The impact of the Four-Hour National Emergency Access Target on 30-day mortality, access block and chronic ED overcrowding in Australian emergency departments.

Journal:	*Emergency Medicine Australasia*
Manuscript ID	EMA-2018-245
Manuscript Type:	Original Research
Date Submitted by the Author:	26-Jun-2018
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Keywords:	National Emergency Access Target, 30 day mortality, access block, ED overcrowding, trend analysis
Abstract:	Objective: Previous research reported strong associations between Emergency Department (ED) overcrowding and mortality. We assessed the effect of the Four-Hour Rule intervention (4HR), [Western Australia (WA) 2009] then nationally rolled out as the National Emergency Access Target

	(Australia 2012) policy on mortality and patient flow. Methods: A longitudinal cohort study of a population-wide 4HR, for 16 hospitals across WA, NSW, ACT and QLD. Mortality trends were analysed for 2-4 years before and after 4HR using interrupted time-series technique. Main outcome measures: Effect of 4HR on patient flow markers and admitted 30-day mortality trends, and association over time between mortality and patient flow marker performance during the study period. Results: There were 40,281 deaths from 952,726 emergency admissions. All jurisdictions, except ACT, had improved flow and access block after 4HR. Age-standardised mortality was decreasing before the intervention. Post intervention, WA had a significant reduction in mortality rate of -0.28 per 1000 patients per quarter (p=0.040) whilst QLD had mixed results and NSW/ACT trends did not change significantly. Meta-regression of aggregated data for hospitals grouped on flow performances did not show significant mortality changes associated with the policy. Conclusions: The 4HR was introduced as a means of driving hospital performance by applying a time target. Patient flow improved, but the evidence for mortality benefit was weak with improvement only in WA. Further research with data from a larger number of hospitals over a longer time is needed to discern the long-term effects of the policy.

The impact of the Four-Hour National Emergency Access Target on 30-day mortality, access block and chronic ED overcrowding in Australian emergency departments.

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Key Findings:

- Previous research indicated that Emergency Department (ED) over-crowding and access block are strongly associated with increased mortality but our longitudinal data in 16 hospitals across several states showed significant long-term reductions in mortality rates in WA but not in the other jurisdictions.
- The association between access block and 30-day mortality remains controversial.
- Longer time series analyses are required to confirm or reject the hypothesis that mortality can be reduced by improving chronic ED overcrowding.

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Abstract

Objective: Previous research reported strong associations between Emergency Department (ED) overcrowding and mortality. We assessed the effect of the Four-Hour Rule intervention (4HR), [Western Australia (WA) 2009] then nationally rolled out as the National Emergency Access Target (Australia 2012) policy on mortality and patient flow.

Methods: A longitudinal cohort study of a population-wide 4HR, for 16 hospitals across WA, NSW, ACT and QLD. Mortality trends were analysed for 2-4 years before and after 4HR using interrupted time-series technique.

Main outcome measures: Effect of 4HR on patient flow markers and admitted 30-day mortality trends, and association over time between mortality and patient flow marker performance during the study period.

Results: There were 40,281 deaths from 952,726 emergency admissions. All jurisdictions, except ACT, had improved flow and access block after 4HR. Age-standardised mortality was decreasing before the intervention. Post intervention, WA had a significant reduction in mortality rate of -0.28 per 1000 patients per quarter (p=0.040) whilst QLD had mixed results and NSW/ACT trends did not change significantly. Meta-regression of aggregated data for hospitals grouped on flow performances did not show significant mortality changes associated with the policy.

Conclusions: The 4HR was introduced as a means of driving hospital performance by applying a time target. Patient flow improved, but the evidence for mortality benefit is controversial with improvement only in WA. Further research with more representative data

from a larger number of hospitals over a longer time across Australia is needed to increase statistical power to detect long-term effects of the policy.

Introduction

Emergency Department (ED) overcrowding has been identified as a critical issue for emergency care worldwide (1-6). ED overcrowding has been associated with poorer organisational performance and adverse clinical outcomes (1, 2, 6, 7). Of most concern is the association between ED overcrowding and increased mortality (1, 2, 6, 8-11). Two Canadian studies identified chronic ED overcrowding as a systemic problem that can happen because of prolonged strain on hospital and healthcare resources (15, 16).

The United Kingdom (UK) introduced the "four hour rule" in 2002 with subsequent reports of improved patient flow but with limited research and no demonstrated mortality benefits (12). In April 2009, the state government of Western Australia (WA) introduced a version of the 4-Hour Target (13). This was further modified and implemented across Australia in 2012 as the National Emergency Access Target, known as NEAT (9, 14). In this paper, the two policies have been abbreviated as 4HR.

Previous studies have reported excess mortality up to 30% for inpatients who presented to an overcrowded ED in Australia (8, 10, 11). Three Australian studies suggested significant mortality decreases associated with major improvement in 4HR performance but there was a lack of pre-4HR data to assess changes in mortality trends (9, 13, 15). An interrupted time-series (ITS) analysis on the six-hour target in New Zealand found significantly improved trends for both elective patient and ED deaths, but no significant effect on mortality for acutely admitted patients (16).

The aim of this study was to assess the impact of the 4HR on patients dying within 30 days of their last ED admission and the association between excess mortality and improvements in ED flow and access block as proxies for chronic ED overcrowding.

Methods

Study design, Data source, and Participants

We conducted a longitudinal cohort study of adult (≥18 years) ED patients using de-identified record-linkage data from 16 metropolitan hospitals in four jurisdictions, namely Western Australia (WA, four hospitals), New South Wales (NSW, six hospitals), Australian Capital Territory (ACT, two hospitals) and Queensland (QLD, four hospitals). Data were sourced from the Emergency Department Data Collection, the Hospital Morbidity (or Admitted Patient) Data Collection, and the Mortality Register. Hospital admission and mortality records were matched with corresponding ED visits.

The 4HR policy was introduced at different times in Australia. In WA, the three major metropolitan hospitals implemented 4HR in April 2009, and the non-major metropolitan hospital in October 2009. NEAT started in January 2012 across Australia. The cohort was analysed relative to the time of introduction of 4HR: 2005 until 2013 for WA, and 2010 until 2013 for the three eastern jurisdictions.

Data definitions

Admissions in this study refer to those lasting >24 hours (i.e., excluding short-stay admissions ≤24 hours) regardless of whether they were admitted to ED observation units or inpatient wards.

Admitted patient 30-day mortality rate was calculated as the number of patients who died within 30 days of the date of their last admitted ED presentation divided by the total number of patients who had emergency-admissions in each quarter. Mortality rates are expressed per 1,000 patients. Age-standardised mortality rates were calculated using the direct standardisation method, based on Australia's 30 June 2001 Standard Population.

