

CHEMICAL PATHOLOGY

Identifying low value pathology test ordering in hospitalised patients: a retrospective cohort study across two hospitals



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Summary

The push to identify low value care has led to scrutiny of pathology test re-ordering. The objective of this study was to identify the patterns of ordering pathology tests among inpatients in teaching hospitals and model strategies to reduce unnecessary testing. This was a retrospective cohort study of all adult medical and surgical inpatients admitted to one major teaching hospital and one rural hospital in the same health district over 2 years. Obstetric, gynaecological, intensive care, elective/day procedures and dialysis admissions were excluded. Orders for electrolytes, urea and creatinine (EUC), full blood count (FBC), thyroid stimulating hormone (TSH), glycated haemoglobin (HbA1c), vitamin D, and troponin, date of order, and value of the resulting test, were obtained from a health district data warehouse. Pathology results were mapped to each inpatient day.

EUC and FBC constituted over 90% of all inpatient pathology requests for these six tests. Between 40–45% of inpatients had EUC and/or FBC performed daily. After the first couple of tests, the retest interval was consistently around 24 hours, regardless of the previous value of the test, consistent with a culture of routine ordering. This was less pronounced in the rural hospital compared to the urban teaching hospital. Lockouts (applied when previous tests normal) or minimum retest intervals (applied to previously normal and abnormal tests) of various lengths were tested on the data to find optimal combinations that reduced unnecessary tests without missing too many very abnormal tests. A lockout of 48 hours for EUC and 48 hour lockout combined with a 12 hour minimum retest interval for FBC appear optimal to reduce over ordering and could save approximately AU\$400/inpatient bed per year at a single teaching hospital.

There is evidence of low value re-ordering of EUC and FBC pathology tests. Implementation of a computerised physician order entry system with inbuilt prompts to restrict unnecessary re-ordering of pathology tests may be a practical solution.

Key words: Haematology; pathology tests; inpatients; economic evaluation; adults; biochemistry.

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INTRODUCTION

Like the United States and Canada, Australia has a strong focus on changing the way we think about healthcare, questioning the notion ‘more is always better’.¹ The aim of Choosing Wisely Australia, and internationally, is to both identify and reduce investigations and treatments that are of low value, with the outcome of improving the provision of healthcare.¹ More data are needed to eliminate waste, through an evidence-based selection of low value care candidates.²

Although only a small proportion of a hospital’s total healthcare budget (~5%), laboratory tests are the highest volume medical activity, and a reasonable target for scrutiny for low value care, particularly given the invasive nature of phlebotomy and the burden of repetitive and unnecessary tests.³

Eaton *et al.*⁴ have recently summarised the evidence-based guidelines for reducing repetitive laboratory testing, suggesting the most effective interventions include a combination of provider education, performance feedback, and a restrictive computerised physician order entry system (CPOE). However, the evidence base on which to make decisions regarding retest intervals is far from robust and is based mainly on consensus statements. Based on the definition by Lang and Croal, minimum retest intervals are the shortest period before a test should be repeated, based on the properties of the test paired with the clinical situation in which it is used.⁵ Here within, the term ‘lockout’ is used where the value of the previous test is a predictor of the need for a subsequent test. Therefore lockouts are only applied when the previous test result is normal.

We set out to look at current patterns of ordering for common pathology tests among hospital inpatients with a

view to developing an evidence base on which we could make informed decisions about lockouts and minimum retest intervals, potentially as part of a CPOE system.

METHODS

Ethics

The research was approved as a clinical audit and quality improvement project by the Hunter New England Local Health District's Director of Clinical Governance and received a waiver of approval from the Hunter New England Human Research Ethics Committee (23 January 2014).

Setting

John Hunter Hospital (JHH) is located in Newcastle, New South Wales (NSW), Australia, and is the largest hospital within the Hunter New England Local Health District, servicing a population of more than 800,000 Australians, with approximately 650 beds (500 medical and surgical). John Hunter Hospital functions as a tertiary referral, major trauma, and teaching hospital, with a Level 6 Emergency Department. Laboratory services are located onsite and until 2017, all laboratory requests were made using paper-based forms.

For comparison, data were similarly obtained from Tamworth Rural Referral Hospital (TRRH), a regional hospital of 265 beds serving a population of around 50,000, in the same Local Health District, located in Tamworth, NSW.

