## ORIGINAL CONTRIBUTION

# The Effect of Laboratory Testing on Emergency Department Length of Stay: A Multihospital Longitudinal Study Applying a Cross-classified Random-effect Modeling Approach

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## Abstract

*Objectives:* The objective was to examine the relationship between laboratory testing (including test volume and turnaround time [TAT]) and emergency department (ED) length of stay (LOS), using linked patient-level data from four hospitals across 4 years.

*Methods:* This was a retrospective, multisite cohort study of patients presenting to any one of four EDs in New South Wales, Australia, during a 2-month period (August and September) in 2008, 2009, 2010, and 2011. Data from ED information systems were linked to laboratory test data. A cross-classified random-effect modeling approach was applied to identify factors affecting ED LOS, taking into account the correlation between patients' presentations at the same hospital and/or in the same calendar year. Number of test order episodes (tests ordered at one point in time during the ED stay) and TAT (time from laboratory order receipt to result available) were examined.

*Results:* As the number of test order episodes increased, so did the duration of patient ED LOS ($p < 0.0001$). For every five additional tests ordered per test order episode, the median ED LOS increased by 10 minutes (2.9%, $p < 0.0001$); each 30-minute increase in TAT was, on average, associated with a 5.1% (17 minutes; $p < 0.0001$) increase in ED LOS, after adjustment for other factors. Patients presenting to the ED at night (7 p.m. to 7 a.m.) had longer stays than those presenting during the daytime, although the median TATs at nights were shorter than those during the daytime.

*Conclusions:* Laboratory testing has a direct effect on patients' LOS in ED. Laboratory TAT, number of testing episodes, and test volume influence ED LOS. Targeted increases of ED resources and staffing after-hours may also contribute to reductions in ED LOS.

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Hospitals are looking for ways to reduce emergency department (ED) crowding and length of stay (LOS), both of which are associated with higher rates of preventable medical errors[1] and poor patient outcomes, including increased mortality.[2–4] Laboratory test results are crucial to diagnostic workup and patient management decisions and thus a potentially important contributor to ED patient flow. Turnaround

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time (TAT) for laboratory results is frequently used as a key performance indicator of laboratory service performance.[5]

The relationship between laboratory TAT and patient LOS in ED is unclear.[5] A simulation study by Storrow et al.[6] in 2008 suggested that decreased TAT could improve ED efficiency and reduce ED LOS. A small single-site study that examined 101 blood tests at one ED over a short period (27 hours) by Gill et al.[7] in 2012 showed an association between prolonged LOS and TAT. Francis et al. in 2009[8] reported a relationship between laboratory work process design and LOS in ED, but they were unable show a direct relationship between TAT and ED LOS. In 2005, Holland et al.[9] found that a reduction in tests with extremely long TATs was associated with a reduction in average ED LOS. A limitation of the study was the use of aggregated hospital-level data without adjustments for patient and ED presentation-related characteristics. In addition, most of above studies only focused on a subset of laboratory tests,[7,8] rather than all requested laboratory tests.

We aimed to address several of the limitations of previous studies by assessing the relationship between all laboratory test TATs on ED LOS across four hospitals. We used data linkage methods to examine the relationship between laboratory testing characteristics, including TAT, the overall number of tests, test order episodes, and ED LOS.

## METHODS

### Study Design

This was a retrospective, multisite cohort study of patients presenting at four Australian EDs. A cross-classified random-effect modeling approach was applied to identify factors affecting ED LOS, taking into account the correlation between patients' presentations at the same hospital and/or in the same calendar year. Ethics approval was granted by the relevant Local Health District Human Research Ethics Committee (HREC: Project No. 11/146) and ratified by the University of New South Wales HREC (Project No. 11380).

### Study Setting and Population

The study was conducted at a single, fully accredited laboratory service supporting the EDs at four Australian hospitals (three metropolitan and one regional). The laboratory service provided comprehensive biomedical laboratory services including the following laboratory specialties: anatomical pathology, blood bank, clinical chemistry, microbiology, endocrinology, hematology, molecular genetics, and immunology. The regional ED received an average of 82 to 93 patient presentations per day during the study period, while the average rate at the metropolitan EDs was 113 to 170. The regional ED admitted 20% to 22% of patients into the hospital and had a return ED visit rate (both planned and unplanned) between 3 and 6%. The metropolitan EDs admitted 28% to 29% of patients into the hospital and had a return ED visit rate (both planned and unplanned) of 2% to 4%. While the laboratory service was administratively a single entity, a physical laboratory was situated within each of the hospitals that hosted an ED and,

therefore, the vast bulk of laboratory testing for ED was processed onsite. There were no satellite laboratories dedicated to ED laboratory testing, but emergency physicians could request high-priority status for the laboratory test requests made to the hospital laboratory.

