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The impact of the implementation of electronic ordering on hospital pathology services

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This project was funded by an Australian Government Department of Health and Ageing:
Quality Use of Pathology Program grant

Suggested citation:

Georgiou A, Vecellio E, Toouli G, Eigenstetter A, Li L, Wilson R, Westbrook JI. The impact of the implementation of electronic ordering on hospital pathology services. Report to Commonwealth of Australia, Department of Health and Ageing, Quality Use of Pathology Committee. Australian Institute of Health Innovation, University of New South Wales, Sydney. October 2012.

Published 2012
Centre for Health Systems and Safety Research
Australian Institute of Health Innovation
University of New South Wales

ISBN: 978-0-7334-3194-4

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SECTION I: EXECUTIVE SUMMARY

Project aim

This project aimed to assess the impact of electronic ordering systems, on the quality use of pathology services across six hospital sites and different pathology departments, for the following areas:

- the legibility and completeness of laboratory test orders and the impact on Central Specimen Reception work processes (Quality of test orders).
- the volume and mix of tests ordered examined by such factors as Diagnosis-related Groups (DRGs), adjusted for clinical activity where appropriate, and the prevalence of add-on and repeat testing (Effectiveness).
- the timeliness of the pathology laboratory process (Turnaround time).
- the impact of pathology performance (e.g., laboratory test turnaround times) on the duration of patient stay in the emergency department (Patient outcome).

The project also produced a benefits realisation framework, made up of performance indicators, that can be used to guide the assessment of electronic ordering in a pathology service and to monitor what works (or doesn't work), where, and in what circumstances. The project was funded by an Australian Government Department of Health and Ageing, Quality Use of Pathology Program grant.

Project setting

An electronic medical record (EMR) system utilising Cerner PowerChart became available at Hospitals A, B, and C, on 26 October 2009; Hospital D on 29 June 2009, Hospital E on 1 October 2008, and Hospital F on 9 March 2009. The EMR allowed the clinicians to create electronic orders. In 2011, electronic ordering was used for approximately 66% of pathology test orders across the six hospitals.

Laboratory test order errors

Electronic ordering systems (referred to as EMR in the settings involved in this study) are expected to eliminate legibility problems in handwritten orders and to reduce errors, particularly during the pre-analytic phase involving patient identification and specimen collection and labelling. They are also able to contribute to improvements in the quality of

the information provided to the laboratory, thus increasing efficiency and effectiveness in the laboratory.

A longitudinal analysis of laboratory errors including a period after the implementation of the EMR showed an increase in the number of errors, both as raw frequency and as a rate per 1000 test order episodes. This increase was accounted for by the introduction of a new class of errors associated with the EMR and the processes surrounding its use. A cross-sectional analysis, comparing the error rate for EMR orders with that for paper orders (for the same period of time), indicated that the overall error rate for many categories of error was lower for EMR orders than for paper orders. Critically, this pattern was consistent for all three Incident Information Management System (IIMS) categories of errors that relate particularly to patient safety issues.

Test volume

A series of analyses across the six hospital sites was undertaken to compare test volumes and aspects of the effectiveness of the test order process. A comparison of the rates before (2008) and after (2011) the implementation of the EMR, indicated that the mean number of tests ordered in each test order episode decreased significantly at each of the hospitals. Taken for all hospitals, the mean number of tests for each episode fell from 4.63 in 2008 to 4.36 in 2011.

Diagnosis-related Group casemix

Our comparison of the number of tests undertaken per admission and grouped in DRG categories provided examples such as A06B (Tracheostomy w/ventilation >95hrs) where the mean number of tests per admission fell from 181.10 in 2008 to 156.77 in 2011, but where the corresponding mean length of stay rose from 646 hours to 696 hours. Alternatively, for E62A (Respiratory infections) the numbers were 40.60 to 42.81 for mean number of tests and 305 to 289 hours for mean length of stay. The use of DRGs also provided a valuable means to examine test ordering patterns across hospitals. Our analysis of the test ordering profiles for F74Z (Chest pain) at four hospital emergency departments (EDs) highlighted similar test ordering patterns (e.g., Troponin, EUC, and Automated Differential tests were consistently the most frequently ordered tests). There were some differences in test ordering profiles, especially for the lower volume tests, between hospitals compared across the pre- and post-EMR periods. The mean number of C-Reactive protein tests per ED presentation

varied both between hospitals and between years. At three of the EDs the mean number of C-Reactive protein tests per ED presentation was higher in 2011 than in 2008.

Add-on testing

Add-on tests are test assays that are performed on an existing specimen within the pathology service. The reasons for ordering an add-on test may include; requiring a base-line test result in cases where treatment has already commenced, the ordering clinician neglecting to order all relevant tests in the first instance, or simply to avoid subjecting certain vulnerable patients to additional phlebotomies. Add-on tests are labour-intensive and disruptive and place a disproportionate burden on laboratory resources. The add-on rates between hospitals ranged from 0.61% (Hospital B; specialist hospital) to 2.24% (Hospital F; metropolitan general hospital). The clinical chemistry and haematology departments, combined, accounted for 70% of all add-on test volume. In the clinical chemistry and haematology departments, add-on tests accounted for 2.56% and 0.69%, respectively, of all ordered tests.

Repeat tests

We compared the rate of paper and EMR-ordered EUC tests which were ordered within one hour and 24-hours of the previous EUC test. In 2011, the overall proportion of repeat EUC testing occurring within one hour of the previous EUC test was significantly greater for paper tests than EMR tests (0.69% and 0.25%, respectively). While, for tests ordered within 24 hours, there was a significantly lower proportion of repeat tests with paper orders than for EMR orders (11.68% and 34.04%, respectively).

Test turnaround time

Laboratory turnaround time (TAT) is the time taken by the laboratory to complete the entire testing process (from when the specimen arrives in the CSR to when a result is available to the clinician). TAT is often used as a key performance indicator of laboratory performance. Our analyses showed that the median data entry time (the time from when the specimen arrives in the CSR until the order is entered into the Laboratory Information System), for all hospitals combined, was three minutes shorter for EMR than paper. This difference was consistent and significant for both EUC and Automated Differential in 2010 and 2011. These decreases contributed to significantly lower median Total Laboratory TATs for EMR orders than for paper orders (for EUC tests, the difference in medians was 12 minutes in 2010 and six minutes in 2011; for Automated Differential tests, the difference in medians was four minutes in 2010 and two minutes in 2011).

Patient outcomes – Emergency Department length of stay

This project used multilevel linear regression modelling to examine the relationship between length of stay (LOS) in the ED along with pathology testing characteristics such as TAT and the volume of tests. The final model, accounting for 24% of the variation in ED LOS, showed that after controlling for the effect of patient age, triage category, number of tests in the test order episode, and ED mode of separation, the ED LOS on average, increased by 9.8% for every 60 minutes increase in the test turnaround time.

Benefits realisation framework

The evidence provided by this research (as summarised above) has highlighted the value of a set of key performance indicators that can be used to measure major features of electronic ordering and its effect on the laboratory processes (predominantly the pre-analytical processes). These indicators can be used for comparisons between hospitals, wards etc., to help monitor and improve the overall safety of patient care, efficiency in the wards, and to help enhance the quality of pathology provided.

In this project, the utilisation of these indicators provided valuable empirical information about the EMR and its impact on pathology services and clinical work processes. Within the CSR they revealed the impact of errors associated with the introduction of the EMR but also showed how the EMR-ordering was associated with significantly fewer IIMS-related errors when compared with paper orders. The introduction of EMR was connected to a significant decrease in the mean number of tests for each test order episode across each hospital when compared before and after EMR implementation. This project used DRG categories to compare the number of tests per admission and to examine test ordering patterns across hospitals. Add-on test rates were investigated between hospital departments to provide benchmarks for future analyses. The analysis of repeat tests for EMR-ordered EUC tests showed that the overall proportion of repeat EUC tests which occurred within one hour of the previous EUC test was significantly lower for EMR than for paper orders. The project identified a significant decrease, for all hospitals, in the median time taken from specimen arrival in the CSR to the time the order was entered in the Laboratory Information System. This decrease contributed to the significantly lower median laboratory TAT measured from the time a specimen arrived at CSR to the time a result was available to the clinician. The project's multi-level linear regression modelling examined the relationship between LOS in

the ED along with pathology testing characteristics such as TAT and the volume of tests, and produced a model that accounted for 24% of ED LOS variation.