Data sources

Data were extracted for all adult medical and surgical admissions between 1 January 2014 and 31 December 2015. Obstetric, gynaecological, intensive care, and elective day procedures were not included. Admissions data were extracted from iPM, the Patient Administration System (PAS). Laboratory data (HL7 messages) were extracted from AUSLAB (Citadel Health, Australia), an Enterprise Class Laboratory Information System. Data were merged at the level of the patient and admission, since the same patient may have had multiple admissions over the study period. Given that our focus was on exploring patterns of ordering for acute hospital inpatients, if a patient was transferred to Rehab, Dialysis, Transition, or Intensive Care at any time, their admission was truncated at the time of transfer. The process of data linkage is shown in [Supplementary Fig. 1 \(Appendix A\)](#).

Patient characteristics

Demographic, disease-related, and hospital information included: age (in years) at admission, classified as 18–39, 40–59, 60–79, 80+; sex (male, female); Charlson comorbidity index,⁶ 0, 1–2, 3–4, ≥ 5 ; admission year (2014, 2015); admitting medical speciality (surgery, medicine); day of week, and time of day test received/processed (day 7am–7pm, night 8pm–6am).

Laboratory tests

Six laboratory tests of interest were initially included: electrolytes, urea and creatinine (EUC); full blood count (FBC); troponin; thyroid stimulating hormone (TSH); 25-hydroxyvitamin D; and glycated haemoglobin (HbA1c). For TSH, vitamin D, and HbA1c, we also included any outpatient values reported for up to 3 months prior to the admission date. For EUC and FBC, which are bundled tests, the most abnormal value for the bundle was used to categorise the overall test result as normal, abnormal, or very abnormal. These reference interval categories are determined by Pathology North, the hospital's accredited pathology provider. A very abnormal or critical result is one that may be considered life threatening, could result in severe morbidity or death, and/or requires urgent clinical intervention. The threshold values for normal, abnormal, and very abnormal are detailed in [Supplementary Table 1 \(Appendix A\)](#).

Study outline

We examined the patterns of ordering for common laboratory tests during hospital admissions, including change over time and whether the time between tests varied based on the prior test result (normal, abnormal, or very abnormal). We then modelled three scenarios for potential restrictions on test ordering: (1) 'lockouts', i.e., periods during which reorders for tests previously within the normal reference interval would be flagged; (2) 'minimum retest intervals', i.e., short periods (generally 12 hours) during which reorders would be flagged for previously normal and abnormal test results (not very

abnormal); and (3) the combination of (1) and (2), which could include a longer retest interval for a previously normal result paired with a short minimum retest interval for a previously abnormal result. From this, we were able to estimate: the number of tests potentially avoided; the proportion of test results that became abnormal or very abnormal during a theoretical period of restriction; and potential cost-savings.

Statistical analysis

For each laboratory test type:

- The mean (SD) number of laboratory tests per admission, per day of service (DOS) were examined, and compared between medical specialties using linear regression with robust standard errors.
- The number and percent of patients with at least one laboratory test ordered on each DOS was examined.
- Change in number of tests ordered per month was examined using linear regression.
- Given that approximately 90% of admissions had ≤ 10 tests, all comparative analyses were limited to test numbers 1–10.

Kaplan–Meier survival analysis was used to calculate the crude median (25th, 75th percentile) time from one test to the next by test number and reference interval, and to test whether a difference was seen in the median time between result ranges for each test number.

Survival analysis was performed to examine whether the time to next test differed by hospital. Cox proportional hazards modelling was performed by test number and result of previous test, adjusted for time of day test ordered, medical specialty, gender, age, Charlson comorbidity index, and admission year.

Lockouts, minimum retest intervals, and a combination of the two were applied for all ordering (day and night). The number of tests (normal, abnormal, and very abnormal) that would be prevented was examined.

All statistical analyses were programmed using SAS v9.4 (SAS Institute, USA). *A priori*, $p < 0.05$ (two-tailed) was used to indicate statistical significance.

RESULTS

Over a 2 year period at JHH, 98,051 patients with 327,690 admissions were extracted. Location, diagnosis, and laboratory data were combined at the level of the patient and admission. The final dataset for analysis included 32,027 patients with 43,363 admissions, and 241,962 laboratory tests. For TRRH, the figures were 10,820 patients with 15,984 admissions and 68,775 tests.

