presentation with same level of exposure variable
Shift of arrival	Categorical 08.00, 15.59 hours – Day 16.00, 23.59 hours – Evening 00.00, 07.59 hours – Night	Associated with different staffing levels and degrees of crowding
Day of week	Categorical 00:00 to 23:59 for each day Monday/Tuesday/Wednesday/ Thursday/Friday/Saturday/Sunday	Mortality association
Season	Categorical: based on New Zealand seasons defined below Spring: September–November Summer: December–February Autumn: March–May Winter: June–August	Mortality association

†NZDep2006 Index of Deprivation 2007, 11th March 2011. Available from URL: http://www.wnmeds.ac.nz/NZDep-info.html.[10] ACC, Accident Compensation Corporation; ACEM, Australasian College for Emergency Medicine.

TABLE 3. *Categories of crowding metric, number of deaths and unadjusted mortality*

Crowding metric†	Categories	Number in category, %	7-day mortality, *n*	7-day mortality, % (95% CI)	Unadjusted hazard ratio	95% CI
Arrivals in previous hour	(0,3]	619 622, 28.2%	3189	0.51 (0.50, 0.53)	Reference	—
	(3,6]	626 550, 28.5%	3095	0.49 (0.48, 0.51)	0.96	0.91, 1.01
	(6,9]	439 266, 20%	2231	0.51 (0.49, 0.53)	0.98	0.93, 1.04
	(9,46]	511 632, 23.3%	2642	0.52 (0.50, 0.54)	0.99	0.94, 1.04
Arrivals in previous 6 h	(0,19]	513 840, 23.4%	2611	0.51 (0.49, 0.53)	Reference	—
	(19,32]	561 360, 25.6%	2879	0.51 (0.49, 0.53)	1.00	0.95, 1.06
	(32,51]	558 898, 25.4%	2708	0.48 (0.47, 0.50)	0.95	0.90, 1.00
	(51,Max]	562 972, 25.6%	2959	0.53 (0.51, 0.54)	1.02	0.96, 1.07
Time to assessment (min)	(0,30]	835 453, 38%	4066	0.49 (0.47, 0.50)	Reference	—
	(30,60]	910 352, 41.4%	4688	0.51 (0.50, 0.53)	1.05	1.01, 1.10
	(60,90]	298 722, 13.6%	1544	0.52 (0.49, 0.54)	1.06	0.99, 1.12
	(90,120]	86 199, 3.9%	480	0.56 (0.51, 0.61)	1.15	1.05, 1.27
	(120,Max]	66 344, 3%	379	0.57 (0.51, 0.63)	1.17	1.05, 1.30
Triage time compliance	(0,28.6]	562 893, 25.6%	2976	0.53 (0.51, 0.55)	Reference	—
	(28.6,46.9]	559 603, 25.5%	2945	0.53 (0.51, 0.55)	0.99	0.94, 1.05
	(46.9,70]	560 969, 25.5%	3005	0.54 (0.52, 0.56)	1.02	0.96, 1.07
	(70,100]	513 605, 23.4%	2231	0.43 (0.42, 0.45)	0.83	0.79, 0.88
Median boarding duration (h)	(0,1]	655 988, 29.9%	3005	0.46 (0.44, 0.47)	Reference	—
	(1,2]	717 329, 32.6%	3458	0.48 (0.47, 0.50)	1.05	1.00, 1.11
	(2,4]	576 856, 26.3%	3105	0.54 (0.52, 0.56)	1.18	1.12, 1.24
	(4,Max]	246 897, 11.2%	1589	0.64 (0.61, 0.68)	1.42	1.33, 1.51
Proportion with boarding duration >2 h	(0,0.25]	727 766, 33.1%	3225	0.44 (0.43, 0.46)	Reference	—
	(0.25,0.5]	754 319, 34.3%	3797	0.50 (0.49, 0.52)	1.13	1.08, 1.18
	(0.5,0.75]	469 550, 21.4%	2697	0.57 (0.55, 0.60)	1.29	1.23, 1.36
	(0.75,1]	245 435, 11.2%	1438	0.59 (0.56, 0.62)	1.34	1.26, 1.42
Proportion with boarding duration >6 h	(0,0.25]	1 827 518, 83.2%	8720	0.48 (0.47, 0.49)	Reference	—
	(0.25,0.5]	275 833, 12.6%	1767	0.64 (0.61, 0.67)	1.35	1.29, 1.43
	(0.5,0.75]	69 372, 3.2%	523	0.75 (0.69, 0.82)	1.58	1.45, 1.73
	(0.75,1]	24 347, 1.1%	147	0.60 (0.51, 0.70)	1.30	1.10, 1.53
Median ED LOS (h)	(0,2]	1 080 764, 49.2%	5019	0.46 (0.45, 0.48)	Reference	—
	(2,4]	856 364, 39%	4360	0.51 (0.49, 0.52)	1.09	1.05, 1.14
	(4,6]	146 300, 6.7%	976	0.67 (0.63, 0.71)	1.44	1.35, 1.55
	(6,8]	44 837, 2%	293	0.65 (0.58, 0.73)	1.42	1.26, 1.60
	(8,115]	68 805, 3.1%	509	0.74 (0.68, 0.80)	1.59	1.45, 1.75
90% ED LOS <4 h	Target met	611 087, 27.8%	2703	0.44 (0.43, 0.46)	Reference	—
	Not met	1 585 983, 72.2%	8454	0.53 (0.52, 0.54)	1.20	1.15, 1.25
95% ED LOS <6 h	Target met	896 682, 40.8%	4012	0.45 (0.43, 0.46)	Reference	—
	Not met	1 300 388, 59.2%	7145	0.55 (0.54, 0.56)	1.23	1.18, 1.27
Access block	(0,0.1]	1 516 438, 69%	7004	0.46 (0.45, 0.47)	Reference	—
	(0.1,0.25]	359 713, 16.4%	2006	0.56 (0.53, 0.58)	1.21	1.15, 1.27