The EDs in the study had a strategy to reduce the duration of each patient's occupancy of an ED bed and minimize the number of consultations with a physician, by encouraging the triage nurse to request standard test panels based on a broad classification of the patient's symptoms. Ordering these laboratory tests during triage meant that test results could be available by the time of the initial physician consultation, facilitating a more rapid assessment and eliminating the need for a further consultation. However, even in cases where test results were not available when the physician consultation occurred, triage nurse ordering of laboratory tests resulted in shorter waiting times for test results and the patient occupying an ED bed for a shorter time.

The laboratory service took a pragmatic approach to the definition of tests within the laboratory information system (LIS). Some tests in the LIS refer to a single test assay (e.g., erythrocyte sedimentation rate), but often a test in the LIS refers to a group of related test assays frequently ordered and analyzed together on automated analyzers (e.g., urea, electrolytes, and creatinine [UEC]). Because the LIS treated these groups of test assays as single tests, our analyses maintained the same definition of tests; i.e., UEC is treated as a single test. Even using this pragmatic definition of tests in the LIS, the data extraction revealed that the study EDs ordered in excess of 550 different tests from the laboratory service during the study period. However, the 20 most frequently ordered tests accounted for 86.3% of all tests ordered from the study EDs (see Data Supplement S1, available as supporting information in the online version of this paper).

### Study Protocol

*Linked ED–Laboratory Data Set.* Laboratory test data for all patients presenting to the four study EDs during August and September of 4 consecutive years (2008 through 2011) were extracted from the LIS. This data set described all the laboratory test requests received during the study period for all the test types offered by the laboratory service. We linked this data set with data from the ED information systems at each of the four EDs to extract patient demographics (age and sex) and ED presentation characteristics (triage category, time and day of the week of presentation, mode of separation [discharged, admitted to hospital, or died], and ED LOS). The data sets were linked using medical record number, ED presentation dates, and laboratory test order episode dates and finalized after extensive validity and integrity tests on the source data. The linked ED–laboratory dataset contained information for all the tests ordered for ED patients who had at least one laboratory test ordered during the study period.

*ED–Laboratory Modeling Data Set.* To undertake valid comparisons between hospitals and across years, we developed data selection criteria to exclude some

patient groups from the final data set. This refined data set was used to model the relationship between TAT and ED LOS (Figure 1).

An ED presentation may involve multiple test order episodes; each test order episode can contain requests for multiple tests. Tests from a single test order episode may be processed in different laboratories within the laboratory service; thus test results could become available at different times. For example, a clinician may order six tests on one occasion. These six tests form a test order episode. Four tests, such as UEC, glucose, liver function tests, and calcium/magnesium/phosphate, are conducted in the chemistry laboratory, while the blood count and prothrombin time are performed in the hematology laboratory. The results for the four chemistry tests may be available first, say in less than 1 hour, while results for the other two tests at the hematology laboratory may take longer, say 1.5 hours. Tests processed at the same laboratory from the same test order episode could also have different TATs due to different testing methods required. For example, UEC and troponin are both performed in the clinical chemistry laboratory, but the immunoassay method used to measure troponin is slower. To further complicate matters, sometimes a subsequent test order episode can occur before all the results of a preceding test order episode are available to the clinician if, for example, another test, such as urine micro test performed by the microbiology laboratory, were to be ordered for the same patient before all the results for the first six tests are available.

Patients with multiple laboratory test order episodes are more likely to be suffering from complicated conditions about which we had insufficient data to control statistically. Therefore, we included only ED presentations with a single laboratory test order episode in the modeling analysis. For the same reason, we only

included patients' first ED presentations during the study period; i.e., we excluded any presentations subsequent to the first one. Last, patients who died in EDs, left at their own risk, or did not wait to be seen were also excluded. The ED–laboratory modeling data set included all the tests ordered for ED patient presentations which met the above inclusion criteria (Figure 1).

***Definitions of Laboratory TAT and ED LOS.*** Laboratory test results that are received after a patient is discharged from the ED clearly do not influence a clinician's decision to discharge and therefore could not affect the ED LOS. We reasoned that clinicians' patient management decisions can be plausibly influenced by all of the test results received prior to discharging the patient from the ED; so, of all laboratory test results, ED LOS is more likely to be dependent on the TAT for the last test result to be received before patient discharge. We termed this the maximum TAT, defined as the time difference between the time of receipt of the relevant specimen at the laboratory and availability in the ED of the last test result before patient discharge. Unless stated otherwise, all references to TAT in this paper refer to the maximum TAT.

The processing time for any hospital service, such as the time a patient remains in an ED bed while awaiting the results of laboratory testing, is associated with time that hospital resources (e.g., bed space, medical equipment, physician's time) are not available to other patients, such as those in the ED waiting room. In this way, laboratory TAT can indirectly influence all aspects of the patient's LOS in the ED, including the interval between arrival and triage and between triage and being seen by a physician. However, laboratory TAT can only directly influence the duration of an individual patient's stay in the ED once a laboratory test has been ordered, and this cannot occur until triage has occurred. Therefore, we defined ED LOS as the time difference between the time of triage and the time of discharge from the ED.

### Data Analysis

The two data sets described in the sections "Study Design" and "Study Setting and Population" were used in the analysis. Based on the linked ED-laboratory data set, the Kruskal-Wallis exact test was used to test the null hypothesis that there was no relationship between the number of test order episodes and ED LOS.