For this study we defined two patient flow markers: *'ED flow'* as the percentage of presentations with an ED length of stay (EDLOS) within 4 hours, and *'access block'* as the percentage of admitted patients who spent more than 8 hours in ED. Overall trend and improvement in patient flow (as described below) are defined as proxies for chronic ED overcrowding.

Statistical analysis

We used ITS analysis for trends in patient flow makers and mortality for each jurisdiction (17) (Appendix 1). Four coefficients were estimated in the ITS model: the baseline level at the last quarter of pre-4HR, the slope pre-4HR, the change in level immediately post-4HR and the change in slope post-4HR (Appendix 1, Figure 1).

We then pooled each of the four sets of ITS mortality estimates for individual hospitals using a random effects meta-regression analysis (18, 19) (Appendix 1, Meta-regression analysis). To assess the association between patient flow and mortality we calculated flow performance of each hospital as percentage change in patient flow markers post-4HR versus pre-4HR. These percentage changes were ranked for grouping the hospitals into tertiles, namely *most improved*, *moderately improved*, and *least improved*. The grouping was conducted separately

for ED flow and access block. Three models were fitted, namely intercept only (model 1); ED flow tertiles (model 2); and access block tertiles (model 3).

Statistical significance was set at α=0.05. Data for ITS analyses were managed and analysed using Statistical Analysis System (SAS) software, version 9.4. Meta-regression analyses were conducted in Stata, version 14.2.

Ethics clearance

The study received ethics approval from the respective Human Research Ethics Committees of Western Australian Department of Health (201403.07), Cancer Institute NSW (HREC/14/CIPHS/30), ACT Department of Health (ETH.3.14.054) and Queensland Health (HREC/14/QGC/30) as well as governance approval from all participating hospitals.

Results

Sample characteristics

Over the study period, there were 3,915,716 ED visits across participating jurisdictions leading to a total of 952,726 ED admissions. The number of ED admissions across jurisdictions before and after 4HR introduction are shown in Table 1. Percentage of admissions (>24 hours) were similar post-4HR versus pre-4HR (Appendix 2 Table 1). Key characteristics of admitted ED visits namely age, gender, ambulance and triage categories did not change substantially between pre-4HR and post-4HR periods (Table 1). There were 40,281 deaths (within 30-days of an admitted ED visit) and the percentage of 30-day deaths decreased post-4HR in all jurisdictions. Annual mortality rates are presented in Appendix 2 (Table 2) for external comparability.

Insert Table 1 about here

Figure 1 displays the observed and estimated trends for patient flow markers - ED flow (i.e. percentage of EDLOS ≤4 hours) and access block (i.e. percentage of EDLOS >8 hours among admitted ED visits). Estimated ED flow was between 35% and 50% at baseline (last quarter of pre-4HR). This increased post-4HR to as high as about 70% in WA and QLD and about 60% in NSW, which equated to an improvement of about 20%-30% in these three states. Estimated levels of access block was between 40% and 55% at baseline which reduced by about 15%-35% post 4HR in WA, NSW and QLD at the end of the study. Table 2 shows the ITS results for trends in patient flow markers, and crude and age-standardised 30-day mortality rate by jurisdiction. All jurisdictions showed worsening trends in ED flow pre-4HR but only the pre-4HR slope for QLD was statistically significant (-0.4% per quarter, p=0.010). Post-4HR trends showed statistically significant improvement for both patient flow markers, except access block for ACT.

Insert Figure 1 about here

Insert Table 2 about here

Figure 2 displays the graphical results for mortality in Table 2. All jurisdictions had downward trends in age-standardised mortality before 4HR implementation but none of them were statistically significant (Boxes 3 and 4). Mortality trend improved significantly after 4HR in WA, with a reduction in age-standardised mortality slope of -0.28 per 1000 per quarter (p=0.040). QLD had a statistically significant mortality drop at the beginning of 4HR of -2.12 per 1000 (p=0.009) followed by a statistically significant increasing trend in age-standardised mortality trend, of 0.62 per 1000 per quarter (p=0.001). However, the observed QLD mortality rate at the end of the study period was not significantly different from expected, if the trend continued from the pre-4HR period (2.20 per 1000, p=0.110). No post-intervention mortality changes were significant in NSW and ACT (p>0.05).

Insert Figure 2 about here

Mortality for all hospitals grouped together showed a downward trend of 0.16 per 1000 per quarter before 4HR (p=0.009) (Table 3). When the hospitals were grouped together in tertiles, the pre-intervention downward trend in mortality was only statistically significant among the top-performing hospitals (i.e., Group 1), with a significant reducing trend of -0.23 per 1000 per quarter for the ED flow grouping and -0.18 per 1000 per quarter for access block. There were no statistically significant changes, in level or in slope, post-4HR for any tertile.

When the performance groups were compared against each other, no statistically significant differences were found in any of the ITS estimates, namely baseline mortality (p=0.347 for ED flow grouping and p=0.053 for access block grouping), pre-4HR slope (p=0.174 and p=0.286, respectively), change in level (p=0.449 and p=0.415) or change in slope (p=0.433 and p=0.186) (Table 3). Mortality results from the ITS analysis for each of the hospital ranked by patient flow improvement are presented in Appendix 2 (Table 3).

Insert Table 3 about here

Discussion

Countries implementing EDLOS time targets, such as UK, New Zealand and Australia, have found major improvements in length of stay and time targets (14, 16, 20). In the UK, the aggregated and individually reported data suggested that at its zenith, 98% of all patients left EDs within 4 hours (20). New Zealand also improved with most district health boards reaching their 95% six-hour target (16). In Australia, the 4HR compliance improved from 64% in 2011-12 to 73% in 2013-14 (21). The improvement was also evident in our results on ED flow (Boxes 2 and 3). It is important to remember that as with any observational study, the 4 HR was an intervention introduced with many other interventions and attribution of

changes cannot be to one single intervention, as highlighted in our qualitative studies (22, 23).

Our study found a significantly reduced 30-day mortality trend in WA post-4HR, but there were no significant changes for NSW, ACT and QLD. A few factors may help explain this difference between WA and the other jurisdictions. Firstly, WA had the most pronounced improvement in access block (about 30%). Secondly, WA had a longer post 4HR period at a higher ED flow rate of 60-70%, and lower access block rates between 20 and 30%. Thirdly, each jurisdiction had different implementation strategies which may have different impacts on mortality.