The number of eligible inpatient admissions per month was relatively stable at ~1800 per month at JHH and ~650 per month at TRRH. However, over the same time period, there was an average increase of 13.8 tests/month at JHH [95% confidence interval (95% CI) –4.8 to 32.3, $p = 0.138$] and 16.6 tests/month at TRRH (95% CI 9.5 to 23.7, $p < 0.001$).

The absolute number of tests over the 2 year time interval at both hospitals is shown in [Supplementary Table 2 \(Appendix A\)](#), whereas the patient and laboratory test characteristics by hospital are shown in [Supplementary Table 3 \(Appendix A\)](#). Given the bulk of test ordering consists of EUC and FBC (>90%), we focus on these two for the remainder of this paper.

Electrolytes, urea and creatinine

A total of 128,479 EUC test sets were ordered at JHH and 30,799 at TRRH. [Table 1](#) shows that although the number of EUC tests/admission appears greater for JHH than TRRH, the fact that LOS is shorter by about 1 day at TRRH means that the number of tests/LOS days is roughly comparable at 0.5–0.8 EUC tests/LOS day. [Figure 1](#) shows that after the first admitted day, roughly 45% of admitted patients had an EUC ordered on any given day at JHH compared to roughly

Table 1 Number of electrolytes, urea and creatinine tests per admission and per length of stay day

| Specialty | John Hunter Hospital | | | | | Tamworth Hospital | | | | |
|-----------|----------------------|-----------|-----------------|---------------------------|--------------------------|----------------------|-----------|-----------------|---------------------------|--------------------------|
| | Admissions, <i>n</i> | Mean LOS | Tests, <i>n</i> | Mean (SD) tests/admission | Mean (SD) tests/LOS days | Admissions, <i>n</i> | Mean LOS | Tests, <i>n</i> | Mean (SD) tests/admission | Mean (SD) tests/LOS days |
| Overall | 43363 | 5.2 (6.1) | 128479 | 3.2 (4.0) | 0.7 (0.5) | 15984 | 4.2 (4.9) | 30799 | 2.1 (2.5) | 0.6 (0.5) |
| Surgery | 25706 | 5.0 (6.0) | 67732 | 2.8 (4.1) | 0.6 (0.4) | 7409 | 4.1 (4.4) | 13839 | 2.0 (2.5) | 0.5 (0.5) |
| Medicine | 17657 | 5.6 (6.2) | 60747 | 3.7 (3.8) | 0.8 (0.5) | 8568 | 4.3 (5.3) | 16946 | 2.2 (2.4) | 0.7 (0.5) |

LOS, length of stay; *n*, number; SD, standard deviation.

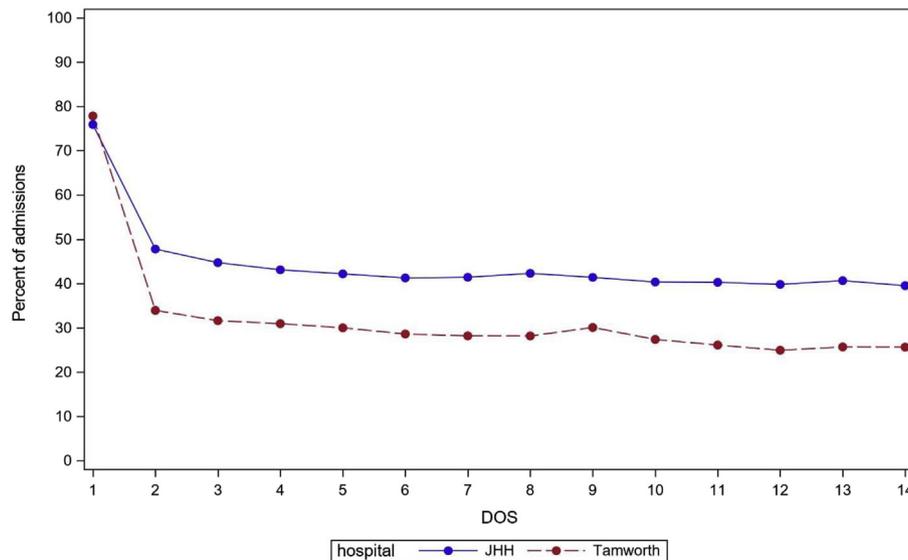


Fig. 1 Percent of admissions that had at least one electrolytes, urea and creatinine (EUC) test ordered, by day of stay (DOS). After the first admitted day, ~40% of admitted patients had an EUC ordered on any given day at John Hunter Hospital (JHH, solid blue line) compared to ~30% at Tamworth Rural Referral Hospital (Tamworth, dashed red line).