The rest of the analysis was undertaken using the ED–laboratory modeling data set. The ratio of TAT and ED LOS was calculated to show the proportion of patient ED LOS accounted for by laboratory testing. The Kruskal-Wallis nonparametric test was applied to examine the association between these proportions across calendar years within each ED.

Presentations within the same ED and/or calendar year are usually correlated, because patients are treated by the same group of clinicians under the same treatment regime. This violates the assumption of independence required in ordinary linear regression modeling. Failure to consider the correlation of the data could lead to underestimation of the standard errors of the estimates.[10] Multilevel modeling (also called random-effect
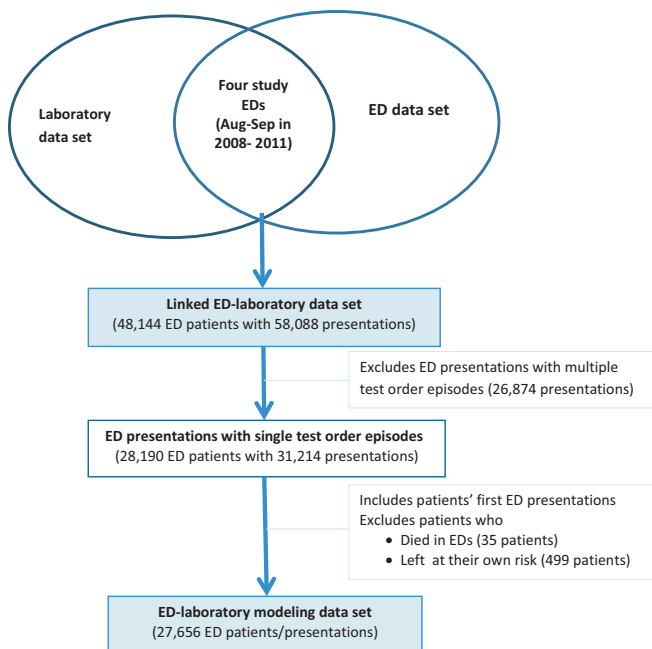


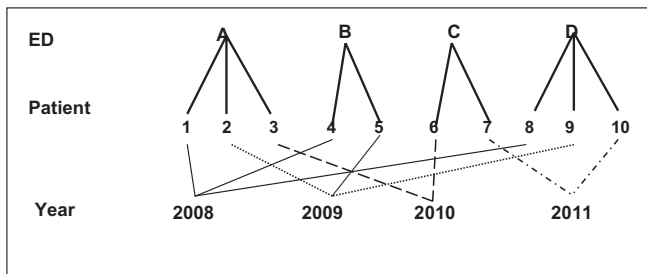**Figure 1.** Data linkage and datasets used for analyses (*shaded*).

modeling) provides a tool to handle such clustered data with consideration of the correlations within the same EDs and/or calendar years.[11]

The cross-classified data structure (Figure 2) required consideration of the cross-classified random effect models. ED patient presentations are cross-classified by EDs and years. For example, patient 1 attended ED A in 2008 while patients 4 and 8 attended EDs B and D in the same year, while patients 2 and 3 attended the same ED in different years. Although all the hospitals in the study were under the same governance of the New South Wales Health Department, new policies and other requirements were introduced each year. ED patient presentations were likely to be affected by the same policies or requirements in force in the same years. Therefore, it was reasonable to consider random main effects of year, ED, and their interaction.

The multilevel model approach provides several advantages over traditional regression analysis. First, in the multilevel model the target of inference is the pre-

sentations at different EDs and years, not the comparison between particular EDs or years in the data set.[12] Second, while it would require 16 parameters to include hospital, year, and their interactions in a fixed-effect model compared with three in a random-effect model, the multilevel model approach is more parsimonious because it provides adequate robustness with two extra parameters.

The ED LOS was log-transformed (natural logarithm) due to the right skewness of the ED LOS distribution and the normality assumption of the specified model. In addition to TAT, the model also included all clinically important variables, such as ED patient demographics (including two categorical variables: age group and sex; see Table 2), the number of tests ordered, and presentation-related characteristics (including three categorical variables: triage category, ED mode of separation, and day of week; see Table 2), as covariates in the above model. The interaction terms between explanatory variables were not included in the model because while they increased the model complexity, they made little difference to the parameters estimated. Variables in the final model were considered statistically significant at $p < 0.05$. Analyses were performed using SAS software version 9.2 and STATA version 12.1.