A non-significant downward mortality trend was observed pre-4HR in each jurisdiction, which was statistically significant when hospital-level estimates were pooled and combined in the meta-regression analysis. It was also significant for the best performing patient flow tertiles. The evidence of a pre-4HR trend of mortality reduction suggested that a decrease over time could occur regardless of 4HR implementation. However, percentage of 30-day deaths decreased in the post-4HR period suggesting that the introduction of 4HR did not adversely affect mortality (Table 1). No significant post-4HR changes in mortality were detected in the overall estimates, or when the hospitals were grouped by flow performance tertiles. In summary, this demonstrates that mortality is not the only reason for ensuring patient flow is good.

Previous Australian studies found that ED overcrowding, access block and/or 4HR compliance were strongly associated with excess mortality (9-11, 13, 15). Our study found significant mortality reduction post-4HR only in WA (-0.28 per 1000 per quarter or a rate of

about -1% per quarter relative to the baseline age-standardised mortality rate of 27.53 per 1000; Table 2). The weak evidence for mortality reduction post-4HR is unexpected, given the significant improvements post-4HR in ED flow and access block in WA (by 1.6% and -2.4% per quarter, respectively) as well as in NSW (2.9% and -2.1%) and QLD (3.5% and -4.8%). If the strong association with 4HR compliance was demonstrable as an effect of the policy, we may have found stronger evidence of mortality reduction over time as 4HR compliance improved, but our findings are inconclusive.

The link between ED overcrowding measures and mortality might be explained temporally by the following. Firstly, cyclical flux (e.g. flu epidemic) and random intermittent surge in demand both in terms of number of patients and the severity of their condition overwhelms the ability of the hospital to cope (episodic association). This episodic increase in demand may partly explain the impact of overcrowding on excess mortality in all of these studies (9-11, 13, 15). Secondly and less well-studied, quality of care may also be compromised in a chronically overcrowded environment (chronic association). The New Zealand study on their six-hour target policy using the ITS methodology found acute admitted patient mortality did not change whilst there were modest improvements in access block of 5-10% from a low 20-25% (16). In our study, post-4HR improvement in patient flow measures suggested that chronic ED overcrowding significantly improved, but the evidence of its impact on mortality reduction was weak.

Study strengths and limitations

The study analysed a relatively representative sample of metropolitan hospitals from four jurisdictions. We used linked data to more exhaustively identify 30-day mortality including deaths that occurred post-discharge. Most of the previous studies were limited to in-hospital

mortality within the same hospital only. We used the ITS technique to account for change from underlying trends in outcomes over time as well as to address the issue of seasonal confounding. The before-after data on 4HR and ITS analysis allowed us to address the questions as to whether chronic ED overcrowding (using patient flow markers) improved with 4HR and whether that improvement was associated with excess mortality.

The study analysed a sample of 16 hospitals from four jurisdictions. Even though this is a large linkage study in terms of the number of patients, the lack of statistical power is a major limitation due to: 1) the short period of time over which to assess trends in mortality in the time-series analysis particularly for the eastern jurisdictions and 2) the limited number of participating hospitals particularly for the meta-regression analysis. Another important limitation was the exclusion of jurisdictions such as Victoria, South Australia, Tasmania and Northern Territory due to restrictions in the data linkage capability or lack of associated investigators from those jurisdictions in our project. In addition, data after 2013 was not available from the data linkage units at the time of requesting the data (end of 2013) and we experienced extensive delays in signing agreements and ethics applications (up to 18 months) and getting the data (up to 16 months). In addition, data linkage accuracy was not the same across jurisdictions.

Another limitation is caused by data definition inconsistencies across jurisdictions, hospitals and time periods. In particular, inpatient admissions could not be accurately determined due to inconsistencies in ward allocations across hospitals and/or over time. Instead, we used admissions lasting >24 hours as a proxy for inpatient admissions. Even so, lower admission threshold and its dilution effect on admitted patient mortality is not a likely issue in our analysis (i.e. potential strength in our study) because we have relatively stable admission

(>24 hours) rates before and after 4HR (Appendix 2 Table 1). There were potential confounders such as the healthy migrant effect that could have reduced mortality over time (24). We did not include diagnosis or co-morbidity indices in our analysis because exploratory analyses indicate that they may be affected by changes in Australian Coding Standards over time (25).

Conclusion

The 4HR was introduced as a time target to drive performance. The impact on mortality was a principal concern underpinning its introduction. Here, the results on mortality are heterogeneous between jurisdictions and between hospitals even when grouped by patient flow performance. Importantly, we found the impact of the 4HR and resultant improvements in patient flow on mortality were not as easy to discern as previously reported (9-11, 13, 15). Longer and larger linked longitudinal data for the post 4HR with longer periods at low access block levels are required to assess whether the post-4HR reduction in excess mortality in WA can be replicated across Australia. It is likely that longer trends involving more hospitals in more jurisdictions will be able to provide the evidence to demonstrate whether there are mortality benefits resulting after the implementation of the Government policy.

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Figure 1 Percentage of ED visits with ED length of stay ≤ 4 hours and percentage of access block by jurisdiction. Vertical line indicates the start of the 4HR policy.