(*Continues*)

TABLE 3. *Continued*

Crowding metric†	Categories	Number in category, %	7-day mortality, *n*	7-day mortality, % (95% CI)	Unadjusted hazard ratio	95% CI
	(0.25,0.5]	236 982, 10.8%	1502	0.63 (0.60, 0.67)	1.38	1.30, 1.46
	(0.5,0.75]	66 830, 3%	536	0.80 (0.73, 0.87)	1.73	1.59, 1.89
	(0.75,1]	17 107, 0.8%	109	0.64 (0.52, 0.76)	1.42	1.17, 1.71
TPCT	(0,21.9]	485 977, 22.1%	2177	0.45 (0.43, 0.47)	Reference	—
	(21.9,52.1]	532 454, 24.2%	2537	0.48 (0.46, 0.50)	1.06	1, 1.12
	(52.1,120]	555 796, 25.3%	2840	0.51 (0.49, 0.53)	1.13	1.06, 1.19
	(120,Max]	622 843, 28.3%	3603	0.58 (0.56, 0.60)	1.27	1.21, 1.34
Boarder number	(0,2]	534 256, 24.3%	2309	0.43 (0.42, 0.45)	Reference	—
	(2,7]	571 831, 26%	2731	0.48 (0.46, 0.50)	1.10	1.04, 1.16
	(7,15]	483 793, 22%	2589	0.54 (0.52, 0.56)	1.22	1.16, 1.29
	(15,59]	607 190, 27.6%	3528	0.58 (0.56, 0.60)	1.33	1.26, 1.4
ED occupancy	(0,0.85]	1 183 715, 53.9%	6003	0.51 (0.49, 0.52)	Reference	—
	(0.85,1]	284 672, 13%	1281	0.45 (0.43, 0.48)	0.88	0.83, 0.94
	(1,1.25]	275 440, 12.5%	1434	0.52 (0.49, 0.55)	1.02	0.96, 1.08
	(1.25,Max]	453 243, 20.6%	2439	0.54 (0.52, 0.56)	1.06	1.01, 1.11
Change in ED occupancy	Decreasing ↓	543 005, 24.7%	2800	0.52 (0.50, 0.54)	Reference	—
	Static 0	551 611, 25.1%	2759	0.50 (0.48, 0.52)	0.97	0.92, 1.02
	Increasing ↑	1 102 454, 50.2%	5598	0.51 (0.50, 0.52)	0.98	0.94, 1.03
Change in TPCT	Decreasing ↓	658 352, 30.0%	3259	0.50 (0.48, 0.51)	Reference	—
	Static 0	11 094, 0.5%	71	0.64 (0.49, 0.79)	1.33	1.05, 1.69
	Increasing ↑	1 527 624, 69.5%	7827	0.51 (0.50, 0.52)	1.03	

†Conditions in the ED when index patient arrives. Categories for each variable were chosen to reflect clinically meaningful groups. Round bracket = includes value, square bracket = up to but not including value. CI, confidence interval; LOS, length of stay; TPCT, total patient care time.