SECTION II: GLOSSARY

Glossary of general terms

BHI	Bureau of Health Information
CPOE	Computerised Provider Order Entry
CSR	Central Specimen Reception
DRG	Diagnosis-related Group
ED	Emergency Department
EDIS	Emergency Department Information System
EMR	Electronic Medical Record
ICT	Information and Communication Technology
IIMS	Incident Information Management System
IQR	Inter-quartile range
ISO	International Organization for Standardization
KIMMS	Key Incident Monitoring and Management Systems
LIS	Laboratory Information System
LOS	Length of stay
NATA	National Association of Testing Authorities
PAS	Patient Administration System
RCPA	Royal College of Pathologists of Australasia
TAT	Turnaround time

Glossary of pathology tests

Automated Diff	Automated Differential (includes full blood count)
CA MG PHOS	Calcium, magnesium, phosphate
CK	Creatine kinase
CKMB	Creatine kinase MB isoenzyme
C-Reactive protein	C-Reactive protein
D-Dimer LIA	D-Dimer Latex Immuno Assay
EUC	Electrolytes, Urea, Creatinine
BLOOD GAS	Blood gases
Glucose	Glucose
LFT	Liver function test
Lipase	Lipase
PT	Prothrombin time
INR	International normalised ratio
APTT	Activated partial thromboplastin time
Troponin	Troponin I and Troponin T
TSH	Thyroid Stimulating Hormone

SECTION III: INTRODUCTION

Pathology services are widely seen as an area where information and communication technologies (ICT) can have a major impact on the efficiency and effectiveness of service delivery.[1] They are information-intense bodies that provide services across primary, secondary and tertiary care and are responsible for leveraging 60-70% of all critical decision-making involving patient admission, discharge and medication choice.[2]

The Electronic Medical Record

Electronic ordering systems (also known as Computerised Provider Order Entry [CPOE]) enable the integration of clinical and patient data systems across the hospital. They provide clinicians with the ability to order diagnostic tests directly via a computer terminal thus eliminating the need for paper test orders which inherently have considerable potential for error.[3] Electronic ordering systems are also seen as the building block for the hospital-wide electronic medical record.[4] There has been considerable support for the introduction of electronic ordering systems across healthcare settings internationally, not least because of the significant advantages they provide pathology services and their contribution to the well-being of patients.[5] These systems can be used to reduce the duplication of test orders, eliminate legibility problems and significantly decrease the possibility of misidentification of patient specimens and order forms.[6] In short they can contribute to greater efficiency, effectiveness and safety in pathology services.[7 8] Electronic ordering systems may also incorporate decision support features which can help clinicians choose the correct test, and make evidence-based decisions that improve the *quality of care* provided to patients.[9]

Despite the potential for electronic systems to improve effectiveness and efficiency across hospital departments, there has been slower than expected diffusion of these systems across healthcare settings over the last decade,[10 11] and there is evidence that important features of these systems remain underutilised or poorly implemented.[10 12] There are many reasons for this – implementation of health information and communication systems is difficult, involving a number of complex organisational and professional challenges beyond the ubiquitous technical issues.[13-15] These challenges include problems associated with reaching agreement about standards across departments (e.g., commonly agreed laboratory order sets or diagnostic algorithms relevant for specified patient conditions).[16] There is also the possibility of clinical resistance to electronic ordering systems and decision support

prompts[17] that may be related to problems with usability, and incompatibility with existing systems and processes for performing clinical and laboratory work.[18]

Project aim

This project aimed to deliver findings, compared between multiple hospital sites and different pathology departments, about the impact of electronic ordering systems on the quality use of pathology services. It aimed to achieve this through the development of a *benefits realisation framework* that assesses: quality (ensuring that the right process is performed well and meets identified needs and other relevant standards);[19] effectiveness (the best possible outcome) or success of the intervention;[20] and timeliness (turnaround times).[21] This involved an examination of the impact of the electronic ordering system on key indicators of laboratory performance and the quality use of pathology across the following areas:

- the legibility and completeness of laboratory test orders and the impact on Central Specimen Reception work processes.
- the volume and mix of tests ordered examined by such factors as Diagnosis-related Groups (DRG), controlling for clinical activity where appropriate, and the prevalence of add-on and repeat testing.
- the timeliness of the pathology laboratory process.
- the impact of laboratory performance (e.g., laboratory test turnaround times) on the duration of patient stay in the emergency department.

The project provided key comparative (between six hospitals) and longitudinal (over time) evidence about the effects of electronic ordering systems; and produced a benefits realisation framework that can be used to monitor what works (or doesn't work), where and in what circumstances. The outputs of this project can be used to enhance the application of electronic ordering systems in hospital pathology settings. The project was funded by an Australian Government Department of Health and Ageing, Quality Use of Pathology Program grant.

Project setting

The project was undertaken across three Local Health Districts/Special Health Networks in New South Wales covering a resident population of around 1.2 million people.[22] The focus was on a group of six hospitals serviced by a single fully accredited pathology laboratory

service which provides comprehensive biomedical laboratory services including the following laboratory specialties: Anatomical Pathology, Blood Bank, Clinical Chemistry, Microbiology, Endocrinology, Haematology, Molecular Genetics and Immunology. The entire pathology service (of which we investigated only a component) employs over 828 staff and deals with approximately 13 million tests annually.

During the initial implementation, the electronic medical record (EMR), which allowed clinicians to create electronic orders, was based on the Cerner PowerChart system, Version 2007.16 and became available at Hospitals A, B, and C on 26 October 2009; Hospital D on 29 June 2009, Hospital E on 1 October 2008, and Hospital F on 9 March 2009. In May 2011, the EMR was upgraded to Cerner PowerChart system, Version 2010.02.16. The Laboratory Information System (LIS) in Hospitals A, B, C, and E is Integrated Software Solutions (ISS) Omnilab v9.4.2 SR10 while in Hospitals D and F the laboratory information system is ISS Omnilab v9.5.2 SR26. Table 1 shows the number of available beds, the number of pathology tests, and number of patients who had pathology tests, at each of the six study hospitals for the month of September 2011. The three large metropolitan general hospitals (A, E, and F) accounted for both the bulk of pathology tests and patients who had pathology tests. The two specialist hospitals, (B and C) and the regional hospital (D), accounted for the smallest proportion of pathology tests.

Hospital	Available Beds	Test numbers	Patients who had tests
A	567	85208	5387
B	187	15316	2129
C	159	23600	1847
D	197	25234	1916
E	654	116045	6362
F	538	82942	5155
Total	2302	348345	22796

Table 1. Number of pathology tests compared by numbers of patients and available beds

The number and proportion of tests that were ordered electronically (EMR) and using the paper system, for each of the six hospitals during the period August-September of 2008 to 2011, are shown in Table 2. In 2009, 41% of all orders across all sites were electronic orders, the remainder were paper orders. With the introduction of EMR at Hospitals A, B, and C, in 2010 the proportion of tests ordered with EMR increased to 64%, and to 66% in 2011. The greatest rate of electronic ordering utilisation was at Hospital D (around three-

quarters of tests ordered electronically); the smallest rate of electronic ordering was at Hospital B (around one-third of tests ordered electronically).