30% at TRRH. Of these tests, 26% were normal, 70% were abnormal and 4% were very abnormal (see [Supplementary Fig. 2A, Appendix A](#)). For JHH, the majority (62%) of tests were normal when the prior test was also normal ([Supplementary Fig. 2B, Appendix A](#)). This increased from 59% for test 2 ($n=3,936/6,622$ normal test 1) to 62% for test 3 ($n=2,667/4,318$ normal test 2), and remained at approximately 64% for tests 4–10. Similarly, for TRRH the majority of tests were normal if all prior tests were normal. When test 1 was normal, 59% ($n=3,936/6,622$) of test 2 were normal. When both tests 1 and 2 were normal, 66.7% ($n=1,585/2,376$) of test 3 were normal, increasing to 92.3% ($n=12/13$) for test 10 when all tests 1–9 were normal. Only 0.2% of EUCs became very abnormal after two or three consecutive normal results ($n=5$ and $n=2$, respectively).

This led us to investigate the retesting interval: how long to the subsequent test when the previous test is normal, abnormal or very abnormal? The results are shown in [Table 2](#). As expected, the interval to the second test is longer when the first test is normal (43 hours at JHH, 95% CI 23–96), compared to when the first test is abnormal (30 hours, 95% CI 19–57) or very abnormal (17 hours, 95% CI 8–24). These times are significantly longer at TRRH (see adjusted hazard ratios >1, [Table 2](#)), although the pattern is similar. However, looking at third, fourth and subsequent tests, it is clear that the effect of previous values quickly fades and tests are ordered at roughly 24 (23–29) hour intervals regardless of the previous

test value; this can be seen down the columns in [Table 2](#) between normal, abnormal and very abnormal prior values. The one noticeable difference is that at TRRH, the retest interval remains at roughly 48 (45–49) hours when the previous test is in the normal range; this hospital seems to resist the trend to routinely order tests every 24 hours.

We also looked at test intervals for tests ordered during the day versus at night. Only 11% of tests were ordered at night (8pm–6am) and the retest interval was substantially shorter for these (see [Supplementary Fig. 3, Appendix A](#)).

Full blood count

A total of 122,733 FBC test sets were ordered at JHH and 28,865 at TRRH. Results for FBC ordering were very similar in pattern to those for EUC. The overall number of tests by service and by hospital is shown in [Supplementary Table 4 \(Appendix A\)](#) and is almost equal in volume to EUC. The frequency of ordering was similar to EUCs, with ~40% of patients on any given day having FBC ordered at JHH, although this was lower at TRRH at ~10%. The time interval for retesting and the pattern was also similar for FBC compared to EUC (see [Supplementary Table 5, Appendix A](#)):

- Time to retesting (second test) was longer after a normal test (47 hours, 95% CI 24–119) than after an abnormal test

Table 2 Median time in hours to next electrolytes, urea and creatinine (EUC) test depending on value of previous EUC test, by hospital