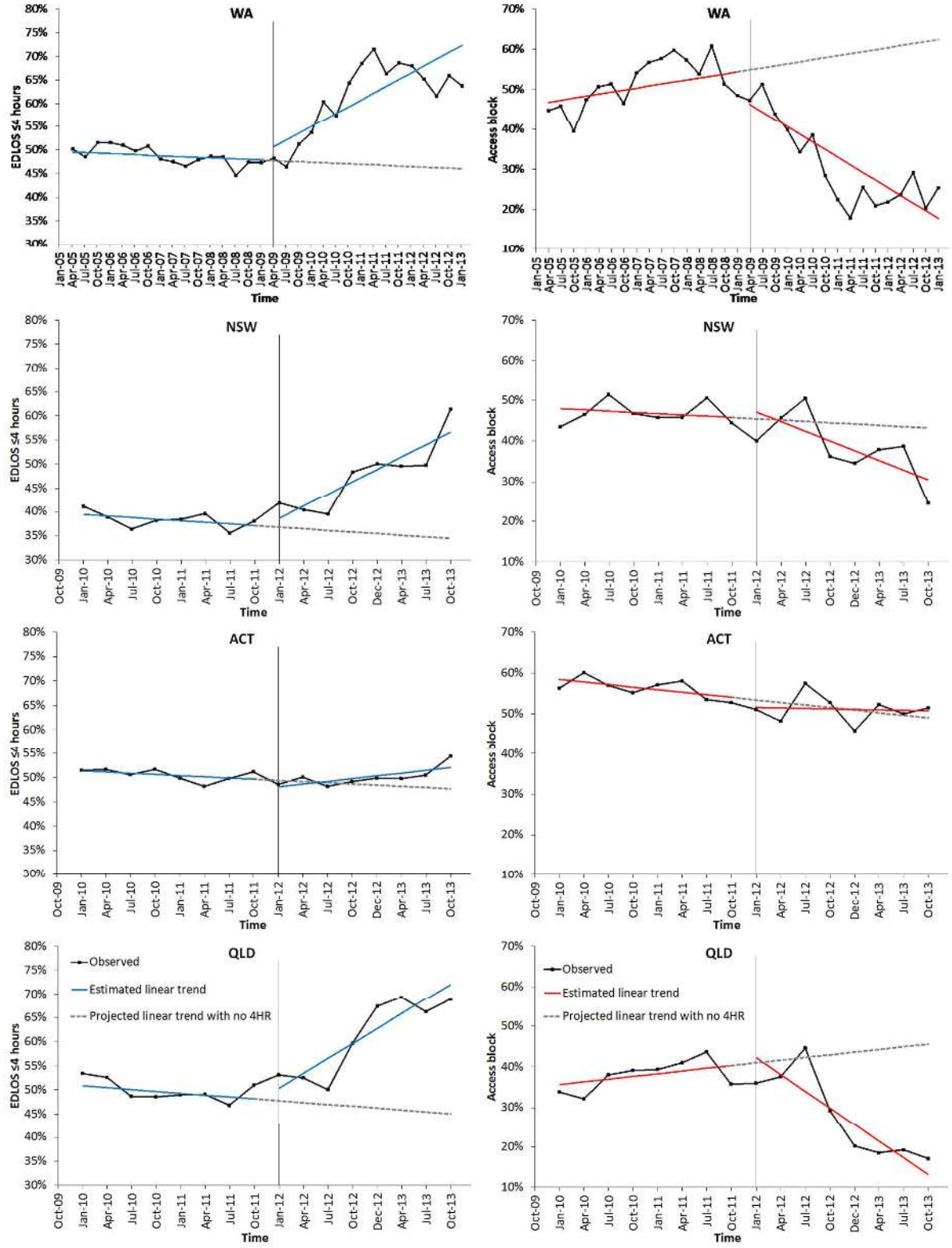


Figure 2 Age-standardised and crude mortality rate per 1000 (within 30 days of last admitted ED presentation) by jurisdiction. Vertical line indicates the start of the 4HR policy.

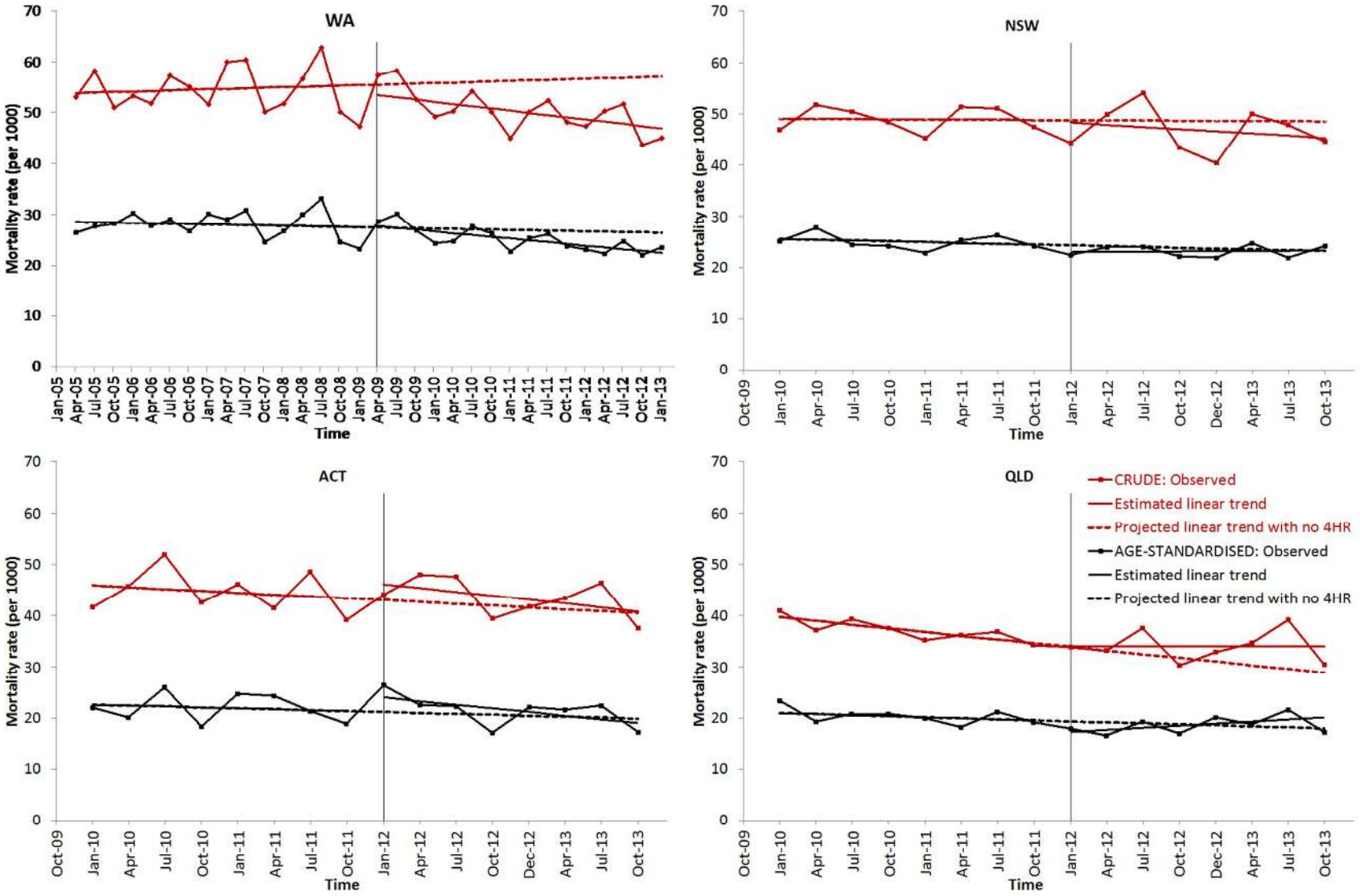


Table 1 Sample characteristics by pre- and post-4HR of ED admissions for adult patients across four jurisdictions.