## RESULTS

### Test Order Episodes and ED LOS
There were 123,455 ED presentations during the study period. In the linked ED–laboratory data set, there were 58,088 ED presentations ($n$ = 48,144 patients) with at least one laboratory test episode and 346,949 tests ordered for these patients. Among these presentations,



**Figure 2.** Schematic of cross-classified data structure with ED patients nested in EDs and years.

Table 1
Proportion of ED LOS Accounted for by Laboratory TAT (i.e., TAT/ED LOS) by ED and ED-year of Presentation (from ED–Laboratory Modeling Data Set)

| Hospital ED* | N | Mean | Median (IQR) | Year | n | Mean | Median (IQR) | p-value† |
|---|---|---|---|---|---|---|---|---|
| A | 7,401 | 0.22 | 0.17 (0.11–0.28) | 2008 | 1,782 | 0.21 | 0.16 (0.10–0.27) | <0.0001 |
| | | | | 2009 | 1,894 | 0.22 | 0.17 (0.10–0.29) | |
| | | | | 2010 | 1,908 | 0.21 | 0.16 (0.09–0.26) | |
| | | | | 2011 | 1,817 | 0.23 | 0.19 (0.13–0.30) | |
| B | 8,967 | 0.21 | 0.17 (0.11–0.27) | 2008 | 2,453 | 0.21 | 0.17 (0.11–0.27) | <0.0001 |
| | | | | 2009 | 2,167 | 0.19 | 0.16 (0.10–0.24) | |
| | | | | 2010 | 2,203 | 0.23 | 0.19 (0.12–0.30) | |
| | | | | 2011 | 2,144 | 0.22 | 0.18 (0.12–0.28) | |
| C | 4,010 | 0.25 | 0.20 (0.12–0.34) | 2008 | 1,030 | 0.25 | 0.20 (0.12–0.34) | <0.0001 |
| | | | | 2009 | 958 | 0.27 | 0.22 (0.13–0.37) | |
| | | | | 2010 | 960 | 0.27 | 0.23 (0.13–0.36) | |
| | | | | 2011 | 1,062 | 0.22 | 0.18 (0.11–0.29) | |
| D | 7,278 | 0.25 | 0.21 (0.13–0.34) | 2008 | 2,038 | 0.26 | 0.21 (0.13–0.34) | <0.0001 |
| | | | | 2009 | 1,819 | 0.25 | 0.20 (0.12–0.33) | |
| | | | | 2010 | 1,724 | 0.27 | 0.24 (0.14–0.36) | |
| | | | | 2011 | 1,697 | 0.24 | 0.20 (0.12–0.32) | |
| Total | 27,656 | 0.23 | 0.19 (0.11–0.3) | 2008 | 7,303 | 0.23 | 0.19 (0.11–0.30) | <0.0001 |
| | | | | 2009 | 6,838 | 0.22 | 0.18 (0.11–0.30) | |
| | | | | 2010 | 6,795 | 0.24 | 0.20 (0.12–0.32) | |
| | | | | 2011 | 6,720 | 0.23 | 0.19 (0.12–0.30) | |

IQR = interquartile range; LOS = length of stay; TAT = turnaround time.
*p-value for the between-ED comparison using Kruskal-Wallis test is <0.0001.
†p-value from the Kruskal-Wallis test.

54% (n = 31,214 presentations for 28,190 ED patients) involved a single laboratory test order episode; 46% of ED presentations involved more than one test order episode (max = 17). The majority of test order episodes (97.3%) contained multiple tests (max = 61, median = 5, with interquartile range [IQR] = 4 to 7). The median ED LOS was shortest for presentations with only one test order episode (5.6 hours) and longest for presentations with 17 test order episodes (40.7 hours, Figure 3). There was a significant positive relationship between the number of test order episodes and ED LOS ($\chi^2$ = 7988 with degrees of freedom [df] = 14, p < 0.0001 from the Kruskal-Wallis exact test).

## ED Presentations With One Test Order Episode Using the ED–Laboratory Modeling Data Set

*ED LOS and TAT.*   There were 27,656 patients/presentations in the ED–laboratory modeling data set, which involved one test order episode and met the study inclusion criteria (Figure 1). Among these ED presentations, the median ED LOS was 334 minutes (IQR = 239 to 469 minutes) and the median TAT was 58 minutes (IQR = 40 to 88 minutes). Laboratory TAT was longest (median = 66 minutes, IQR = 47 to 98 minutes) for patients presenting between 7 a.m. and 1 p.m. and shortest between 7 p.m. to 1 a.m. (median = 48 minutes, IQR = 34 to 74 minutes). TATs on weekends were shortest (median = 51 minutes, IQR = 36 to 78 minutes) while TATs were much longer with little variation on weekdays (median = 58 minutes, IQR = 41 to 88 minutes; to median = 61 minutes, IQR = 42 to 93 minutes). The number of tests within each test order episode ranged from 1 to 33 (median = 4, IQR = 3 to 6).