| Test | Normal prior range, median hours (25%, 75%) | | | Abnormal prior range, median hours (25%, 75%) | | | Very abnormal prior range, median hours (25%, 75%) | | |
|------|---|--------------------|--------------------------|---|--------------------|--------------------------|--|-------------------|--------------------------|
| | JHH | Tamworth | HR ^a (95% CI) | JHH | Tamworth | HR ^a (95% CI) | JHH | Tamworth | HR ^a (95% CI) |
| 2 | 43.2 (23.1, 96.2) | 65.4 (30.2, 194.5) | 1.54 (1.46, 1.63) | 30.0 (19.2, 57.0) | 44.0 (22.4, 103.6) | 1.52 (1.47, 1.58) | 16.7 (8.3, 24.3) | 18.1 (9.3, 28.7) | 1.22 (1.07, 1.40) |
| 3 | 28.0 (23.5, 71.8) | 48.6 (24.3, 120.1) | 1.50 (1.39, 1.62) | 25.3 (22.6, 49.5) | 36.3 (23.7, 73.5) | 1.36 (1.30, 1.42) | 20.0 (8.2, 25.1) | 23.5 (13.6, 28.0) | 1.47 (1.22, 1.77) |
| 4 | 27.3 (23.8, 70.8) | 45.9 (23.9, 98.2) | 1.30 (1.17, 1.44) | 25.2 (23.1, 48.9) | 29.4 (23.7, 71.4) | 1.31 (1.25, 1.39) | 23.1 (9.7, 25.8) | 24.0 (20.2, 28.8) | 1.36 (1.09, 1.70) |
| 5 | 27.8 (23.7, 69.0) | 46.9 (24.1, 111.7) | 1.40 (1.21, 1.61) | 25.1 (23.3, 48.3) | 27.4 (23.8, 67.3) | 1.26 (1.18, 1.34) | 23.1 (14.2, 26.1) | 24.1 (20.3, 31.7) | 1.48 (1.12, 1.96) |
| 6 | 28.8 (23.8, 70.4) | 46.1 (24.2, 76.4) | 1.29 (1.09, 1.54) | 25.1 (23.2, 48.4) | 26.5 (23.6, 55.0) | 1.25 (1.15, 1.35) | 23.2 (12.8, 25.3) | 23.9 (21.5, 25.4) | 1.12 (0.86, 1.44) |
| 7 | 27.5 (23.6, 52.3) | 48.1 (24.4, 123.5) | 1.42 (1.16, 1.74) | 25.0 (23.2, 48.1) | 27.4 (23.7, 68.1) | 1.27 (1.15, 1.39) | 23.9 (19.2, 28.6) | 24.1 (19.9, 27.6) | 0.93 (0.69, 1.26) |
| 8 | 26.3 (23.9, 50.8) | 34.8 (24.2, 72.3) | 1.25 (0.97, 1.63) | 25.1 (23.3, 48.4) | 26.8 (23.6, 50.1) | 1.18 (1.06, 1.33) | 23.8 (18.1, 25.9) | 24.1 (21.6, 25.7) | 0.98 (0.69, 1.39) |
| 9 | 28.5 (23.9, 69.1) | 45.3 (24.4, 79.3) | 1.20 (0.89, 1.63) | 25.2 (23.1, 48.4) | 25.2 (23.5, 50.4) | 1.07 (0.94, 1.22) | 23.5 (19.4, 25.8) | 24.2 (23.3, 49.1) | 1.20 (0.76, 1.91) |
| 10 | 27.5 (24.0, 68.9) | 45.5 (23.7, 103.4) | 1.12 (0.78, 1.60) | 25.1 (23.2, 48.6) | 24.9 (23.4, 49.0) | 0.93 (0.80, 1.07) | 23.8 (20.5, 25.8) | 23.7 (22.5, 31.6) | 0.98 (0.62, 1.55) |

HR, Hazard ratio; JHH, John Hunter Hospital; Tamworth, Tamworth Rural Referral Hospital; 95% CI, 95% confidence interval.
^a Adjusted for time of day test ordered, medical specialty, gender, age, Charlson comorbidity index, and admission year.

(35 hours, 95% CI 20–67) or a very abnormal test (21 hours, 95% CI 12–31).

- Over time, the retest interval for abnormal and very abnormal tests tended to go to 24 hours, i.e., routine ordering on a daily basis.
- TRRH had similar patterns but longer absolute time for their retest intervals.
- The only noteworthy difference was that the retest interval for FBC after a previous normal result tended to stay at 48 hours rather than regress toward 24 hours.

As for EUC, test ordering for FBC at night was only a small proportion of all tests and the interval was shorter than that during the day.

Proposed strategy for reducing low value care

We then worked towards some evidence-based parameters to block low value test ordering. The three options we developed were:

1. Applying lockouts to only previously normal results;
2. Applying a minimum retest interval when results were previously normal or abnormal (not very abnormal);
3. Applying longer lockouts for previously normal results and short (12 hour) minimum retest intervals for previously abnormal results.

We tested lockout periods of various lengths after a normal test result, minimum retest intervals of various lengths and a combination of the two. Results for EUCs are shown in Table 3. A lockout period of 12 hours after a normal test would potentially eliminate 1397 EUC tests (1.1%) at JHH at the risk of missing 11 very abnormal tests (0.8%) over 2 years; this rises to potentially eliminating 15,461 EUC tests for a 48 hour lockout, at the risk of missing 38 very abnormal tests (0.2%). A minimum retest interval applied regardless of whether a previous test result is normal or abnormal would potentially prevent a much larger number of tests (32,057 tests for a minimum retest interval of 24 hours) but at the cost of potentially missing more very abnormal tests (537 or 2.2%).