							Number of Tests (Proportion of Tests Accounted for)	
Hospital	**2008**		**2009**		**2010**		**2011**	
	EMR	**Paper**	**EMR**	**Paper**	**EMR**	**Paper**	**EMR**	**Paper**
A	.	181256 (100%)	.	160690 (100%)	115825 (70%)	50480 (30%)	122024 (68%)	56795 (32%)
B	.	33287 (100%)	.	31887 (100%)	9998 (32%)	21205 (68%)	10124 (33%)	21006 (67%)
C	.	57216 (100%)	.	52502 (100%)	31544 (60%)	20729 (40%)	27755 (56%)	21413 (44%)
D	.	47226 (100%)	31968 (79%)	8395 (21%)	33443 (79%)	8953 (21%)	36422 (73%)	13193 (27%)
E	.	223041 (100%)	132601 (65%)	72095 (35%)	140108 (63%)	81378 (37%)	161935 (68%)	76229 (32%)
F	.	178432 (100%)	100547 (62%)	61749 (38%)	102627 (62%)	62445 (38%)	112029 (66%)	57122 (34%)
Overall	**.**	**720458 (100%)**	**265116 (41%)**	**387318 (59%)**	**433545 (64%)**	**245190 (36%)**	**470289 (66%)**	**245758 (34%)**

Table 2. The volume and proportion of paper- and electronically-ordered (EMR) tests at the six hospitals for August-September 2008-2011.

Any errors identified in the patient demographics or any non-compliance in laboratory requirements regarding test order forms and specimens were documented in the CSR department's error log. Prior to 21 September 2009 this was a paper-based system using error-detail entry sheets (see Appendix I) that were manually collated into a daily log (see Appendix II). The errors were categorised as per the information on the error-detail sheets. On 21 September 2009, a computerised error log (devised in-house and using a Microsoft Access database) was implemented and was available on all CSR computers thus eliminating paper forms and making error logging accessible to staff at their workstations. Initially, the data entry fields and error categories in the computerised error log were similar (but not always identical) to the paper-based system. From 1 March 2010, a revised version of the computerised error log was introduced with the inclusion of a new error category: "EMR test order problem." Appendix III shows a screen shot of the computerised error log screen and the available error category options (including the new "EMR test order problem" category).

Ethics approval

Ethics approval was granted by the South Eastern Sydney 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).

SECTION IV: QUALITY AND SAFETY OF THE TEST ORDERING PROCESS

Introduction

Errors in laboratory medicine can occur at any of the many steps that a specimen passes through, in some cases even before it is processed.[23 24] In the wards, errors can occur during the creation of the test order by the clinician, collection of the specimen by medical, nursing or laboratory staff and transportation of the specimen to the laboratory. In the laboratory, errors can occur during sorting and specimen receipt, laboratory accessioning and data entry. Many of these errors can have an undesirable outcome on patient safety. Electronic ordering systems are expected to eliminate legibility problems in handwritten orders and to reduce errors in both the wards and the laboratory and improve the quality of the information provided to the laboratory, thus increasing efficiency and effectiveness in the laboratory.[25] The pre-analytical phase of the laboratory test process includes all the steps that occur prior to the actual analysis of the specimen in the laboratory. This phase includes patient- and processing-related variables, including patient identification, specimen collection and specimen labelling. The analytical phase relates to the processing of specimens leading to a validated result, and the post-analytical phase begins when the test result is obtained and ends when it is received by the ordering clinician.[26]

Pre-analytical errors generally include problems associated with test orders. Sometimes clinicians order incorrect tests, inaccurately specify some aspect of the test order, or even forget to order a test altogether. In addition, test orders sometimes fail to reach the laboratory, particularly in settings that use paper orders, which can be dropped, misplaced, or otherwise lost.[27] Blood specimens can be unsuitable for testing when, for example, they are too old or of insufficient quantity for an accurate test result to be returned. Specimens can also be taken from the wrong patient, or be collected in the wrong tube or container. Research in this area shows that up to 65% of laboratory errors occur in the pre-analytical phases of the testing cycle,[24 28] often related to issues involving the identification of patients and the labelling of specimens.[29] In 2006, the Royal College of Pathologists of Australasia Quality Assurance Program Pty. Ltd. (RCPA QAP) launched the Key Incident Monitoring and Management Systems (KIMMS) to measure and monitor key incident indicators for pre- and post-analytical areas of laboratory work to help determine the main reasons for specimen misidentification and rejection.[30]

Study design

This part of the project was conducted at the Central Specimen Reception (CSR) of the pathology laboratory located at the campus housing Hospitals A, B, and C, where all specimens and test order forms for those three hospitals are delivered for processing. We undertook a retrospective audit of the pathology service paper-based error log from January to June 2009 and of the revised computerised error log that was in operation from 1 March 2010. Data analysis incorporated all errors recorded up to 9 October 2011.

Pre-analytic stage of the laboratory process

At this pathology service, there are two methods by which a pathology test order can be created. The first uses a handwritten paper test order form on which patient demographic data (e.g., name and date of birth) the tests, and relevant clinical details are recorded by the ordering clinician. This test order form must be signed by an authorised clinician before it is sent to the pathology service with the specimen. The second method of ordering pathology tests is electronic, via the EMR system. The clinician is required to complete the pathology order at a computer terminal and then print a hard copy of the test order form which is sent to the pathology service with the specimen. Specimens may be collected by clinicians directly, or by laboratory phlebotomists during their regular twice-daily blood collection rounds through the wards. Printed test order forms from the EMR use an electronic signature for authorisation. Any subsequent alteration of this printed form, such as the addition of handwritten information, is considered to be unauthorised. If further tests are required after the form is printed a new order must be created.

All test order forms and specimens are received in CSR where they are time-stamped by CSR staff to register the time of receipt. Patient and specimen details are then cross-checked. Figure 1 provides a schematic diagram of the entire CSR workflow process. A LIS-linked barcode (associated with a new test order episode within the LIS) is added to the form, which is then converted into a digital image and archived using an optical scanner. Test order forms and specimens are then transferred to the CSR data entry work area. Laboratory order forms for electronic orders contain at least three barcodes: i) a unique barcode for patient details; ii) unique barcodes for each test (linked to the EMR) and iii) a test order episode barcode (linked to the LIS). Laboratory order forms for paper orders contain only the test order episode barcode (linked to the LIS). In the case of electronic orders, the LIS-linked test order episode and EMR-linked patient detail barcodes are

scanned to retrieve those data. A scan of any of the EMR-linked barcodes will provide a complete list of all the tests ordered in that test order episode. For paper orders, the LIS-linked test order episode barcode is scanned electronically but the remaining information (patient details and the list of tests ordered) must be manually typed into the computerised LIS data entry form. The time-stamp of specimen arrival in the CSR must still be entered manually into the computerised LIS data entry form, for both electronic and paper test orders. Once the data entry process is complete, test order forms are sent for archive and the specimens are delivered to the relevant pathology department for processing and analysis.