The ratio of TAT and ED LOS was calculated for each patient presentation. The median of the ratios of TAT and ED LOS was 0.19 (IQR = 0.11 to 0.30), which implies that TAT might account for 19% of the variation in ED LOS. As shown in Table 1, these ratios varied across
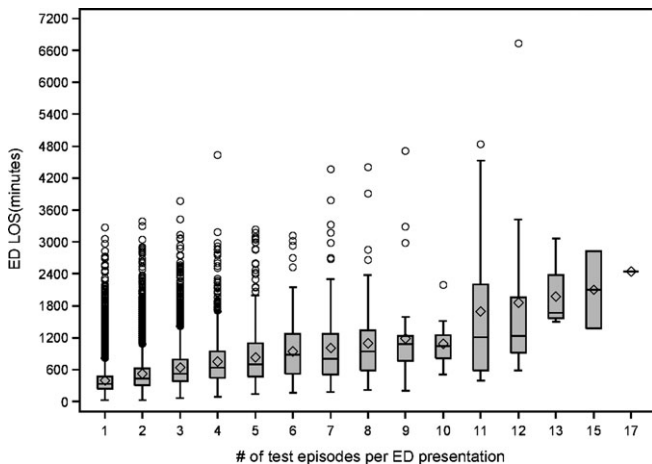


**Figure 3.** Boxplots for ED LOS and the number of test order episodes per admission. Boxplots show mean (*diamond*), median, interquartile range, whiskers (defined as 1.5 times the value of the interquartile range), and outliers for ED LOS grouped by the number of the test order episodes per admission. The greater the number of test order episodes, the longer the patient ED LOS (p < 0.0001). LOS = length of stay.

EDs (p < 0.0001). The ratios of TAT and ED LOS were slightly lower at EDs A and B compared to EDs C and D. This proportion also varied across years in each ED (p < 0.0001).

## Patient Demographic and ED Presentation Characteristics

Table 2 presents the demographic and presentation characteristics of patients included in the modeling data set. The mean (±SD) age was 51 (±24) years and 53% were female. The median ED LOS increased for older patients, but there was little difference between male and female patients. About 12.6% of patient presentations were triaged into categories 1 or 2, defined as suffering from immediately or imminently life-threatening conditions. The crude median ED LOS was shorter for those presentations than for those ED presentations with triage categories 3 to 5. Analysis of mode of separation data revealed that 43% of patients completed treatment and were discharged. Discharged patients had shorter median ED LOS and TAT than was the case for those patients who were admitted as inpatients or transferred to another ward or hospital. Less than one-third of patients (30.7%) presented at EDs at night (between 7 p.m. and 7 a.m.). ED presentations between 1 a.m. and 7 a.m. had the longest median ED LOS. Laboratory TAT was longest for patients presenting between 7 a.m. and 1 p.m. The rate of presentations was relatively uniform from Tuesday to Sunday (between 13.4 and 14.6%), while more ED presentations occurred on Mondays (15.7%). Patients who presented at EDs on Mondays also had the longest median LOS compared to patients presenting on other weekdays, but TATs did not follow the same pattern. TATs on Mondays were no different to other weekdays. TATs were shortest for tests ordered on weekends.

## The Relationship Between ED LOS and TAT

Table 3 shows factors that made significant contributions to ED LOS taking account of the correlations between presentations at the same hospital in the same calendar year. The whole model accounted for 24% of the variation in ED LOS. The inclusion in the model of TAT and the number of tests ordered explains more than 10% of the variation in ED LOS.

Table 3 shows that, everything else being equal, every 30-minute increase in TAT was, on average, associated with a 5.1% increase in ED LOS (95% confidence interval [CI] = 4.9% to 5.3%; p < 0.0001). This is equivalent to a 17-minute increase in the median ED LOS. Every 60-minute increase in TAT was, on average, associated with a 10.5% increase in ED LOS (95% CI = 10.1% to 11.0%, a 35-minute increase in the median ED LOS). Figure 4 shows a positive relationship between TAT and predicted LOS based on the model for patients aged 31 to 50 years presenting at EDs between 1 a.m. and 7 a.m. on Fridays with immediately life-threatening conditions (i.e., triage category 1), who had one test episode with five tests ordered during their ED stay, and were admitted or transferred to hospitals.

The number of tests ordered for each presentation also had a significant impact on ED LOS. For every five additional tests ordered within an ED presentation, the

Table 2
Patient Demographic and ED Presentation Characteristics (From ED–Laboratory Modeling Data Set)