We applied similar lockouts and minimum retest intervals to FBCs. The results are shown in Table 4. A lockout on ordering FBC after a previously normal test of 12 hours would only eliminate 261 tests (0.2%) at JHH over 2 years; a lockout of 48 hours would increase this to 3195 tests without missing a single very abnormal test. The combination of a 12 hour minimum retest interval paired with a 48 hour lockout increases the number of FBC tests prevented at JHH to 8918 (7% of all FBC tests) at a rate of missing 0.2% (n=20) very abnormal results.

Economic savings

In Australia, the fee set by the Medicare Benefits Scheme for a EUC test is AU\$17.70 and for FBC is AU\$16.95. Assuming an override rate of 5% and fee for service model, the 48 hour lockout could potentially lead to saving over AU\$260,000 in EUC tests and AU\$144,000 in FBC tests at JHH alone, over 2 years. Given that JHH has about 500 medical and surgical beds, this works out to ~AU\$400 savings per inpatient bed per year, not including time savings in resident ordering, phlebotomy, management, sending out

Table 3 Effects of lockouts, minimum retest intervals and a combination of the two on electrolytes, urea and creatinine (EUC) test ordering

| | Lockout period (hours) | | EUC tests prevented at John Hunter Hospital | | | | | | | | EUC tests prevented at Tamworth Rural Referral Hospital | | | | | | | |
|---|------------------------|----------|---|------|--------|-------|----------|-----|---------------|-------------------------------|---|-------|--------|-------|----------|------|---------------|--|
| | Normal | Abnormal | Total avoided | | Normal | | Abnormal | | Very abnormal | | Total avoided | | Normal | | Abnormal | | Very abnormal | |
| | | | (% of all EUCs ^a) | n | (%) | n | (%) | n | (%) | (% of all EUCs ^a) | n | (%) | n | (%) | n | (%) | | |
| Lockout (normal only) | 12 | – | 1397 (1.1%) | 841 | 60.2% | 545 | 39.0% | 11 | 0.8% | 171 (0.6%) | 116 | 67.8% | 55 | 32.2% | 0 | 0.0% | | |
| Lockout (normal only) | 24 | – | 7682 (6.0%) | 4770 | 62.1% | 2887 | 37.6% | 25 | 0.3% | 1250 (4.1%) | 782 | 62.6% | 467 | 37.4% | 1 | 0.1% | | |
| Lockout (normal only) | 36 | – | 11537 (9.0%) | 7029 | 60.9% | 4481 | 38.8% | 27 | 0.2% | 1837 (6.0%) | 1097 | 59.7% | 737 | 40.1% | 3 | 0.2% | | |
| Lockout (normal only) | 48 | – | 15461 (12.0%) | 9181 | 59.4% | 6242 | 40.4% | 38 | 0.2% | 2608 (8.5%) | 1468 | 56.3% | 1136 | 43.6% | 4 | 0.2% | | |
| Minimum retest interval (normal and abnormal) | – | 12 | 5368 (4.2%) | 649 | 12.1% | 4543 | 84.6% | 176 | 3.3% | 900 (2.9%) | 110 | 12.2% | 759 | 84.3% | 31 | 3.4% | | |
| Minimum retest interval (normal and abnormal) | – | 24 | 24369 (19.0%) | 3323 | 13.6% | 20509 | 84.2% | 537 | 2.2% | 4401 (14.3%) | 557 | 12.7% | 3749 | 85.2% | 95 | 2.2% | | |
| Lockout + minimum retest interval | 12 | 12 | 6614 (5.1%) | 1409 | 21.3% | 5018 | 75.9% | 187 | 2.8% | 1059 (3.4%) | 220 | 20.8% | 808 | 76.3% | 31 | 2.9% | | |
| Lockout + minimum retest interval | 24 | 12 | 12645 (9.8%) | 5223 | 41.3% | 7221 | 57.1% | 201 | 1.6% | 2113 (6.9%) | 875 | 41.4% | 1206 | 57.1% | 32 | 1.5% | | |
| Lockout + minimum retest interval | 36 | 12 | 16361 (12.7%) | 7425 | 45.4% | 8734 | 53.4% | 202 | 1.2% | 2690 (8.7%) | 1185 | 44.1% | 1471 | 54.7% | 34 | 1.3% | | |
| Lockout + minimum retest interval | 48 | 12 | 20102 (15.6%) | 9530 | 47.4% | 10359 | 51.5% | 213 | 1.1% | 3439 (11.2%) | 1555 | 45.2% | 1849 | 53.8% | 35 | 1.0% | | |

Table lists the number of tests that would potentially be eliminated, by reference interval category.