Characteristic	WA (n=393395)				NSW (n=322608)				ACT (n=63289)				QLD (n=173434)			
	Pre-4HR (n=180809)		Post-4HR (n=212586)		Pre-4HR (n=154274)		Post-4HR (n=168334)		Pre-4HR (n=30377)		Post-4HR (n=32912)		Pre-4HR (n=86213)		Post-4HR (n=87221)	
	Number	%	Number	%	Number	%	Number	%	Number	%	Number	%	Number	%	Number	%
Age (>65 years)	87900	48.6	100459	47.3	74136	48.1	80374	47.7	13189	43.4	14572	44.3	37424	43.4	38817	44.5
Gender (Male)	94453	52.2	110885	52.2	78779	51.1	85676	50.9	15355	50.5	16537	50.2	44697	51.8	44977	51.6
Arrived by Ambulance	100551	55.6	113857	53.6	85848	55.6	93834	55.7	14515	47.8	15257	46.4	51805	60.1	52445	60.1
Triage category 1	6747	3.7	8031	3.8	4065	2.6	5136	3.1	539	1.8	567	1.7	2953	3.4	2573	2.9
Triage category 2	42555	23.5	51231	24.1	37304	24.2	45484	27.0	6078	20.0	6772	20.6	22669	26.3	22451	25.7
Triage category 3	81578	45.1	100944	47.5	71180	46.2	75392	44.8	15534	51.1	16738	50.9	47692	55.3	48553	55.7
Triage category 4	48340	26.7	50360	23.7	37201	24.1	37949	22.6	7631	25.1	8267	25.1	10757	12.5	11548	13.2
Triage category 5	1584	0.9	2012	1.0	4465	2.9	4297	2.6	595	2.0	568	1.7	2142	2.5	2096	2.4
Death within 30 days of an admitted ED visit	8902	4.9	9659	4.5	6843	4.4	6882	4.1	1236	4.1	1264	3.8	2871	3.3	2624	3.0

Table 2 Estimates (and 95% CI) for Interrupted Time Series (ITS) analysis of ED flow (% EDLOS ≤4 hours), access block (% EDLOS >8 hours among admitted ED visits), and age-standardised and crude mortality rates (per 1000), by jurisdiction[1]

Outcome	Jurisdiction	Level at just before 4HR[2]	Slope pre-4HR (per quarter)	Change in level immediately post-4HR	Change in slope post-4HR (per quarter)
ED flow	WA	47.9% (44.4%, 51.4%)	-0.1% (-0.6%, 0.3%)	2.9% (-2.3%, 8.2%)	**1.6% (0.8%, 2.3%)****
	NSW	37.1% (33.5%, 40.7%)	-0.3% (-1.2%, 0.5%)	1.9% (-3.7%, 7.5%)	**2.9% (1.7%, 4.1%)****
	ACT	49.6% (48.0%, 51.3%)	-0.2% (-0.6%, 0.1%)	-1.4% (-3.9%, 1.2%)	**0.8% (0.3%, 1.4%)**
	QLD	48.2% (47.4%, 48.9%)	**-0.4% (-0.6%, -0.2%)**	**2.5% (0.9%, 4.2%)**	**3.5% (3.2%, 3.7%)*****
Access block	WA	54.4% (45.6%, 63.3%)	0.5% (-0.5%, 1.5%)	-8.5% (-19.5%, 2.4%)	**-2.4% (-3.9%, -0.9%)***
	NSW	45.7% (43.2%, 48.3%)	-0.3% (-1.0%, 0.4%)	1.7% (-2.9%, 6.3%)	**-2.1% (-2.9%, -1.2%)****
	ACT	54.1% (50.3%, 57.8%)	-0.6% (-1.5%, 0.3%)	-1.8% (-7.8%, 4.1%)	0.5% (-0.8%, 1.8%)
	QLD	40.3% (36.8%, 43.8%)	0.7% (-0.2%, 1.6%)	1.4% (-4.7%, 7.4%)	**-4.8% (-6.0%, -3.7%)*****
Age-standardised mortality	WA	27.53 (25.93, 29.13)	-0.07 (-0.24, 0.10)	0.27 (-1.70, 2.25)	**-0.28 (-0.55, -0.02)**
	NSW	24.52 (22.72, 26.33)	-0.16 (-0.59, 0.28)	-1.29 (-4.12, 1.54)	0.20 (-0.41, 0.81)
	ACT	21.39 (17.84, 24.95)	-0.18 (-1.03, 0.67)	2.85 (-2.72, 8.42)	-0.53 (-1.74, 0.67)
	QLD	19.63 (18.85, 20.41)	-0.20 (-0.39, 0.00)	**-2.12 (-3.42, -0.81)**	**0.62 (0.35, 0.88)**
Crude mortality	WA	50.47 (48.97, 51.97)	0.14 (-0.04, 0.31)	-2.10 (-4.47, 0.28)	**-0.55 (-0.79, -0.31)**
	NSW	48.82 (46.76, 50.88)	-0.04 (-0.57, 0.50)	-0.48 (-4.11, 3.15)	-0.40 (-1.09, 0.29)
	ACT	43.37 (38.28, 48.46)	-0.35 (-1.57, 0.86)	3.06 (-4.91, 11.04)	-0.39 (-2.12, 1.33)
	QLD	34.66 (31.43, 37.89)	-0.71 (-1.49, 0.06)	0.06 (-5.00, 5.13)	0.71 (-0.38, 1.80)

[1] Estimates in bold indicate statistical significance at p<0.05. * denotes p<0.01 and ** denotes p<0.001.

[2] Statistical significance is not indicated for the baseline level (i.e. the intercept) because it tests whether it is significantly different from zero (which is not clinically useful in this context).

Table 3 Meta analyses of association between implementation of 4HR and age-standardised mortality rate (per 1000) among admitted adults, analysed in three separate groups based on the individual hospitals' (pre-post) change in % EDLOS ≤ 4 hours and access block performance [a]