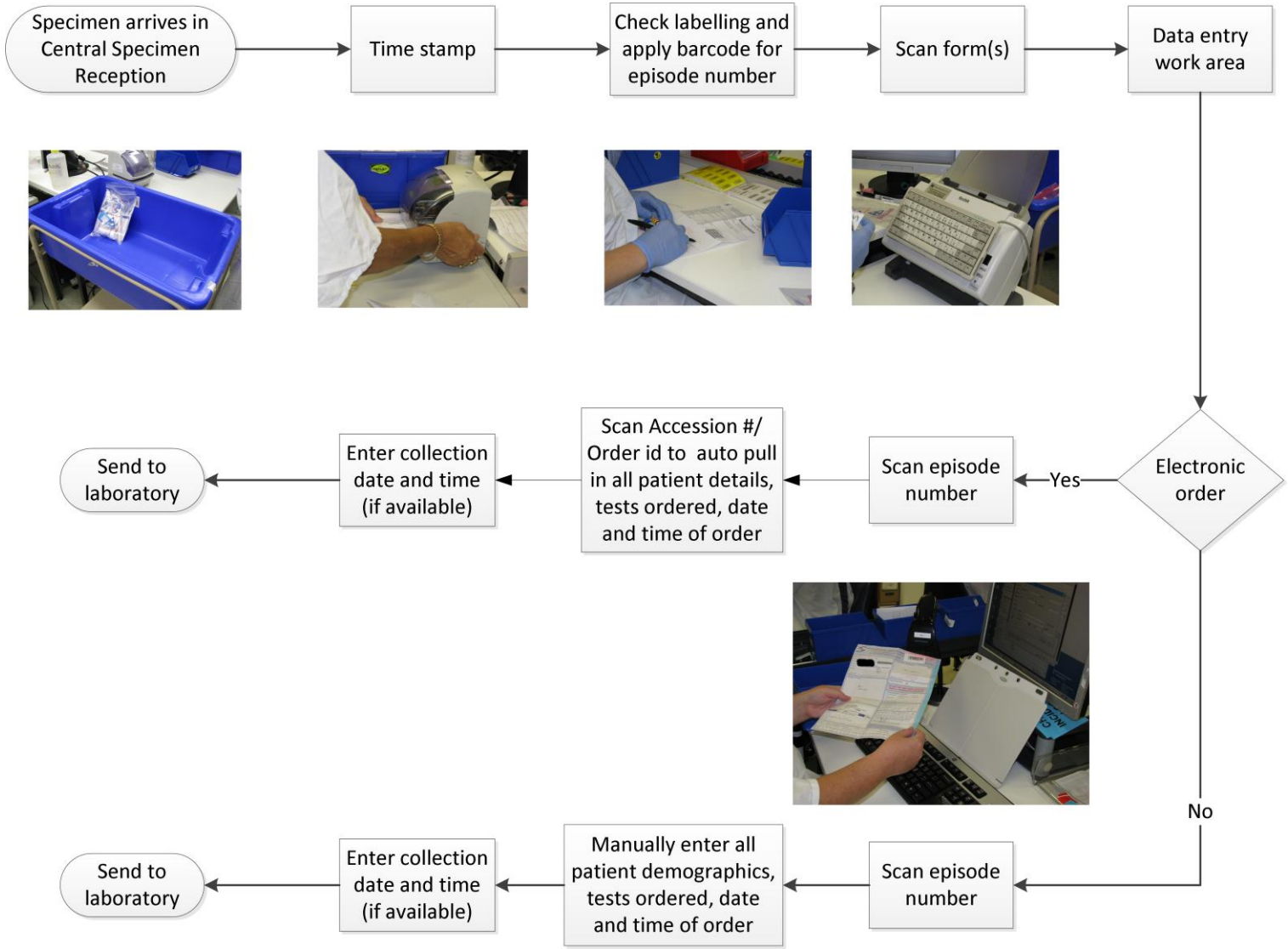


Figure 1. Flow diagram for how specimens and test order forms are processed within Central Specimen Reception.

CSR error categories

The type of errors recorded in the CSR error log prior to the introduction of the EMR can be grouped in to three broad classes:

1) Errors that are directly linked to patient safety and need to be reported to the Incident Information Management System (IIMS);
2) Errors that are related to the efficiency and effectiveness of laboratory functions;
3) Errors that are attributable or related to the introduction of EMR and associated process changes.

Definitions for each of the error categories are provided in Table 3.

1. IIMS related categories – the pathology service has a policy that mislabelled, mismatched and unlabelled errors automatically generate an IIMS event due to the fact that these errors are potentially serious and can cause harm to the patient.	
Mislabelled specimen	Specimen and test order form are both labelled with the details of the wrong person.
Mismatched specimen	Details on the specimen and test order form are not for the same patient (e.g., specimen labelled with patient A details but test order form labelled with patient B details).
Unlabelled specimen	Specimen with no patient details or no patient label.
2. Efficiency and effectiveness categories – the following categories incorporate errors that are related to the efficiency and effectiveness of laboratory functions.	
Accident to specimen	Unable to process specimen due to laboratory accident (e.g., tube broke in centrifuge, inappropriately handled or lost).
Insufficient specimen	Insufficient specimen to perform all the tests.
Leaking specimen	Specimen leaked in transit to the laboratory.
Wrong specimen type	Incorrect specimen type collected (e.g., urine collected instead of blood).
Collection requirement not met	Specimen unable to be processed due to collection requirements not being met (e.g., specimen not collected in correct tube, or not transported on ice or bacterial instead of viral swab collected).
Unlabelled or no request form	Problem with test order form, either unlabelled or none received.
Test set	Incorrect tests entered either by clinician or laboratory (e.g., hepatitis B surface antigen ordered instead of hepatitis B surface antibody to check for immune status).
Patient details problem	Some problem with patient details (e.g., date of birth not entered).
Unsigned request form	Test order form not signed by ordering clinician.
Other	One of several miscellaneous problems (e.g., test cancelled, episode cancelled). In many cases no details were entered into the error log.

3. Errors that are attributable to changed work processes brought on by EMR	
EMR test order problem	Error that has been attributed to the electronic medical record (e.g., electronic test order form had a hand written test appended). Hand written amendments to electronic orders can occur for a number of reasons: • Clinician forgot to order a test, and instead of entering a new electronic order, the test order was handwritten on an EMR print-out. • A clinician requested that a test be added to an original order made by a different clinician. • Patient was discharged making it difficult for the clinician to add a test to an existing order. • EMR test order problems can also occur when a second or subsequent electronic order is created for a patient and only one specimen is collected. If all test order forms are not sent to the pathology service with the specimen then the pathology service is required to locate the remaining form(s) (since all test order forms must be accounted for). • EMR test order problems were sometimes logged for paper orders when the EMR was down or not available.
No specimen received	Test order form received with no specimen.

Table 3 Definitions of error categories in the CSR error log.

Data collection and analysis

Data from the paper-based CSR error log were collected for a six-month period prior to the introduction of the computerised CSR error log (January to June 2009) and were compared longitudinally with matching periods after the implementation of electronic ordering (January to June 2010 and 2011; using data from the computerised error log). The cross-sectional analysis of the computerised error log covered the period from 1 March 2010 (the date that "EMR test order problem" became available as an error category) until 9 October 2011 (the last date before data extraction was performed). Scanned images of test order forms were also available for confirmation of error details. An experienced member of the research team (a laboratory manager/researcher) audited and analysed the error log categories in consultation with senior staff in the pathology service. Over an eight month period (August 2011 to March 2012), 20 meetings were held with CSR staff (supervisor, assistant supervisor and data entry staff) to generate a process map of the workflow process, and to investigate the differences between processes used for paper and electronic test order forms in the processing of errors. Regular iterative feedback sessions were held with senior staff to confirm the validity of the findings.

The error details field in the paper-based and computerised error logs were used to confirm (and adjust if necessary) the classification of errors into the correct categories. Errors were considered as incorrectly classified in cases where the free-text entered in the error log could not be plausibly connected with the chosen error category. Examples of such misclassification of errors are shown in Table 4, for example, where a "Mislabelled specimen" error had been incorrectly classified in the "Other" category. In the case of the paper-based error log, no discrepancies were found between the error category and error details fields for any of the errors, so no reclassification was required. In the case of the computerised error log, for the period of the main cross-sectional analysis (1 March 2010 to 9 October 2011), a total of 7825 errors were logged for test orders coming from the three hospitals (A, B, and C). Of these errors, 947 (12.10%) were classified as "Test set" or "Other" errors; categories often used when an error could not be classified in a more specific category. The classification of 338 (35.69%) of these errors was judged to be inconsistent with the information provided in the free-text details field of the error and were reclassified. A subsequent detailed inspection attempted to reclassify the 553 (58.39%) "Test Set" or "Other" errors that contained no additional information in the free-text details field. For each of these errors, the scanned image of the original test order form was retrieved from the digital archive and was visually inspected for additional information that might inform the error type classification. Based on information found in the associated test order form, 86 errors (all from the "Other" error category) were reclassified, 59 (68.60%) of these errors were associated with a clinician making a handwritten amendment to a printed copy of an EMR order.