^a Total number of EUC tests: N=128,479 for John Hunter Hospital; N=30,799 for Tamworth Rural Referral Hospital.

Table 4 Effects of lockouts, minimum retest intervals and a combination of the two on full blood count (FBC) ordering

| | Lockout period (hours) | | FBC tests prevented at John Hunter Hospital | | | | | | | | FBC tests prevented at Tamworth Rural Referral Hospital | | | | | | | |
|---|------------------------|----------|---|------|--------|-------|----------|----|---------------|-------------------------------|---|-------|--------|-------|----------|------|---------------|--|
| | Normal | Abnormal | Total avoided | | Normal | | Abnormal | | Very abnormal | | Total avoided | | Normal | | Abnormal | | Very abnormal | |
| | | | (% of all FBCs ^a) | n | (%) | n | (%) | n | (%) | (% of all FBCs ^a) | n | (%) | n | (%) | n | (%) | | |
| Lockout (normal only) | 12 | – | 261 (0.2%) | 137 | 52.5% | 124 | 47.5% | 0 | 0.0% | 47 (0.2%) | 20 | 42.6% | 27 | 57.4% | 0 | 0.0% | | |
| Lockout (normal only) | 24 | – | 1560 (1.3%) | 870 | 55.8% | 690 | 44.2% | 0 | 0.0% | 300 (1.0%) | 174 | 58.0% | 126 | 42.0% | 0 | 0.0% | | |
| Lockout (normal only) | 36 | – | 2329 (1.9%) | 1260 | 54.1% | 1069 | 45.9% | 0 | 0.0% | 453 (1.6%) | 248 | 54.7% | 205 | 45.3% | 0 | 0.0% | | |
| Lockout (normal only) | 48 | – | 3195 (2.6%) | 1635 | 51.2% | 1560 | 48.8% | 0 | 0.0% | 616 (2.1%) | 327 | 53.1% | 289 | 46.9% | 0 | 0.0% | | |
| Minimum retest interval (normal and abnormal) | – | 12 | 5846 (4.8%) | 106 | 1.8% | 5720 | 97.8% | 20 | 0.3% | 831 (2.9%) | 22 | 2.6% | 803 | 96.6% | 6 | 0.7% | | |
| Minimum retest interval (normal and abnormal) | – | 24 | 27636 (22.5%) | 692 | 2.5% | 26866 | 97.2% | 78 | 0.3% | 4641 (16.1%) | 190 | 4.1% | 4429 | 95.4% | 22 | 0.5% | | |
| Lockout + minimum retest interval | 12 | 12 | 6087 (5.0%) | 241 | 4.0% | 5826 | 95.7% | 20 | 0.3% | 875 (3.0%) | 42 | 4.8% | 827 | 94.5% | 6 | 0.7% | | |
| Lockout + minimum retest interval | 24 | 12 | 7344 (6.0%) | 964 | 13.1% | 6360 | 86.6% | 20 | 0.3% | 1125 (3.9%) | 195 | 17.3% | 924 | 82.1% | 6 | 0.5% | | |
| Lockout + minimum retest interval | 36 | 12 | 8085 (6.6%) | 1348 | 16.7% | 6717 | 83.1% | 20 | 0.2% | 1276 (4.4%) | 269 | 21.1% | 1001 | 78.4% | 6 | 0.5% | | |
| Lockout + minimum retest interval | 48 | 12 | 8918 (7.3%) | 1717 | 19.3% | 7181 | 80.5% | 20 | 0.2% | 1436 (5.0%) | 347 | 24.2% | 1083 | 75.4% | 6 | 0.4% | | |

Table lists the number of tests that would potentially be eliminated, by reference interval category.

^a Total number of FBC tests: N=122,733 for John Hunter Hospital; N=28,865 for Tamworth Rural Referral Hospital.

hard copy results, etc. However, in reality inpatient tests in Australia are covered under service level agreements (between hospitals and pathology services) and hence the individual cost of each test is hidden to the ordering clinician, which may influence behaviour.

DISCUSSION

Given the push to reduce low value care, we analysed patterns of ordering for common pathology tests among inpatients. We found that the vast majority of test orders were for EUCs and FBCs (>90%) and so we focused our attention on these two tests.