| Variables | n (%) | Median ED LOS (IQR), Minutes | Median TAT (IQR), Minutes |
|---|---|---|---|
| Age group, yr | | | |
| <31 | 6,826 (24.7) | 304 (221–420) | 54 (37–81) |
| 31–50 | 6,752 (24.5) | 310 (225–441) | 56 (39–84) |
| 51–70 | 6,516 (23.6) | 335 (238–469) | 57 (40–88) |
| ≥71 | 7,562 (27.4) | 389 (281–539) | 63 (44–97) |
| Sex | | | |
| Male | 13,034 (47.2) | 333 (237–470) | 56 (39–87) |
| Female | 14,622 (52.9) | 334 (240–467) | 59 (41–88) |
| Triage | | | |
| Immediately life-threatening (1) | 267 (1.0) | 274 (168–423) | 53 (35–76) |
| Imminently life-threatening (2) | 3,192 (11.6) | 293 (208–407) | 60 (43–88) |
| Potentially life-threatening (3) | 13,029 (47.2) | 333 (240–467) | 58 (40–89) |
| Potentially serious (4) | 10,522 (38.1) | 353 (250–488) | 56 (39–86) |
| Less urgent (5) | 646 (2.4) | 315 (220–454) | 54 (36–84) |
| ED mode of separation | | | |
| Admitted/transferred to another ward/hospital | 15,674 (56.7) | 391 (276–551) | 62 (42–97) |
| Treatment completed within ED | 11,982 (43.4) | 281 (211–373) | 54 (38–78) |
| Time of day of presentation | | | |
| 1 a.m.–7 a.m. | 2,750 (10.0) | 368 (250–515) | 59 (39–98) |
| 7 a.m.–1 p.m. | 9,465 (34.3) | 337 (246–453) | 66 (47–98) |
| 1 p.m.–7 p.m. | 9,731 (35.2) | 323 (234–446) | 55 (39–81) |
| 7 p.m.–1 a.m. | 5,710 (20.7) | 334 (231–551) | 48 (34–74) |
| Day of week of presentation | | | |
| Monday | 4,339 (15.7) | 352 (248–494) | 61 (42–93) |
| Tuesday | 4,018 (14.6) | 335 (242–469) | 61 (42–91) |
| Wednesday | 4,027 (14.6) | 329 (238–466) | 61 (42–90) |
| Thursday | 3,752 (13.6) | 329 (234–463) | 61 (42–91) |
| Friday | 4,015 (14.6) | 334 (240–462) | 58 (41–88) |
| Saturday | 3,702 (13.4) | 328 (235–462) | 52 (37–79) |
| Sunday | 3,803 (13.8) | 328 (233–464) | 51 (36–78) |

IQR = interquartile range; LOS = length of stay; TAT = turnaround time

Table 3
The Relationship Between ED LOS and TAT: Model Results

| Variables | Category | % Change* (95% CI) | p-value |
|---|---|---|---|
| Age, yr | <31 | –3.9 (–5.4 to –2.4) | <0.0001 |
| | 31–50† | | |
| | 51–70 | 3.5 (1.9 to 5.2) | <0.0001 |
| | ≥71 | 12.3 (10.6 to 14.1) | <0.0001 |
| Triage category | Immediately life-threatening (1)† | | |
| | Imminently life-threatening (2) | 10.2 (4.0 to 16.7) | 0.001 |
| | Potentially life-threatening (3) | 36.6 (29.1 to 44.5) | <0.0001 |
| | Potentially serious (4) | 48.0 (39.9 to 56.7) | <0.0001 |
| | Less urgent (5) | 39.8 (30.8 to 49.4) | <0.0001 |
| Mode of separation | Admitted/transferred† | | |
| | Treatment completed within ED | –26.5 (–27.4 to –25.6) | <0.0001 |
| Time | 1 a.m.–7 a.m.† | | |
| | 7 a.m.–1 p.m. | –7.6 (–9.5 to –5.8) | <0.0001 |
| | 1 p.m.–7 p.m. | –6.7 (–8.5 to –4.9) | <0.0001 |
| | 7 p.m.–1 a.m. | 2.0 (–0.2 to 4.2) | 0.08 |
| Day of week | Monday | 6.2 (4.1 to 8.3) | <0.0001 |
| | Tuesday | 1.7 (–0.4 to 3.8) | 0.1 |
| | Wednesday | 0.2 (–1.9 to 2.3) | 0.9 |
| | Thursday | –1.2 (–3.2 to 1.0) | 0.3 |
| | Friday† | | |
| | Saturday | 3.0 (0.9 to 5.2) | 0.006 |
| | Sunday | 3.8 (1.7 to 6.0) | <0.0001 |
| TAT (for each additional 30 minutes) | | 5.1 (4.9 to 5.3) | <0.0001 |
| Number of tests ordered (for each additional five tests ordered) | | 2.9 (1.5 to 4.4) | <0.0001 |

IQR = interquartile range; LOS = length of stay; TAT = turnaround time.
*The percentage change in the ED LOS for one defined unit increase in the continuous explanatory variables while all other variables in the model are held constant. In case of categorical explanatory variables, % change refers to the percentage change in the ED LOS compared to the reference category.
†Reference category.
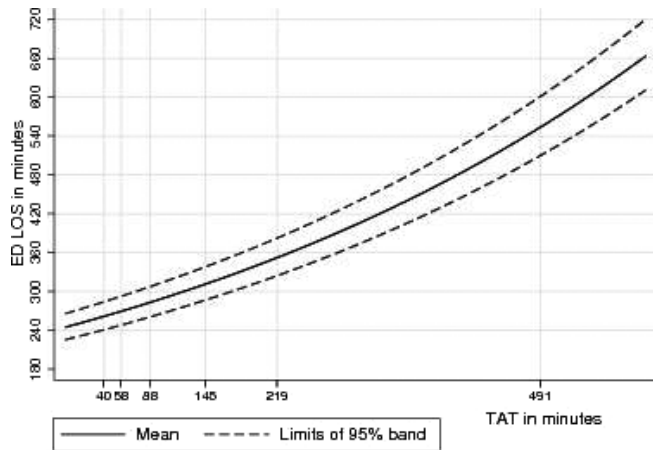
**Figure 4.** Mean LOS and 95% confidence limits based on the model (values labeled on the x-axis are the 25th, 50th, 75th, 90th, 95th, and 99th percentiles of TAT) for patients aged 31 to 50 years presenting at EDs between 1 a.m. and 7 a.m. on Fridays with immediately life-threatening conditions (i.e., triage category 1), who had one test episode with five tests ordered during ED stay and were admitted/transferred to hospitals. LOS = length of stay; TAT = turnaround time.

patient experienced on average, a 10-minute increase (2.9% increase with 95% CI = 1.5% to 4.4%; p < 0.0001) in median LOS adjusting for the other factors in the model.