Original category	**Error details**	**Reclassified category**
Other	Mislabelled specimen	Mislabelled specimen
Other	Hand written tests	EMR test order problem
Other	Specimen not on ice	Collection requirements
Other	No specimen received	No specimen received
Test set	Green swab received	Collection requirements

Table 4. Examples of how the re-coding criteria were applied to the error categories

A test order episode refers to a single occasion where a clinician orders one or more pathology tests involving one or more pathology departments. By expressing the number of errors as a proportion of test order episodes, i.e., as a rate, it is possible to

control for the volume of test orders being processed at any particular time or by a particular system (i.e., paper vs. electronic orders).

Frequency of test order errors

The volume and rates of errors for each of the three periods January to June of 2009, 2010 and 2011 is presented in Table 5. The 2009 period covers the period prior to the introduction of EMR. The total number of errors increased from 1772 in 2009 to 2282 and 2452 in 2010 and 2011 respectively. When measured as a rate per 1000 test order episodes, this resulted in rates of 9.66, 12.67 and 13.48, for 2009 to 2011 respectively. The error rate in 2010 was approximately 30% higher than it was in 2009. The vast majority of this increase in errors reported was accounted for by errors classified as "EMR test order problem" (n=280) and "No specimen received" (increase of 197). It is also possible that some of the errors recorded as "Other" (increase of 55) and "Test set" (increase of 15) contributed to this increase in error rate between 2009 and 2010. Thus the increase in errors across time is largely due to a new category of errors associated with the electronic ordering process.

		Error Rate per 1000 Test Order Episodes (Number of Errors)		
	Error Type	**2009**	**2010**	**2011**
IIMS related categories	Mislabelled specimen	0.32 (58)	0.14 (25)	0.20 (37)
	Mismatched specimen	0.36 (66)	0.64 (116)	0.78 (142)
	Unlabelled specimen	1.75 (321)	1.35 (243)	1.64 (298)
Efficiency and effectiveness categories	Accident to specimen	0.13 (24)	0.11 (20)	0.14 (26)
	Insufficient specimen	0.23 (43)	0.19 (34)	0.24 (44)
	Leaking specimen	0.20 (36)	0.17 (30)	0.23 (41)
	Collection requirements not met	1.19 (219)	1.23 (221)	1.58 (287)
	Unlabelled or no request form	0.03 (5)	0.36 (65)	0.27 (49)
	Patient details problem	0.08 (14)	0.08 (15)	0.17 (31)
	Unsigned request form	0.12 (22)	0.01 (2)	0 (0)
	Test set	0.72 (133)	0.82 (148)	0.53 (97)
	Other	0.09 (17)	0.4 (72)	0.67 (122)
Errors that are attributable to changed work processes brought on by EMR	EMR test order problem	n/a	1.56 (280)	1.45 (263)
	No specimen received	4.44 (814)	5.61 (1011)	5.58 (1015)
Total Errors		**9.66 (1772)**	**12.67 (2282)**	**13.48 (2452)**
Total Test Order Episodes		**183495**	**180059**	**181892**

Table 5. Comparison of the rates and frequencies with which each type of error was recorded, collapsed across Hospitals A, B, and C, before the implementation of EMR (Jan-Jun 2009) and after the implementation of EMR (Jan-Jun 2010 and Jan-Jun 2011).

A detailed breakdown of the types of errors recorded as "EMR test order problem" is shown in Table 6. It shows that, across all three hospitals, 66.72% of errors were related to an order erroneously handwritten onto an EMR test order form print-out. This type of error generally occurred when the ordering clinician sought to amend an existing electronic order by altering the print-out of the order rather than creating a new order within the EMR. That is, in these instances, the ordering clinician treated the print-out of the order as though it was itself the order, rather than as a token representing the

EMR order. (See Appendix IV for an example of a print-out of an electronic order that was manually altered, classified as a "Handwritten request on an EMR order" error). A further 26.48% had no information and could not be further categorised; and 6.80% reported a variety of reasons related to EMR order number problems, duplicate forms and wrong types of EMR order. Further analysis of the CSR error log revealed that 418 (61.83%) "EMR test order problem" errors required laboratory staff to contact the clinician or ward to request corrective action for the problem (to get a new order form from the clinician/ward, or to get a signed test order form from the clinician/ward).

	Hospital			
Error details	**A**	**B**	**C**	**Total**
Handwritten request on an EMR order	65.24% (n=274)	64.47% (n=49)	71.11% (n=128)	66.72% (n=451)
Order number problem (number filed, used, invalid or discontinued)	3.10% (n=13)	5.26% (n=4)	2.22% (n=4)	3.11% (n=21)
Multiple forms (2 forms, 3 forms) / Duplicate Forms	1.90% (n=8)	0% (n=0)	0% (n=0)	1.18% (n=8)
EMR order incorrect (swab instead of fluid, urine received for swab, etc)	2.86% (n=12)	2.63% (n=2)	0.56% (n=1)	2.22% (n=15)
Change of tests	0.23% (n=1)	0% (n=0)	0% (n=0)	0.15% (n=1)
Add-on test	0.23% (n=1)	0% (n=0)	0% (n=0)	0.15% (n=1)
No information provided	26.43% (n=111)	27.63% (n=21)	26.11% (n=47)	26.48% (n=179)
Total	**420**	**76**	**180**	**676**

Table 6. The types of errors described in the error details free text for errors classified as "EMR test order problem" for electronic test orders only, and the frequency and rate at which they were recorded (01/03/2010 – 09/10/2011).

Errors of the "EMR test order problem" category have repercussions for CSR workflow. This begins with the need for CSR to complete an entry into the computerised error log that is then followed up by a designated laboratory error "trouble-shooter" who contacts the ordering clinician for corrective action (see Appendix VI). This results in delays to the pathology testing process. Table 7 compares the median data entry time between test order episodes that had an "EMR test order problem" error and median data entry time for all test order episodes (test order episodes with, and without, and errors logged). The median data entry time was three minutes (60%) longer when an "EMR test order problem" error was logged compared to the median data entry time of all test order episodes. A large part of this time delay

was accounted for by additional time required for data entry staff in the CSR to make an entry in the computerised error log. When taking into consideration the amount of time required for the "trouble-shooter" to contact the clinician or ward and for the latter to take corrective action, as shown in the Total Laboratory TAT section of Table 7, the median TAT was three hours (181 minutes; 220%) longer when a "EMR test order problem" occurred than for all test order episodes.

	EMR test order problem	**All Test Order Episodes**
Median Data Entry time (mins)	8	5
	Z=7.65, *p*<.001	
Median Total Lab TAT (mins)	263	82.14
	Z=8.91, *p*<.001	
Total Episode Count (n=)	174	124119

Wilcoxon signed-rank tests of significance

Table 7. Comparison of median TATs for test order episodes that resulted in an "EMR test order problem" tests and the median TAT for all test order episodes.

Our cross-sectional analysis compared the volume and nature of errors for paper and EMR orders. Table 8 details the volume and rates of errors for electronic orders and paper orders across the hospitals for the period 1 March 2010 to 9 October 2011. The table shows that EMR uptake, during the analysis period, for each of the hospitals was 68.92% at Hospital A, 32.28% at Hospital B, and 58.46% at Hospital C. When considering the overall error rates across all hospitals, the rate of errors per 1000 test order episodes for the three IIMS-related problems was consistently lower for EMR orders than for paper orders: 0.10 vs. 0.31 for "Mislabelled specimen" errors, 0.49 vs. 1.42 for "Mismatched specimen" errors, and 1.37 vs. 1.65 for "Unlabelled specimen" errors. Chi-square (χ^2) tests of independence, shown in Table 8, revealed that these differences in rates were all significant ($p<.001$, $p<.001$, $p<.01$, respectively).