The general patterns of ordering for EUCs and FBC were similar between medicine and surgery services and similar between a large teaching hospital and a rural referral hospital. We find that if a test is normal on one occasion, it is likely to be normal (>60% chance) on the subsequent test; the likelihood of a very abnormal result is consistently less than 5%. Hence the idea of ordering tests regularly 'just to keep an eye on things' or to detect emerging problems is a very low yield approach. Although the remainder of tests (35%) are abnormal, the degree of abnormality may not be sufficiently severe to influence the retest interval in clinical practice.

The time from the initial EUC test to the second EUC test is influenced by the value of the first test; the interval at JHH is close to 43 hours when the previous test is normal, 30 hours when it is abnormal, and 17 hours when it is very abnormal. However, with subsequent tests after the second or third inpatient test, the retest intervals converge towards every 24 hours. Results were similar with FBC. These data suggest that after the first 2 or 3 inpatient days, staff are ordering pathology tests routinely every 24 hours regardless of the previous value; this trend is less marked at the rural hospital. It is possible that the acuity of patients is lesser at TRRH, but our analyses were adjusted for age, gender, comorbidity score, admission year and service, and the results are present despite these adjustments. We hypothesise that this is related to the level of seniority of those ordering the tests; at JHH most of the ordering is performed by junior staff (interns and junior registrars), whereas at TRRH senior consultants are more directly involved. Sedrak *et al.* showed that the most common reasons reported by residents for ordering pathology tests were: habit (90%), lack of knowledge of costs (86%), diagnostic uncertainty (82%), and fear of embarrassment (76%); it is likely that similar factors are at play in our setting.⁷

We used our data and results to start developing an evidence base to guide potential changes in a CPOE. We sought to strike a balance between overly restrictive electronic rules and the need for clinical judgement and autonomy. Where a result was normal, we would try to find a retest interval that reduced unnecessary tests as much as possible without increasing the chance of missing a very abnormal test. We found that a lockout of 48 hours for both EUC and FBC could reduce unnecessary tests substantially without missing too many very abnormal tests. Pairing the lockout with a 12 hour minimum retest interval for FBC more than doubled the number of tests prevented with only a very small increase (0.2% at JHH and 0.4% at TRRH) in the rate of very abnormal results requiring override. Given the serious nature of very abnormal results, we interpret the proposed lockouts with a low tolerance (0.2–0.4%) for missing very abnormal

tests, but recognise the potential for greater cost savings if a higher threshold is applied. For example, for EUCs a lockout of 48 hours paired with a minimum retest interval of 12 hours would prevent 20,102 (16% of all EUCs) tests, missing 213 (1.1%) very abnormal results. The ability for clinicians to exert judgement on when to appropriately override should be tested before thresholds are relaxed to maximise cost savings.

The literature around changing ordering practice has been reviewed by Eaton *et al.*⁴ and the Quality Use of Pathology Program in Australia.⁸ They find that educational programs, and audit and personalised feedback both appear to be effective but require intensive effort; the former appears to wane in efficacy (e.g., Miyakis *et al.*).⁹ Price signals, although initially effective,¹⁰ may lose their impact, and electronic warning flags are quickly met with 'alert fatigue'.¹¹ Restricting ordering using electronic means is effective and also sustained with minimal cost.¹²

Our results suggest a potential novel approach of 'hard-wiring' or at least flagging evidence-based lockouts in a CPOE, based on the results and timing of the previous test. We suggest applying a lockout (potentially 48 hours) to EUC and FBC orders where the default value is the cancellation of the test but the ordering physician is able to override this to allow for clinician judgement. This 'nudge', i.e., moving from ignoring the alert to having to override the alert, may be sufficient to shift ordering behaviour. Procop *et al.*¹³ found that such a 'hard' stop to unnecessary tests was successful in reducing tests and was sustained over 2 years.

Our study was performed using data from only one large teaching hospital and one rural hospital, both in the same local health district, so it may not be possible to generalise to other settings. These analyses reflect reduced test ordering for FBC and UECs only (~90% of all tests we examined). Although the number of repeat tests for TSH, vitamin D and HbA1c are small, these tests are relatively expensive, and may contribute significantly to pathology costs. An electronic solution that can prevent unnecessary repeat testing should be applied to these tests also.

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APPENDIX A. SUPPLEMENTARY DATA

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.pathol.2019.06.003>.

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