Results

There were 5 793 767 ED visits to the study hospitals by 2 214 865 individuals over the 7-year study period. There were 17 795 visits with data errors which were excluded. A further 50 465 patients had missing data for one or more variables, these were excluded from the multivariable analysis. This left 2 146 605 individuals for the multivariable analysis (96.9%).

The demographics of the study population, variation in crowding metrics by level of hospital and unadjusted mortality according to each category of the covariates are shown in Appendix S1. Level 4 hospitals had higher levels of crowding. Patients in triage categories 1 and 2, greater than 65 years and who arrived by ambulance had the highest mortality. Mortality was highest in the winter and lowest towards the end of the week, most likely representing different types of presentations during those times. There was a reduction in mortality by year, which may be an artefact of the selection process, as the first visit in the database in the earlier years is more likely also to be the last visit for that person. However, there was also a trend over time towards reduced mortality by a overall visit in this cohort.[3]

Table 3 shows the number and proportion of deaths within 7 days for each category of crowding metric.

There were trends towards increased risk of mortality as crowding increased for: time to assessment; boarding duration; ED LOS; access block, total patient care time (TPCT); number of boarders and when TPCT was static. There was a reduced risk of mortality for high triage time compliance, and when ED occupancy was 85–99%. Compliance with both ED LOS targets was associated with lower mortality. The number of arrivals (1 and 6 h) or change in occupancy at time of arrival were not associated with mortality.

Multivariate analysis

Table 4 shows the association with mortality for each crowding metric after confounding variables that were associated with mortality

TABLE 4. *Adjusted mortality by crowding metric*

Crowding metric†	Categories	Hazard ratio	95% CI	*P*	AIC difference‡
Arrivals in previous hour	(0,3]	Reference	—		+2.9
	(3,6]	0.99	0.94, 1.04	0.690	
	(6,9]	0.99	0.93, 1.05	0.670	
	(9,46]	**0.91**	**0.85, 0.97**	**0.005**	
Arrivals in previous 6 h	(0,19]	Reference	—		+11.3
	(19,32]	1.03	0.97, 1.09	0.290	
	(32,51]	0.96	0.91, 1.03	0.260	
	(51,Max]	**0.90**	**0.84, 0.97**	**0.004**	
Time to assessment (min)	(0,30]	Reference	—		−2.9
	(30,60]	0.97	0.92, 1.01	0.170	
	(60,90]	0.97	0.91, 1.03	0.280	
	(90,120]	1.01	0.92, 1.12	0.810	
	(120,Max]	0.89	0.79, 1.01	0.067	
Triage time compliance	(0,28.6]	Reference	—		+7.0
	(28.6,46.9]	0.96	0.91, 1.02	0.180	
	(46.9,70]	**1.06**	**1.01, 1.12**	**0.030**	
	(70,100]	1.01	0.95, 1.08	0.730	
Median boarding duration (h)	(0,1]	Reference	—		−0.3
	(1,2]	0.98	0.93, 1.04	0.500	
	(2,4]	1.03	0.97, 1.09	0.320	
	(4,Max]	1.06	0.98, 1.13	0.130	
Proportion with boarding duration >2 h	(0,0.25]	Reference	—		−1.4
	(0.25,0.5]	1.03	0.98, 1.08	0.300	
	(0.5,0.75]	1.04	0.98, 1.11	0.140	
	(0.75,1]	**1.07**	**1.00, 1.15**	**0.050**	
Proportion with boarding duration >6 h	(0,0.25]	Reference	—		+3.9
	(0.25,0.5]	**1.09**	**1.03, 1.16**	**0.002**	
	(0.5,0.75]	1.06	0.96, 1.17	0.260	
	(0.75,1]	1.08	0.92, 1.28	0.350	
Median ED LOS (h)	(0,2]	Reference	—		−4.2
	(2,4]	1.02	0.97, 1.06	0.490	
	(4,6]	1.08	1.00, 1.17	0.056	
	(6,8]	1.01	0.89, 1.15	0.860	
	(8,115]	1.02	0.92, 1.14	0.670	
90% ED LOS <4 h	Target met	Reference	—		+4.8
	Not met	**1.07**	**1.01, 1.12**	**0.011**	
95% ED LOS <6 h	Target met	Reference	—		+1.3
	Not met	1.04	1.00, 1.09	0.068	
Access block	(0,0.1]	Reference	—		+9.7
	(0.1,0.25]	**1.10**	**1.05, 1.17**	**0.000**	
	(0.25,0.5]	**1.09**	**1.02, 1.17**	**0.009**	
	(0.5,0.75]	**1.15**	**1.04, 1.28**	**0.007**	
	(0.75,1]	1.08	0.89, 1.31	0.420	