	Error Rate per 1000 Test Order Episodes (Number of Errors)							
	Hospital							
	A		**B**		**C**		**Overall**	
	EMR	**Paper**	**EMR**	**Paper**	**EMR**	**Paper**	**EMR**	**Paper**
EMR Uptake Rate (01/03/2010 – 09/10/2011)	68.92%		32.28%		58.46%		62.34%	
Error Category	**IIMS related categories**							
Mislabelled specimen	0.08 (23)	0.52 (41)	0.07 (3)	0.13 (8)	0.16 (13)	0.17 (7)	0.10 (39)	0.31 (56)
							χ^2=36.51, *p<.001*	
Mismatched specimen	0.44 (126)	2.18 (172)	0.46 (19)	0.73 (44)	0.70 (55)	0.97 (39)	0.49 (200)	1.42 (255)
							χ^2=141.18, *p<.001*	
Unlabelled specimen	1.12 (324)	2.31 (182)	1.34 (55)	0.80 (48)	2.28 (180)	1.65 (66)	1.37 (559)	1.65 (296)
							χ^2=7.16, *p<.01*	
Efficiency and effectiveness categories								
Collection requirements not met	1.03 (298)	1.70 (134)	1.37 (56)	0.53 (32)	2.63 (208)	2.15 (86)	1.37 (562)	1.41 (252)
Unlabelled or no request form	0.16 (47)	0.47 (37)	0.24 (10)	0.30 (18)	0.28 (22)	0.32 (13)	0.19 (79)	0.38 (68)
Patient details problem	0.05 (15)	0.28 (22)	0.42 (17)	0.33 (20)	0.10 (8)	0.15 (6)	0.10 (40)	0.27 (48)
Test set	0.45 (129)	1.03 (81)	0.54 (22)	0.40 (24)	0.96 (76)	0.75 (30)	0.55 (227)	0.75 (135)
Unsigned request form	0.00 (1)	0.01 (1)	0.00 (0)	0.03 (2)	0.00 (0)	0.07 (3)	0.07 (1)	0.07 (6)
Other	0.21 (60)	0.46 (36)	0.34 (14)	0.30 (18)	0.44 (35)	0.70 (28)	0.27 (109)	0.46 (82)
Accident to specimen	0.09 (26)	0.10 (8)	0.29 (12)	0.12 (7)	0.30 (24)	0.15 (6)	0.15 (62)	0.12 (21)
Insufficient specimen	0.08 (22)	0.05 (4)	0.15 (6)	0.05 (3)	0.66 (52)	0.45 (18)	0.20 (80)	0.14 (25)
Leaking specimen	0.06 (18)	0.18 (14)	0.56 (23)	0.08 (5)	0.67 (53)	0.12 (5)	0.23 (94)	0.13 (24)
Errors attributable to EMR work processes								
EMR test order problem	1.45 (420)	1.44 (113)	1.86 (76)	0.35 (21)	2.28 (180)	0.90 (36)	1.65 (676)	0.95 (170)
No specimen received	7.05 (2040)	3.78 (298)	3.76 (154)	1.48 (89)	10.01 (791)	2.92 (117)	7.29 (2985)	2.82 (504)
Total Errors	**12.27 (3549)**	**14.52 (1143)**	**11.40 (467)**	**5.63 (339)**	**21.47 (1697)**	**11.48 (460)**	**13.96 (5713)**	**10.85 (1942)**

Table 8. Comparison of the rates and frequencies with which each type of error was recorded at Hospitals A, B, and C. (01/03/2010 – 09/10/2011.)

SECTION V: EFFECTIVENESS OF THE TEST ORDERING PROCESS

The effectiveness of a pathology laboratory service refers to the quality of the service provided to clinicians, hospitals and, ultimately, to patients.[20 31] Whilst the effectiveness of the pathology service is affected by the complex array of systems and processes within the service, it is also influenced by external factors often outside the control of the pathology service. For example, how information, such as orders, is communicated between the computer system in the ward and the computer system in the pathology service; and what clinical contextual information is provided to assist the pathology service in processing the test order and providing an appropriate interpretation. The effectiveness of the pathology service also depends on what they are required to do, such as the volume of tests being ordered; the types of tests being ordered and whether they are suitable for the patient condition,[32] whether repeat tests are ordered at appropriate times, whether they can inform diagnosis and treatment; and the proper utilisation of add-on testing, which can have a disproportionate effect on pathology service workload.[33-35] New ICT systems have the potential to provide decision support to assist clinicians in making appropriate decisions and thereby improve the effectiveness of patient care.[36 37] One example of this is the ability of the EMR to alert the ordering clinician to a duplicate order (see Appendix V).

Methods

Data Extraction

The initial LIS data extraction generated a dataset containing information relating to all pathology tests conducted on specimens received by the pathology service departments in the period January 2008 and September 2011. Our analyses were conducted only on pathology tests that were ordered by the six study hospitals. The analysis was focused by further limiting the dataset to pathology tests conducted on specimens received during August and September for each year: 2008, 2009, 2010, and 2011. This reduced dataset contained information relating to 3,227,101 pathology tests. Within the dataset, 429,068 (13.3%) records were found to be duplicate entries (where the values in every field were identical). Once duplicate records were removed, the dataset contained information for 2,798,033 tests. A further 30,359 records were removed because they related to laboratory workflow rather than identifying an actual test order. This left 2,767,674 pathology test records associated with 130,060 patient records (who may have had multiple admissions in hospital). This dataset formed the basis for the

subsequent analysis of test volume and turnaround times. Another adjustment was made to these data to account for a small proportion of tests whose turnaround time was recorded with a value less than zero minutes (for data entry time, 10,474 such records were found; for Total Laboratory TAT, 890 such records were found). These records were flagged and did not contribute to analyses of TATs, but were included in other analyses.

In order to assess the volume of test ordering per patient encounter (from patient admission to the hospital until their discharge) it was necessary to extract patient encounter data from the Patient Administration System (PAS) and Emergency Department Information System (EDIS) of the hospitals. These patient encounter data covered the period between 1 August and 30 September of 2008, 2009, 2010, and 2011. A number of steps were taken to ensure the integrity and consistency of these patient encounter datasets before they were linked to the test order dataset. The final linkage occurred between records for 147,280 patient admissions (extracted from the PAS), and records for 176,015 ED presentations (extracted from the EDIS), with the records for 2,767,674 pathology test orders (extracted from the LIS).

Data Linkage

All data integrity and validity checks, and linkage were performed in IBM SPSS Statistics 20.0.0. The datasets extracted from the PAS and EDIS were comma-separated values (CSV) format; the in-built SPSS data opening functions were used to import the data.

The patient admission dataset from the PAS and the ED presentation dataset from the EDIS were merged with the Test Order dataset from the LIS and the entire merged dataset was sorted by patient, patient admission dates and times, and specimen collection dates and times. Test orders where the specimen was collected after the patient admission and before the patient discharge, for matching patients, could be confidently attributed to those patient encounters. Data linkage between the three datasets allowed a single test order to be linked with either the PAS or EDIS dataset, or both datasets simultaneously. The SPSS "LAG" function was used to compare the patient, patient admission dates/times, and specimen collection dates/times of the sorted merged datasets and to associate, where valid and appropriate data were found, patient admission, discharge, and demographic information with the relevant test order data. In

cases where specimen collection for a test order occurred either before patient admission, after patient discharge, or where no patient encounter data could be found, no linkage was performed. Therefore, these test orders were excluded from all analyses where linked data were necessary (e.g., comparisons of test rates per patient admission and DRG casemix). Once the linkable patient presentation and admission data from the EDIS and PAS datasets were merged, the merged dataset was cleaned to remove orphan patient admission information (presentations and admissions for which no associated pathology tests were found).

Data Analysis

Data analyses were conducted using IBM SPSS Statistics 20.0.0 and Microsoft Excel 2007. A number of different statistical tests were used for tests of significance. These depended on the nature of the data being analysed, and the research question being addressed. At various points of this report, analyses used independent-sample *t*-tests, chi-square (χ^2) tests of independence, Mann-Whitney U tests, and Wilcoxon signed-rank tests. In all cases, the alpha-value for significance was set at $p < .05$.