	% EDLOS ≤ 4 hours grouping			% access block grouping		
	Est.	95% CI	P [b]	Est.	95% CI	P
Level at just before 4HR			0.347 [b]			0.053 [b]
Group 1: most improved	25.3	21.0, 29.7	-- [c]	23.8	19.6, 28.1	-- [c]
Group 2: moderately improved	22.7	18.7, 26.6	-- [c]	22.5	17.9, 27.2	-- [c]
Group 3: deteriorated/ least improved	21.0	16.5, 25.5	-- [c]	22.5	17.7, 27.3	-- [c]
Overall	23.0	20.6, 25.5	-- [c]	23.0	20.6, 25.5	-- [c]
Slope pre-4HR (per quarter)			0.174			0.286
Group 1: most improved	**-0.23**	**-0.36, -0.10**	**0.002**	**-0.18**	**-0.31, -0.06**	**0.008**
Group 2: moderately improved	-0.17	-0.43, 0.10	0.200	-0.27	-0.56, 0.02	0.064
Group 3: deteriorated/ least improved	0.05	-0.23, 0.33	0.700	0.11	-0.30, 0.53	0.569
Overall	**-0.16**	**-0.28, -0.05**	**0.009**	**-0.16**	**-0.28, -0.05**	**0.009**
Change in level immediately post-4HR			0.449			0.415
Group 1: most improved	0.42	-2.28, 3.11	0.744	0.38	-2.03, 2.78	0.739
Group 2: moderately improved	-1.67	-4.22, 0.88	0.180	-0.34	-3.12, 2.44	0.795
Group 3: deteriorated/ least improved	0.11	-3.02, 3.25	0.938	-2.16	-5.37, 1.05	0.170
Overall	-0.46	-2.02, 1.09	0.533	-0.46	-2.02, 1.09	0.533
Change in slope post-4HR (per quarter)			0.433			0.186
Group 1: most improved	-0.10	-0.49, 0.29	0.577	-0.15	-0.44, 0.14	0.277
Group 2: moderately improved	0.26	-0.22, 0.74	0.261	0.11	-0.36, 0.59	0.613
Group 3: deteriorated/ least improved	-0.07	-0.60, 0.45	0.774	0.43	-0.18, 1.04	0.154
Overall	0.01	-0.24, 0.27	0.927	0.01	-0.24, 0.27	0.927

[a] Estimates with p<0.05 are in bold.

[b] P-value tests for significant differences between the three groups.

[c] P-value is not provided because the test for whether the mortality rate at just before 4HR (i.e. the intercept) is significantly different from zero is not clinically useful in this context.

APPENDIX 1: STATISTICAL METHODS

Interrupted time series analysis

An interrupted time series (ITS) analysis is a statistical method of analysing time series data known to be interrupted by an intervention at a known point in time. This was conducted using quarterly data, to ensure sufficient data (time) points for stability and reliability of trend assessment and estimation (1). This is particularly necessary for the 12 hospitals in the Eastern jurisdictions, where only two years of post-intervention data were available. However, for mortality outcomes, to enable external comparability and generalizability, estimates of annual mortality rates among admitted patients were also calculated and reported descriptively but not inferentially in Appendix 2.

In this study, the ITS model is written as (1-3):

$$Y_t = \beta_0 + \beta_1 (Quart)_t + \beta_2 (Period)_t + \beta_3 (Quart\_Post)_t + e_t$$

where Y represents the % EDLOS ≤4 hours, access block or mortality as the outcome variable at time t;

Quart is the sequential number of quarters across both periods of analysis with 0 centred on the quarter just before 4HR/NEAT started;

Period is a dummy variable taking the values '0' for the pre-4HR/NEAT and '1' for the post-4HR/NEAT segment;

Quart_Post is 0 in the pre-4HR/NEAT period and the sequential number of quarters in the post-4HR/NEAT period;

β_0 estimates the baseline level at the time point when *Quart*=0 (i.e. the intercept);

β_1 estimates the slope pre-4HR/NEAT;

β_2 estimates the change in level in the beginning of 4HR/NEAT, i.e. immediately after 4HR/NEAT introduction; and

β_3 estimates the change in slope post-4HR/NEAT.

Tables 1 and 2 show the coding for the time variables in the datasets for ITS analysis in WA and the eastern jurisdictions, respectively. The presented coefficients are illustrated in Figure 1.

PROC AUTOREG in SAS version 9.4 was employed for the ITS analysis (4).

Table 1. Data coding for WA

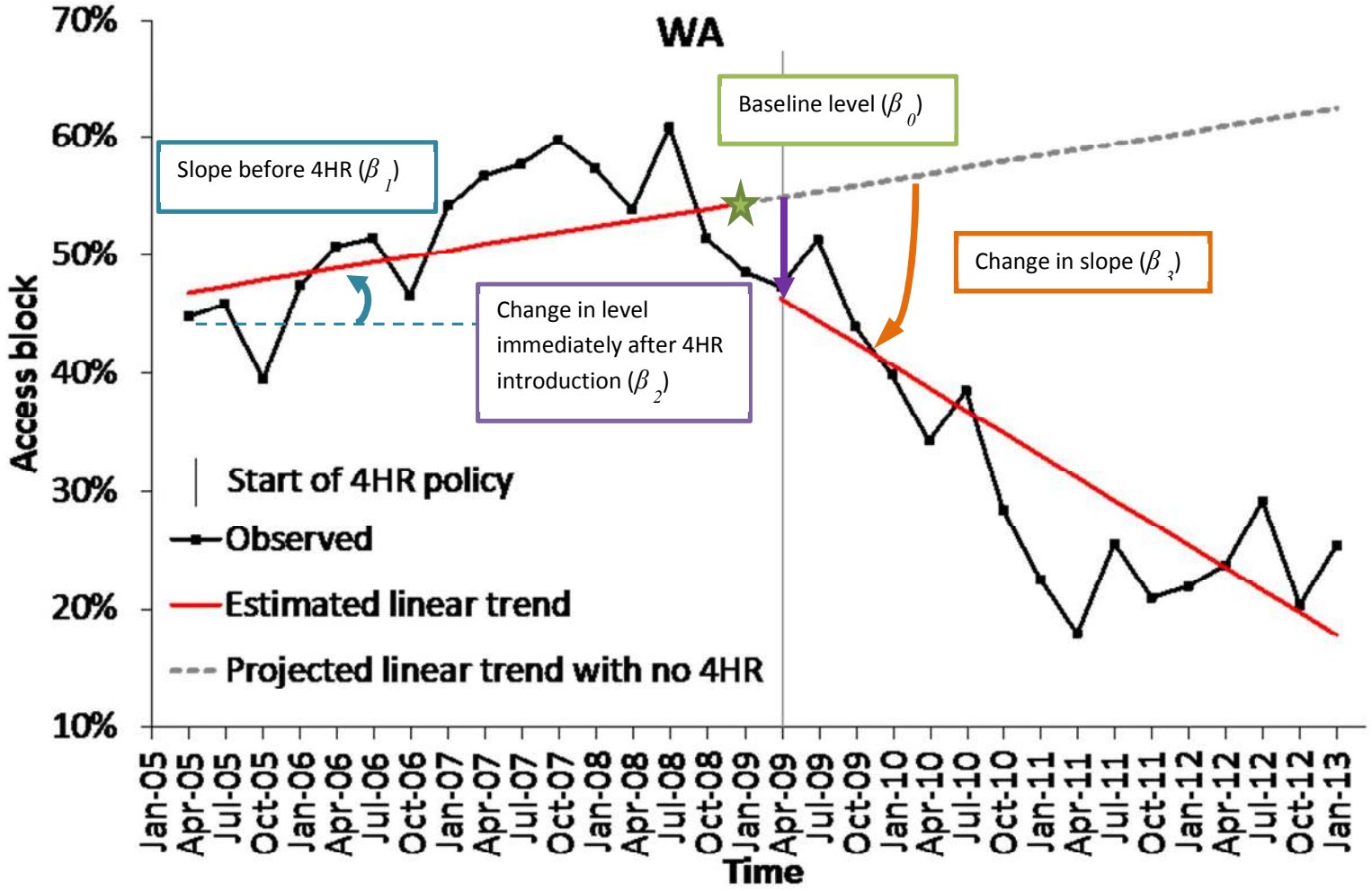
Time period	*Y* (outcome)	*Quart*	*Period*	*Quart_Post*
2005 Apr quarter	y_1	-15	0	0
2005 Jul quarter	y_2	-14	0	0
2005 Oct quarter	y_3	-13	0	0
2006 Jan quarter	y_4	-12	0	0
2006 Apr quarter	y_5	-11	0	0
2006 Jul quarter	y_6	-10	0	0
2006 Oct quarter	y_7	-9	0	0
2007 Jan quarter	y_8	-8	0	0
2007 Apr quarter	y_9	-7	0	0
2007 Jul quarter	y_{10}	-6	0	0
2007 Oct quarter	y_{11}	-5	0	0
2008 Jan quarter	y_{12}	-4	0	0
2008 Apr quarter	y_{13}	-3	0	0
2008 Jul quarter	y_{14}	-2	0	0
2008 Oct quarter	y_{15}	-1	0	0
2009 Jan quarter	y_{16}	0	0	0
2009 Apr quarter[1]	y_{17}	1	1	0
2009 Jul quarter	y_{18}	2	1	1
2009 Oct quarter	y_{19}	3	1	2
2010 Jan quarter	y_{20}	4	1	3
2010 Apr quarter	y_{21}	5	1	4
2010 Jul quarter	y_{22}	6	1	5
2010 Oct quarter	y_{23}	7	1	6
2011 Jan quarter	y_{24}	8	1	7
2011 Apr quarter	y_{25}	9	1	8
2011 Jul quarter	y_{26}	10	1	9
2011 Oct quarter	y_{27}	11	1	10
2012 Jan quarter	y_{28}	12	1	11
2012 Apr quarter	y_{29}	13	1	12
2012 Jul quarter	y_{30}	14	1	13
2012 Oct quarter	y_{31}	15	1	14
2013 Jan quarter	y_{32}	16	1	15