(*Continues*)

TABLE 4. *Continued*

Crowding metric†	Categories	Hazard ratio	95% CI	*P*	AIC difference‡
TPCT	(0,21.9]	Reference	—		−4.5
	(21.9,52.1]	1.00	0.93, 1.07	0.940	
	(52.1,120]	1.02	0.95, 1.10	0.580	
	(120,Max]	1.03	0.94, 1.13	0.490	
Boarder number	(0,2]	Reference	—		−2.4
	(2,7]	0.96	0.90, 1.02	0.200	
	(7,15]	0.92	0.85, 1.00	0.057	
	(15,59]	**0.90**	**0.82, 0.98**	**0.021**	
ED occupancy	(0,0.85]	Reference	—		−1.5
	(0.85,1]	**0.91**	**0.86, 0.97**	**0.005**	
	(1,1.25]	0.98	0.92, 1.05	0.550	
	(1.25,Max]	0.94	0.88, 1.01	0.088	
Change in ED occupancy	Decreasing ↓	Reference	—		−1.5
	Static 0	0.96	0.91, 1.01	0.150	
	Increasing ↑	0.97	0.92, 1.01	0.160	
Change in TPCT	Decreasing ↓	Reference	—		−4.5
	Static 0	1.15	0.90, 1.47	0.270	
	Increasing ↑	1.00	0.95, 1.04	0.810	

†Conditions in the ED when index patient arrives. ‡Difference between the AIC of covariate model (triage category, age, arrival mode, ACC status, ethnicity, season, deprivation, day of week) and the AIC of model including the crowding metric: higher values=better model. AIC differences +/-2 indicate competing (equivalent) models. Round bracket = includes value, square bracket = up to but not including value. Bold indicates statistical significance. ACC, Accident Compensation Corporation; AIC, Akaike information criterion; CI, confidence interval; LOS, length of stay; TPCT, total patient care time.

(triage category, age, arrival mode, Accident Compensation Corporation status, ethnicity, season, deprivation and day of week) were considered.

Arriving during the highest quartile of the number of arrivals in the previous hour (HR 0.91, 95% CI 0.85, 0.97) or 6 h (HR 0.90, 95% CI 0.84, 0.97) were associated with lower mortality, with AIC +2.9 and +11.3, respectively. Triage time compliance (47–70%) was associated with a 6% higher risk of mortality (HR 1.06, 95% CI 1.01, 1.02), with AIC +7.0.

There was 10% higher 7-day mortality for patients arriving at times when more than 10% of patients due for ward admission had access block (HR 1.10, 95% CI 1.05, 1.17), AIC +9.7. Consistent with this, presenting at times when the boarding duration for more than a quarter of admitted patients was more than 6 h was also associated (HR 1.09, 95% CI 1.03, 1.16), AIC +3.9. Non-compliance with a 90% 4-h ED LOS target was associated with increased mortality (HR 1.07, 95% CI 1.01, 1.12), AIC +4.8.

Metrics that did not improve the mortality model were: median boarding duration, boarding duration more than 2 h, non-compliance with a 95% 6-h ED LOS target, ED occupancy and change in ED occupancy at time of arrival (Table 4). Metrics that made the model worse were time to assessment, TPCT, change in TPCT and number of boarders (Table 4).

Discussion

This study is the first to demonstrate the association between different crowding measures and mortality within 7 days of presentation to ED in New Zealand.