Test volume

The volume of pathology tests ordered by clinicians varied greatly between hospitals. These differences are not necessarily driven by factors associated with patient acuity or by the type of medical service.[32] Table 9 compares the mean number of tests ordered for each test order episode for each year from 2008 to 2011 when EMR was introduced at each of the hospitals. It shows that the overall mean rates of tests per test ordering episode were uniformly and consistently lower across all six study hospitals in 2011 (after the introduction of EMR) than in 2008, independent sample *t*-tests found the difference significant in all hospitals.

	Year				
Hospital	**2008**	**2009**	**2010**	**2011**	**Mean Difference: 2008 - 2011**
A	4.68	4.20	**4.51**	**4.62**	0.06 $t(77447.1)=2.37$, $p<.05$
B	3.16	3.03	**3.07**	**3.09**	0.07 $t(20585.3)=2.08$, $p<.05$
C	4.42	3.91	**4.19**	**4.15**	0.27 $t(24647.7)=2.95$, $p<.001$
D	4.70	**4.14**	**3.98**	**4.35**	0.36 $t(20726.1)=7.62$, $p<.001$
E	4.65	**4.17**	**4.33**	**4.49**	0.16 $t(100742.4)=7.26$, $p<.001$
F	5.04	**4.32**	**4.38**	**4.32**	0.72 $t(70372.9)=26.39$, $p<.001$
Overall	*4.63*	*4.11*	*4.27*	*4.36*	*0.27* $t(317634.6)=21.72$, $p<.001$

Independent sample *t*-tests

Table 9. A comparison, between years, of the mean number of tests ordered in each test order episode at the six study hospitals. Numbers in normal text are pre-EMR implementation; numbers in bold are post-EMR implementation; numbers in italics are overall rates.

A comparison of the mean number of tests per admission and mean length of stay between the six study hospitals and across the four years is shown in Table 10. A comparison of the mean number of tests per admission, at each hospital, for the periods before and after the availability of electronic ordering, reveals an inconsistent pattern of results. Hospitals A and E showed an increase in the number of tests per patient admission, whereas Hospitals C and D showed a reduction in the mean tests per patient admission. Lastly, the rate at Hospitals B and F was similar in 2011 to what it was in 2008. The mean length of stay was, however, shorter at all hospitals in 2011 compared to 2008.

				Mean Number of Tests Per Admission (Number of Tests/Number of Admissions) Mean Length of Stay (hours)
Hospital	**2008**	**2009**	**2010**	**2011**
A	19.91 (75172/3776) 181	19.51 (70036/3589) 191	**19.57 (71714/3665) 189**	**20.15 (76795/3812) 163**
B	7.22 (8560/1185) 128	7.98 (9068/1137) 131	**7.37 (7938/1077) 118**	**7.35 (8053/1096) 115**
C	16.26 (21851/1344) 110	18.29 (24121/1319) 117	**15.80 (22568/1428) 98**	**14.97 (21511/1437) 95**
D	13.53 (24172/1787) 101	**13.19 (24037/1822) 88**	**13.17 (24160/1835) 90**	**12.61 (26262/2083) 86**
E	19.17 (98553/5141) 146	**20.76 (102565/4941) 141**	**20.77 (108502/5224) 138**	**22.41 (119276/5322) 143**
F	17.35 (75958/4377) 134	**18.34 (72151/3935) 156**	**15.81 (78686/4977) 122**	**17.28 (84370/4882) 130**

Table 10. A comparison, between years, of the mean number of pathology tests ordered in each patient admission, at each of the six study hospitals. Numbers in normal text are pre-EMR implementation; numbers in bold are post-EMR implementation.

Diagnosis-related Groups (DRG)

Assessing test types and volume by matched diagnosis-related groups (DRGs) allows analyses to control for the variability of test ordering between different categories as a means of examining patterns and variations of pathology ordering.[4 38] A comparison of the mean number of tests per admission and mean length of stay, between the four years, for the top-10 DRGs based on pathology utilisation, is shown in Table 11. When comparing the period before electronic ordering was available (2008) with the period after it was available and well-established (2011), the pattern of results was inconsistent. Some DRGs showed an increase in the number of tests per patient admission, for example G02A (Major bowel procedure) showed a considerable increase from a mean of 76.11 to 91.88 tests per patient admission, whereas other DRGs (e.g., A06B [Tracheostomy]) showed a reduction in the mean tests per patient admission. Similarly, mean length of stay was reduced over time for DRGs such as E65B (Chronic Obstructive Airways Disease) but increased for F62B (Heart Failure & Shock). Conversely, the consistency in test volumes and length of stay for L61Z (Haemodialysis) is what would be expected for this category.

		Mean Number of Tests Per Admission (Number of Tests/Number of Admissions) Mean Length of Stay (hours)			
DRG		**2008**	**2009**	**2010**	**2011**
A06B	**Tracheostomy w/ ventilation >95hrs + and -**	181.10 (10866/60) 646	179.31 (10400/58) 886	159.77 (11823/74) 636	156.77 (12071/77) 696
Z60A	**Rehabilitation +**	72.86 (7140/98) 1205	74.49 (8045/108) 1070	83.99 (7475/89) 1350	91.16 (10392/114) 1160
L61Z	**Haemodialysis**	5.26 (8720/1657) 7	4.86 (5413/1113) 7	4.90 (6087/1242) 7	5.27 (5481/1041) 7
E62A	**Respiratory infections +**	40.60 (5359/132) 305	36.51 (3395/93) 225	37.94 (3870/102) 244	42.81 (5308/124) 289
F74Z	**Chest pain**	8.67 (3973/458) 27	9.52 (3978/418) 33	9.08 (4810/530) 29	8.87 (4888/551) 25
A06A	**Tracheostomy w/ ventilation >95hrs + only**	301.05 (6021/20) 2026	296.82 (3265/11) 2437	224.68 (4269/19) 956	250.75 (3009/12) 1150
F62B	**Heart failure & shock –**	19.26 (4294/223) 123	21.08 (3141/149) 120	22.23 (4423/199) 134	21.75 (4612/212) 128
E65B	**Chronic Obstructive Airways Disease -**	16.32 (4602/282) 135	17.88 (3630/203) 132	16.02 (3829/239) 128	17.63 (4319/245) 118
G02A	**Major bowel procedure +**	76.11 (2740/36) 471	84.69 (4319/51) 502	71.17 (3274/46) 483	91.88 (5513/60) 445
G67B	**Oesophagitis & Gastroenteritis +**	9.98 (3382/339) 47	10.11 (3436/340) 44	9.80 (3792/387) 43	9.87 (3059/310) 39
Overall (Top-10 DRGs)		**17.28 (57097/3305) 109**	**19.27 (49022/2544) 126**	**18.33 (53652/2927) 113**	**21.36 (58652/2746) 128**
DRG code with +: "with catastrophic complications" DRG code with -: "without catastrophic complications"					

Table 11. A comparison, between years, of the mean number of pathology tests ordered in each patient admission, for each of the ten DRG admission codes associated with the highest pathology utilisation.

A more detailed analysis of pathology testing using DRGs comparing test volume, proportions, and rank (in parentheses) of the highest-utilisation pathology tests (all tests accounting for at least the 90th percentile of test volume for each hospital for each year), for patients within the ED who were admitted to a hospital ward with the DRG of F74Z (Chest pain) is presented in Table 12. The highest ranked groups of tests (Troponin, EUC [electrolytes, urea, and creatinine], Automated Differential and Liver Function

Tests) were consistently selected and ranked as the four most frequently ordered tests at all the hospitals, for both pre-EMR and post-EMR periods. The mean number of C-Reactive protein tests per ED presentation varied both between hospitals and between years. At three of the EDs the mean number of C-Reactive protein tests per ED presentation was higher in 2011 than in 2008 (Hospital ED "A": from a mean of 0.02 C-Reactive protein tests per ED presentation, in 2008, to a mean of 0.08 tests per presentation; Hospital ED "D": from a mean of 0.24 tests to 0.31 tests; and Hospital ED "F": from a mean of 0.13 tests to 0.21 tests), while the opposite was true for the ED at Hospital ED "E" (from a mean of 0.11 tests to 0.06 tests).