After the other factors in the model were adjusted for, patients aged 71 years or older were more likely to have longer stays in the ED. On average, they stayed 12.3% longer than patients aged 31 to 50 years (p < 0.0001, Table 3). The median ED LOS for patients aged 31 to 50 years was 310 minutes, while for those patients aged 71 or older the median ED LOS was 38 minutes longer (348 minutes). Patients with less urgent conditions in general stayed longer than those with life-threatening conditions. ED LOS for those patients who completed treatment within an ED and were discharged was 26.5% shorter than for patients admitted as inpatients or transferred to another ward or hospital (p < 0.0001).

Day of the week and time of the day of presentation to an ED had significant effects on ED LOS (p < 0.0001, Table 3). Patients presenting at EDs during the day (7 a.m. to 7 p.m.) had significantly shorter ED LOS than those who presented at night (7 p.m. to 1 a.m.; p < 0.0001). On average, the median LOS for patients presenting during the daytime was 25 to 28 minutes shorter (6.7% to 7.6% decrease) than the median LOS of patients presenting 1 a.m. to 7 a.m. ED LOS was not significantly different between patients who presented at night (7 p.m. to 1 a.m.) and from 1 a.m. to 7 a.m. (p = 0.08). Patients presenting on Mondays stayed 6.2% longer than those who presented on Fridays (p < 0.0001); those who presented on Saturdays or Sundays stayed 3.0% to 3.8% longer than those who presented on Fridays (p = 0.006 and p < 0.0001). ED LOS for patients presenting on other weekdays was not significantly different to the ED LOS of those presenting on Fridays.

## DISCUSSION

We found that, on average, for every additional 30-minute increment in test TAT there was a 17-minute increase in median ED LOS. These findings provide an empirical confirmation of a simulation study undertaken by Storrow et al.,[6] which estimated the effect of decreasing TAT on ED efficiency and showed that a 60-minute reduction in TAT (from 120 to 60 minutes) was estimated to produce a 30-minute decrease in ED LOS (from 166 to 136 minutes). While we have attempted to render the findings more accessible by describing this relationship in terms of the impact of a specific change in TAT on median ED LOS, it is important to remember that there is great variation from ED presentation to ED presentation, in the relationship between TAT and ED LOS. It is easy to imagine that if, for example, laboratory tests were ordered along with radiology or imaging studies, the impact of laboratory TAT on ED LOS may be nil if the radiology or imaging study result takes longer to arrive; on the other hand, the impact of laboratory TAT on ED LOS may be 1:1 if all other examinations and procedures are complete and the discharge or transfer decision is awaiting the arrival of laboratory test results.

A strength of our study was its use of a large, individual patient-level, multisite, longitudinal data set. The Kruskal-Wallis tests showed that there were significant differences in the ratios of ED LOS and TAT across different hospitals and calendar years. Our multilevel cross-classified modeling approach is not only appropriate to the data structure, but also takes into consideration unmeasured contextual factors, including staffing structures, organizational culture, and policies in force and work practices and across different hospitals and/or calendar years. A secondary analysis of U.S. data from the National Hospital Ambulatory Medical Care Survey undertaken by Kocher et al.[13] for the years 2006 through 2008 also found ED presentations involving testing were associated with prolonged LOS in the ED. The tests in that study covered both laboratory tests (including blood tests and urinalysis) and imaging tests. However, the models used did not include test TAT or test volumes. Only dummy variables for the involvement of different test types were considered. In addition, their models failed to consider the correlation structures of the data, possibly within states, EDs, and years. This failure to adjust for correlation could lead to their p-values being too small and CIs too narrow.[14]

Various strategies to reduce TAT and test volume, such as improving preanalytic processes, have received considerable attention.[8,15–19] Studies have shown that improving preanalytic processes can improve clinical chemistry TATs from a central laboratory,[20] and redesigning laboratory processes has been shown to be associated with a significant reduction in LOS in the ED from a single-site trial in Australia.[8] Stuart et al.[21] evaluated an intervention developed to improve test-ordering practice at an ED in an urban hospital in Australia. They showed a 40% reduction in the ordering rate of laboratory tests within the ED using a three-part intervention program, consisting of implementing a test-ordering

protocol, education program for medical staff and an audit/feedback process.[21]

The variations of TATs were shown by day of week and time of day. Laboratory TAT was longest for patients presenting between 7 a.m. and 1 p.m. and shortest between 7 p.m. to 1 a.m. TATs on weekends were shortest while TATs were much longer with little variation on weekdays. Given that the EDs did not operate their own dedicated laboratories, one explanation for these variations of TATs is that laboratory workload coming from other areas of the hospital, i.e., a "rest-of-the-hospital" factors, may have had an effect on TAT for pathology tests requested from the ED. Laboratory workload was less on weekends and at night when no other outpatient services were operating and referring pathology tests, and inpatient clinical review and activity are also likely to be less than on weekdays during business hours.