Access block was found to be the crowding metric most associated with increased mortality within 7 days of ED presentation. Patients arriving at times when more than 10% of admitted patients had an ED LOS greater than 8 h had 10% higher mortality within 7 days, a clinically important difference. Although the observed risk was lower than previously reported in Australia,[1,2] this is likely due to including mortality for all ED patients in the current study, whereas the previous research considered mortality for admitted patients.

Although the measure with the biggest influence on the model was number arriving in the previous 6 h, this was only statistically significant at the highest quartile of arrivals and the association was with a reduction in mortality, which was unexpected. It may be that the system problems

associated with long ED stays are more important with respect to a possible causal chain between ED crowding and mortality than simply the number arriving at ED, especially if those arriving previously were low acuity patients, who have been shown to have little effect on crowding.[16]

Arriving at times when EDs were not able to meet a 90% 4-h access time was also associated with higher mortality, consistent with Canadian research which found presenting at times of long ED stays was associated with higher mortality for discharged patients.[17] The association between national emergency access times and mortality observed in this study is also consistent with prior Australian research.[18] Although the observed association for an ED LOS threshold of 95% of patients with staying less than 6 h was in a similar direction, this was not statistically significant and lead to a competing model. This finding may be confounded by the introduction of the shorter stays in ED target in New Zealand from July 2009, which may have modified clinician behaviour and data accuracy related to this threshold, potentially weakening the observed association.[3,19]

Although time to assessment did not influence the model, poor triage time compliance was weakly associated with increased mortality, suggesting that this should not be neglected as an ED quality measure.

ED occupancy did not influence the model importantly although occupancy between 85 and 99% was statistically significantly associated with lower mortality. ED occupancy is related mathematically to the number arriving × LOS (Little's Law).[20] It is possible that the opposite influences on the model observed for number arriving and ED LOS served to nullify the influence of occupancy, or that system issues related to long ED stays for admitted patients are more important than occupancy in the association between ED crowding and mortality.

These findings suggest that improving hospital capacity and inpatient resources to cope with acute admissions should be the focus of efforts to reduce preventable mortality for acute patients, rather than efforts to prevent minor patients presenting to ED.

Limitations

The analysis is limited by the source data, which did not contain information relating to the type of disease and co-morbidity. As around 40% of ED visits at the time the source data was collected did not trigger the threshold for mandatory coding of visits (ED visits are not required to be coded specific diagnoses by the Ministry or Health unless there is an ED LOS of more than 3 h or a hospital admission results) this information was not likely to be available for a large proportion of the studied population, so these data were not actively sought.[3] Instead, age acted as a surrogate for complexity and surrogates of disease severity (arrival mode and triage category) were also included. A further limitation of the source data is that the data included in the present study is 8 years old at the time of publication. This was unavoidable as the collection, merging and cleaning of data from the national collections and DHBs for 5.7 million ED visits took several years for the original study, which was only recently published.[3] Secondly, contemporaneous data on ED capacity was required to determine ED occupancy and this was only available from surveys of ED occupancy conducted in 2010–2012.[9]

We recognise that concerns have been raised about the signal to noise ratio when using raw mortality as an outcome, as most deaths are not preventable. If this was the case, we would not expect to find any association between any of the crowding metrics and mortality. That there were more deaths for people presenting to crowded EDs suggests that these deaths were potentially preventable.

Although more robust than an unadjusted analysis, the findings from the current adjusted analysis should be interpreted with caution. To date, the interactions between the confounding variables have not been explored. It is possible that a better model of confounding variables may be found if interactions between the covariates were included, and this may affect the strength or direction of the observed associations.

Conclusion

Access block had the strongest association with 7-day mortality. That ED occupancy and the number of arrivals were not associated with increased mortality suggests that system issues related to long ED stays may be most important in the link between ED crowding and mortality.

Acknowledgements

The authors would like to acknowledge Dr Susan Wells and Dr Vanessa Selak for their support and feedback on the content of the manuscript.

Author contributions

PGJ: Study concept and design, data extraction, data presentation, data analysis, draft manuscript, revise manuscript. Overall responsibility for manuscript. BvdW: study design, database development, statistical analysis, revise manuscript.

Competing interests

None declared.