[1] The intervention started 6 months later in 2009 Oct quarter in the non-major metropolitan hospital, so the time period range for this hospital is 2005 Oct quarter to 2013 Jul quarter.

Table 2. Data coding for the eastern jurisdictions

Time period	*Y* (outcome)	*Quart*	*Period*	*Quart_Post*
2010 Jan quarter	y_1	-7	0	0
2010 Apr quarter	y_2	-6	0	0
2010 Jul quarter	y_3	-5	0	0
2010 Oct quarter	y_4	-4	0	0
2011 Jan quarter	y_5	-3	0	0
2011 Apr quarter	y_6	-2	0	0
2011 Jul quarter	y_7	-1	0	0
2011 Oct quarter	y_8	0	0	0
2012 Jan quarter	y_9	1	1	0
2012 Apr quarter	y_{10}	2	1	1
2012 Jul quarter	y_{11}	3	1	2
2012 Oct quarter	y_{12}	4	1	3
2013 Jan quarter	y_{13}	5	1	4
2013 Apr quarter	y_{14}	6	1	5
2013 Jul quarter	y_{15}	7	1	6
2013 Oct quarter	y_{16}	8	1	7

Figure 1. Definition of estimates in the analysis



Meta-regression analysis

Meta-regression analysis was performed with each set of 16 interrupted time series (ITS) estimates from the 16 Emergency Departments (EDs), *viz.* four sets of β_0 , β_1 , β_2 and β_3 corresponding to the baseline level, trend pre-intervention, level change and slope change, respectively, as the four outcome variables. Three models were fitted for each set of ITS estimates:

Model 1: An intercept-only model to obtain an **overall pooled estimate** at the national level from all 16 EDs.

Model 2: ED flow (% EDLOS ≤4 hours) performance tertiles entered as a categorical independent variable in the model.

Model 3: Access block performance tertiles entered as a categorical independent variable in the model.

Hospital was treated as a random effect in the meta-regression models. Models 2 and 3 were used to obtain a pooled ITS estimate for each tertile and to test for differences between the three performance tertiles.

The user-written Stata program ***metareg*** was used for the meta-regression analysis (5). Meta-type analysis was applied because ethics constraints and different time periods for different jurisdictions did not allow combination of individual patient-level data.

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APPENDIX 2: SUPPLEMENTARY TABLES

Table 1. Sample characteristics by pre- and post-4HR of ED presentations for adult patients across four jurisdictions

Characteristic	WA (n=1652136)				NSW (n=1080189)				ACT (n=353965)				QLD (n=829426)			
	Pre-4HR (n=733622)		Post-4HR (n=918514)		Pre-4HR (n=511258)		Post-4HR (n=568931)		Pre-4HR (n=169643)		Post-4HR (n=184322)		Pre-4HR (n=403059)		Post-4HR (n=426367)	
	Number	%	Number	%	Number	%	Number	%	Number	%	Number	%	Number	%	Number	%
Age (>65 years)	187226	25.5	227232	24.7	135331	26.5	151460	26.6	34574	20.4	40016	21.7	88221	21.9	95822	22.5
Gender (Male)	389013	53.0	479217	52.2	254566	49.8	281649	49.5	82421	48.6	87759	47.6	200689	49.8	208856	49.0
Arrived by Ambulance	237750	32.4	280337	30.5	181534	35.5	200304	35.2	38905	22.9	43651	23.7	153565	38.1	168621	39.5
Triage category 1	10898	1.5	13258	1.4	5772	1.1	7261	1.3	859	0.5	897	0.5	5269	1.3	4041	0.9
Triage category 2	122090	16.6	159022	17.3	71029	13.9	91260	16.1	19266	11.4	22943	12.4	61158	15.2	62327	14.6
Triage category 3	249480	34.0	342261	37.3	185214	36.3	207262	36.5	53394	31.5	62447	33.9	188238	46.7	204843	48.0
Triage category 4	311444	42.5	357898	39.0	190556	37.3	202299	35.6	73249	43.2	78027	42.3	121025	30.0	130735	30.7
Triage category 5	39621	5.4	46003	5.0	58344	11.4	60328	10.6	22875	13.5	20008	10.9	27369	6.8	24421	5.7
Admitted >24 hours	180809	24.6	212586	23.1	154274	30.2	168334	29.6	30377	17.9	32912	17.9	86213	21.4	87221	20.5