Our study demonstrated that patients' ED LOS is significantly affected by a number of factors, including patient age, triage, mode of separation, and time and day of ED presentation. ED patients triaged in urgent categories, i.e., categories 1 and 2, need to be attended to within 2 and 10 minutes, respectively,[22] which explains why these patients on average had shorter ED LOS than patients triaged in other less urgent categories, i.e., categories 3 to 5. Patients presenting during the daytime (7 a.m. to 7 p.m.) had a shorter LOS than those presenting at night (7 p.m. to 7 a.m.) while the median TATs at night were shorter than those during the daytime. This may suggest that other factors, including ED staffing and resources, are contributing to ED LOS. Patients who presented on Mondays and weekends stayed longer than those who attended EDs on Fridays. In 2007, the Institute of Medicine's (IOM) publication, "Hospital-based Emergency Care at the Breaking Point," described the emergency care system as one that is affected by a myriad of environmental forces, ranging from staffing across the hospital and community to increases in chronic disease, an aging population, and levels of general practice availability.[23] Many of these factors are beyond the control of any one ED. However, it is necessary to understand these forces and structure ED responses accordingly.[23,24] Nevertheless, as the IOM emphasizes, there are also factors where the ED can impose its control. The findings from our study outline the potential value that may be gained by examining ways to improve laboratory TAT, testing episodes, and test ordering practices, as key elements in reducing ED LOS. The description of how ED LOS fluctuates as a function of time of day and day of week can also assist clinicians and hospital administrators to manage patients' expectations and their satisfaction with the quality of care delivery. Targeted increases of ED resources and staffing after-hours may also contribute to reducing ED LOS at the specific times highlighted.

## LIMITATIONS

In the modeling data set, we excluded ED patient presentations with multiple laboratory test order episodes because these patients were more likely to be suffering from complicated conditions about which we had insufficient data to control statistically. Although more than half of all presentations (54%) in the linked data set involved a single laboratory test order episode, the inclusion of all ED patients in the modeling analyses would have provided more in-depth understanding of complexity of ED LOS. Additional information, not available for the present study, such as details of patients' illnesses and complexity, utilization of other services such as radiology or imaging studies, type of treatment, hospital bed occupancy, and workload and clinical staffing levels, could also have provided a further dimension to our understanding. In this study, the median ratio of TAT and ED LOS is 0.19, suggesting that other activities within the EDs accounted for the majority of variations in ED patients' stay (81%). This was also confirmed by the variation accounted for by the model. The inclusion of TAT and the number of tests ordered explained only 10% of the variation in ED LOS. A recent study,[25] for example, showed that the seniority of the doctor receiving the laboratory test results was associated with ED LOS, as sometimes junior medical officers were unable to make decisions despite the rapid availability of a result.

By including both metropolitan and regional EDs in this study we have made an effort to generate findings that are broadly representative of the situation for the majority of Australian EDs. Operating characteristics at EDs in other countries may differ from these, and the generalizability of these findings may be reduced for EDs whose operating characteristics are starkly different to these. For example, the Centers for Disease Control and Prevention National Center for Health Statistics (CDC/NCHS) reported that in 2010, approximately 17% of ED visits concluded in a patient being admitted as an inpatient or transferred to hospital,[26] while the proportion admitted at the EDs in this study was 20 to 22 and 27% to 28% at regional and metropolitan EDs, respectively. In cases such as these, the strength of the relationship between laboratory test utilization and TATs and ED LOS might be different to the one we have reported. We can make no a priori prediction of the direction that such a change might take.

The relatively small number of EDs and years in this study limited our ability to test the variance components of the cross random-effect model because the null distribution used for the tests of variance components are asymptotic and rely on a large number of clusters, i.e., EDs and years. Last, our use of linked administrative data sets from different sites over years allowed us to identify a positive relationship between laboratory testing characteristics and ED LOS, but not to establish a definitive causal relationship.

## CONCLUSIONS

This study makes a valuable contribution to our understanding of how different laboratory testing characteristics, including turnaround time, the number of tests, and test order episodes, affect ED length of stay. Clinicians' ordering practices affect ED length of stay through the number of laboratory tests that they order, and laboratory service performance affects ED length of stay through the time needed to process laboratory test

requests. Variations in clinician practices and laboratory performance are suitable targets for quality improvement.

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## Supporting Information

The following supporting information is available in the online version of this paper:

**Data Supplement S1.** Frequently ordered tests in study EDs.