Data availability statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

References

1. Richardson DB. Increase in patient mortality at 10 days associated with emergency department overcrowding. *Med. J. Aust.* 2006; **184**: 213–6.
2. Sprivulis PC, Da Silva JA, Jacobs IG, Jelinek GA, Frazer ARL. The association between hospital overcrowding and mortality among patients admitted via Western

Australian emergency departments. *Med. J. Aust.* 2006; **184**: 208–12.
3. Jones P, Wells S, Harper A *et al.* Impact of a national time target for ED length of stay on patient outcomes. *N. Z. Med. J.* 2017; **130**: 15–34.
4. Australasian College for Emergency Medicine. *Statement on the Delineation of Emergency Departments 2013*. [Cited 28 Oct 2018.] Available from URL: https://acem.org.au/getmedia/aa6c120d-bd9f-4850-a257-2b9a8f3860b3/S12_Statement_on_the_Delineation_EDs_Nov-12_v05-(1).aspx
5. Ministry of Health. *National Non-Admitted Patient Collection*. [Cited 4 Dec 2020.] Available from URL: https://www.health.govt.nz/nz-health-statistics/national-collections-and-surveys/collections/national-non-admitted-patient-collection
6. Ministry of Health. *National Minimum Dataset (Hospital Events)*. [Cited 4 Dec 2020.] Available from URL: https://www.health.govt.nz/nz-health-statistics/national-collections-and-surveys/collections/national-minimum-dataset-hospital-events
7. Ministry of Health. *National Health Index*. [Cited 4 Dec 2020.] Available from URL: https://www.health.govt.nz/our-work/health-identity/national-health-index/national-health-index-overview
8. Jones P, Chalmers L, Wells S *et al.* Implementing performance improvement in New Zealand emergency departments: the six hour time target policy national research project protocol. *BMC Health Serv. Res.* 2012; **12**: 45.
9. Jones PG, Olsen S. Point prevalence of access block and overcrowding in New Zealand emergency departments in 2010 and their relationship to the 'Shorter Stays in ED' target. *Emerg. Med. Australas.* 2011; **23**: 587–92.
10. McCarthy ML, Ding R, Pines JM, Zeger SL. Comparison of methods for measuring crowding and its effects on length of stay in the emergency department. *Acad. Emerg. Med.* 2011; **18**: 1269–77.
11. Jo S, Jin YH, Lee JB, Jeong T, Yoon J, Park B. Emergency department occupancy ratio is associated with increased early mortality. *J. Emerg. Med.* 2014; **46**: 241–9.
12. Burnham KP, Model Selection ADR. *Multimodel Inference: A Practical Information-Theoretic Approach*. New York: Springer-Verlag, 2002.
13. Therneau T. *A Package for Survival Analysis in S_. version 2.38*. 2015. [Cited 4 Dec 2020.] Available from URL: https://CRAN.R-project.org/package=survival
14. Kassambara A, Kosinski M. *survminer: Drawing Survival Curves using 'ggplot2'*. R package version 0.4.3.999. 2018. [Cited 4 Dec 2020.]
15. Therneau T. *coxme: Mixed Effects Cox Models*. R package version 2.2–10. 2018. [Cited 4 Dec 2020.] Available from URL: https://CRAN.R-project.org/package=coxme
16. Schull MJ, Kiss A, Szalai JP. The effect of low-complexity patients on emergency department waiting times. *Ann. Emerg. Med.* 2007; **49**: 257–64.e1.
17. Guttmann A, Schull M, Vermeulen M, Stukel T. Association between waiting times and short term mortality and hospital admission after departure from emergency department: population based cohort study from Ontario, Canada. *BMJ* 2011; **342**: d2983.
18. Sullivan C, Staib A, Khanna S *et al.* The National Emergency Access Target (NEAT) and the 4-hour rule: time to review the target. *Med. J. Aust.* 2016; **204**: 354.
19. Tenbensel T, Chalmers L, Jones P, Appleton-Dyer S, Walton L, Ameratunga S. New Zealand's emergency department target - did it reduce ED length of stay, and if so, how and when? *BMC Health Serv. Res.* 2017; **17**: 678.
20. Little JDC. Little's law as viewed on its 50th anniversary. *Oper. Res.* 2011; **59**: 536–49.

Supporting information

Additional supporting information may be found in the online version of this article at the publisher's web site:

Appendix S1. Variables used in the analysis.
Appendix S2. Crowding metrics and survival.