Table 2. Age-specific, age-standardised and crude mortality rate (within 30 days of last admitted ED visit) per 1000 by jurisdiction

Jurisdiction		Pre-4HR				Post-4HR			
		2005 (WA)	**2006 (WA)**	***2007 (WA)* / 2010 (others)**	***2008 (WA)* / 2011 (others)**	***2009 (WA)* / 2012 (others)**	***2010 (WA)* / 2013 (others)**	**2011 (WA)**	**2012 (WA)**
WA	18-59 years	19.5	19.0	17.5	16.9	17.6	15.7	15.2	13.8
	60-69 years	49.8	56.5	56.5	58.4	54.6	51.7	48.9	50.0
	70-79 years	84.9	84.1	81.3	88.7	82.4	77.0	77.3	71.2
	80-89 years	118.4	113.0	128.5	121.6	124.0	114.6	112.4	109.9
	≥ 90 years	167.5	186.7	194.4	179.3	179.2	180.4	190.1	188.1
	Age-standardised	32.1	32.3	31.5	31.4	31.2	28.7	28.0	26.4
	Crude	61.9	61.9	63.4	61.8	62.1	56.8	56.6	54.6
NSW	18-59 years	--	--	15.6	14.9	13.2	14.1	--	--
	60-69 years	--	--	54.2	53.8	50.6	48.9	--	--
	70-79 years	--	--	76.8	74.6	75.9	71.0	--	--
	80-89 years	--	--	110.3	113.2	115.1	108.0	--	--
	≥ 90 years	--	--	179.4	167.7	164.6	158.0	--	--
	Age-standardised	--	--	28.7	28.0	26.5	26.3	--	--
	Crude	--	--	55.8	55.3	54.5	51.9	--	--
ACT	18-59 years	--	--	10.3	12.3	12.0	12.5	--	--
	60-69 years	--	--	53.0	51.2	54.0	42.6	--	--
	70-79 years	--	--	73.9	69.4	66.7	65.3	--	--
	80-89 years	--	--	120.2	112.1	112.6	114.4	--	--
	≥ 90 years	--	--	206.5	182.7	204.0	171.7	--	--
	Age-standardised	--	--	24.7	25.3	25.3	24.2	--	--
	Crude	--	--	51.3	49.5	50.7	48.4	--	--
QLD	18-59 years	--	--	12.3	12.2	10.1	12.4	--	--
	60-69 years	--	--	46.8	42.5	40.7	44.7	--	--
	70-79 years	--	--	71.8	59.3	60.9	58.7	--	--
	80-89 years	--	--	96.5	92.2	81.8	84.1	--	--
	≥ 90 years	--	--	134.6	128.4	122.5	105.2	--	--
	Age-standardised	--	--	24.2	22.6	20.4	22.4	--	--
	Crude	--	--	44.1	40.5	38.6	39.4	--	--

Table 3. Estimates from interrupted time series (ITS) analysis for age-standardised mortality rate (per 1000) within 30 days of ED presentation with hospital admission lasting >24 hours) for each of the 16 hospitals.[1]

% EDLOS ≤ 4 hours		Access block		Baseline level at just before 4HR/NEAT[2]	Slope pre-4HR/NEAT (per quarter)		Change in level immediately post-4HR/NEAT		Change in slope post-4HR/NEAT (per quarter)	
Group[3]	Rank	Group[3]	Rank	Est.±s.e.	Est.±s.e.	P	Est.±s.e.	P	Est.±s.e.	P
1	3	1	3	27.18±1.61	-0.02±0.18	0.916	-1.93±2.39	0.427	-0.16±0.26	0.545
1	8	1	6	31.84±1.94	-0.08±0.22	0.733	2.14±2.88	0.463	-0.41±0.31	0.202
1	12	1	8	21.60±2.64	-0.91±0.63	0.173	-2.30±4.13	0.587	1.19±0.89	0.206
1	13	1	3	26.89±0.57	**-0.27±0.07**	**<0.001**	**2.01±0.91**	**0.036**	-0.16±0.09	0.088
1	13	1	10	17.82±2.02	-0.18±0.48	0.710	-3.01±3.17	0.361	0.93±0.68	0.197
2	16	2	17	27.69±2.17	-0.58±0.52	0.286	1.14±3.39	0.743	0.10±0.73	0.889
2	21	2	19	17.35±2.41	0.11±0.58	0.846	-1.14±3.78	0.769	0.05±0.82	0.952
2	25	2	16	18.14±0.60	**-0.33±0.15**	**0.046**	0.36±1.00	0.729	0.26±0.20	0.220
2	27	2	22	25.54±2.05	-0.25±0.49	0.612	-0.40±3.21	0.903	0.17±0.69	0.812
2	28	2	14	24.52±1.55	0.10±0.37	0.792	-3.49±2.43	0.177	-0.23±0.52	0.665
2	32	3	29	23.49±1.41	0.56±0.35	0.134	**-8.25±2.34**	**0.004**	**1.05±0.47**	**0.046**
3	48	1	14	16.93±1.36	0.11±0.15	0.492	0.16±2.01	0.936	-0.24±0.22	0.275
3	37	3	32	27.98±3.62	0.69±0.86	0.439	-7.77±5.67	0.196	-0.41±1.22	0.741
3	38	3	26	21.62±1.33	-0.22±0.32	0.507	-0.83±2.09	0.699	**1.05±0.45**	**0.038**
3	42	3	25	19.64±2.32	0.16±0.55	0.784	2.24±3.63	0.549	-0.92±0.78	0.261
3	45	3	28	26.44±2.07	-0.15±0.50	0.770	1.87±3.25	0.576	-0.54±0.70	0.455

[1] Estimates with p<0.05 are in bold.
[2] P-values are not provided because this tests whether mortality rate at just before 4HR/NEAT (the intercept) is significantly different from zero (which is not clinically useful in this context).
[3] 1=most improved; 2=moderately improved; 3=deteriorated/least improved.

We acknowledge Brydan Lenne who was employed in the preliminary stages of the project, for ethics application preparation and ethics submissions, and her contribution in the planning stages and data collection.

We thank Peter Sprivulis, Paul Tridgell and Paul Middleton for their participation and contribution in the early stages of the data analysis and contributions with the Project Management Committee. We also thank all the participants for their contribution in time and information provided.

A full acknowledgment of all investigators and partner organisations is available at the following link: https://swscs.med.unsw.edu.au/project/validation-and-impact-four-hour-rule-emergency-department-large-data-linkage-study