Number of Tests (Mean Number of Tests per ED Presentation) % of tests (rank)								
Hospital ED	**A**		**D**		**E**		**F**	
Test	**2008**	**2011**	**2008**	**2011**	**2008**	**2011**	**2008**	**2011**
N of Patients (N of ED presentations)	**108 (111)**	**133 (134)**	**33 (34)**	**87 (91)**	**140 (143)**	**133 (134)**	**159 (158)**	**179 (183)**
TROPONIN	133 (1.20) 21.25% (1)	186 (1.39) 23.72% (1)	52 (1.53) 22.22% (1)	145 (1.59) 22.52% (1)	174 (1.22) 19.62% (1)	177 (1.32) 22.61% (1)	219 (1.39) 20.20% (1)	266 (1.45) 21.11% (1)
EUC	117 (1.05) 18.69% (2)	136 (1.01) 17.35% (2)	33 (0.97) 14.10% (2)	91 (1.00) 14.13% (2)	150 (1.05) 16.91% (2)	137 (1.02) 17.50% (2)	165 (1.04) 15.22% (2)	184 (1.01) 14.60% (2)
AUTOMATED DIFF	114 (1.03) 18.21% (3)	134 (1.00) 17.09% (3)	33 (0.97) 14.10% (2)	90 (0.99) 13.98% (3)	145 (1.01) 16.35% (3)	133 (0.99) 16.99% (3)	160 (1.01) 14.76% (3)	180 (0.98) 14.29% (3)
LFT	60 (0.54) 9.58% (4)	71 (0.53) 9.06% (4)	22 (0.65) 9.40% (4)	62 (0.68) 9.63% (4)	126 (0.88) 14.21% (4)	89 (0.66) 11.37% (4)	79 (0.50) 7.29% (5)	117 (0.64) 9.29% (4)
PT/INR/APTT	19 (0.17) 3.04% (7)	35 (0.26) 4.46% (6)	21 (0.62) 8.97% (5)	50 (0.55) 7.76% (6)	62 (0.43) 6.99% (5)	65 (0.49) 8.30% (5)	99 (0.63) 9.13% (4)	101 (0.55) 8.02% (5)
CA MG PHOS	8 (0.07) 1.28% *(11)	44 (0.33) 5.61% (5)	16 (0.47) 6.84% (6)	59 (0.65) 9.16% (5)	21 (0.15) 2.37% (9)	50 (0.37) 6.39% (6)	75 (0.47) 6.92% (6)	91 (0.50) 7.22% (7)
GLUCOSE	47 (0.42) 7.51% (5)	33 (0.25) 4.21% (7)	14 (0.41) 5.98% (7)	44 (0.48) 6.83% (7)	58 (0.41) 6.54% (6)	12 (0.09) 1.53% (10)	37 (0.23) 3.41% (8)	96 (0.52) 7.62% (6)

							Number of Tests (Mean Number of Tests per ED Presentation) % of tests (rank)	
Hospital ED	**A**		**D**		**E**		**F**	
Test	**2008**	**2011**	**2008**	**2011**	**2008**	**2011**	**2008**	**2011**
D-DIMER LIA	16 (0.14) 2.56% (9)	22 (0.16) 2.81% (9)	6 (0.18) 2.56% *(9)	14 (0.15) 2.17% (10)	27 (0.19) 3.04% (7)	14 (0.10) 1.79% *(9)	38 (0.24) 3.51% (7)	35 (0.19) 2.78% *(10)
LIPASE	26 (0.23) 4.15% (6)	13 (0.10) 1.66% (11)	6 (0.18) 2.56% (9)	20 (0.22) 3.11% *(9)	8 (0.06) 0.90% (14)	24 (0.18) 3.07% (7)	34 (0.22) 3.14% (9)	41 (0.22) 3.25% (8)
C-REACTIVE PROTEIN	2 (0.02) 0.32% (19)	11 (0.08) 1.40% (12)	8 (0.24) 3.42% (8)	28 (0.31) 4.35% (8)	16 (0.11) 1.80% *(10)	8 (0.06) 1.02% (11)	20 (0.13) 1.85% (11)	39 (0.21) 3.10% (9)
BLOOD GAS	19 (0.17) 3.04% (7)	31 (0.23) 3.95% (8)		1 (0.01) 0.16% (17)	8 (0.06) 0.90% (14)	20 (0.15) 2.55% (8)	13 (0.08) 1.20% (12)	15 (0.08) 1.19% (12)
TSH	3 (0.03) 0.48% (16)	3 (0.02) 0.38% (17)	6 (0.18) 2.56% (9)	12 (0.13) 1.86% (11)	5 (0.03) 0.56% (16)	8 (0.06) 1.02% (11)	21 (0.13) 1.94% (10)	17 (0.09) 1.35% (11)
URINE MICRO	5 (0.05) 0.80% (14)	17 (0.13) 2.17% *(10)	3 (0.09) 1.28% (14)	4 (0.04) 0.62% (13)	10 (0.07) 1.13% (13)	5 (0.04) 0.64% (14)	6 (0.04) 0.55% (17)	15 (0.08) 1.19% (12)
AMYLASE	1 (0.01) 0.16% (25)	2 (0.01) 0.26% (21)	4 (0.12) 1.71% (13)	7 (0.08) 1.09% (12)	25 (0.17) 2.82% (8)	8 (0.06) 1.02% (11)	8 (0.05) 0.74% (15)	4 (0.02) 0.32% (15)
CK	8 (0.07) 1.28% (11)	1 (0.01) 0.13% (25)	5 (0.15) 2.14% (12)	1 (0.01) 0.16% (17)	3 (0.02) 0.34% (17)	1 (0.01) 0.13% (21)	13 (0.08) 1.20% (12)	4 (0.02) 0.32% (15)
PT/INR	11 (0.10) 1.76% (10)				16 (0.11) 1.80% (10)	1 (0.01) 0.13% (21)		
CKMB							10 (0.06) 0.92% *(14)	1 (0.01) 0.08% (26)
* indicates the lowest ranked test, for each hospital for each year, that must be included for a minimum of the 90th percentile of tests based on test utilisation.								

Table 12. A comparison, between 2008 and 2011 at the ED of four hospitals, of the tests (number, rate per presentation, proportion, and rank) ordered for patients within the ED who were eventually admitted to a ward with a DRG of F74Z (Chest pain). (Note: Very low volume tests are not shown.)

Add-on testing

Add-on tests are tests that are performed on an existing specimen previously submitted to the pathology service with an earlier test order. The reasons for ordering an add-on test are many including situations when a clinician requires a base-line result in cases where treatment has already commenced, when the clinician neglected to order all prescribed tests, or even situations when a clinician wants to avoid subjecting vulnerable patients or children to additional phlebotomies. Add-on tests are labour-intensive and disruptive for the laboratory and place a disproportionate burden on laboratory resources.[18 33-35 39] Interruptions to the routine work flow, interruption of clinical staff and delayed testing of the specimen are part of the impact of add-on testing. Measuring the number of add-on tests allows the laboratory to identify any major problem areas.[33-35]

Procedures to reliably identify add-on tests were not implemented until 2011 and, therefore, it was not possible to compare the add-on test rate for the period before electronic ordering became available. The results reported in Table 13 contrast add-on test rates for different hospitals and pathology departments. They show a variation between hospitals of between a minimum of 0.61% (Hospital B; specialist hospital) and maximum 2.24% (Hospital F; metropolitan general hospital). There were considerable differences in the rate at which add-on tests were ordered in the different departments. The departments with the highest proportion of add-ons were Serology, Immunology and Endocrinology (7.78% 7.22% and 6.33% respectively). The add-on test rates in the clinical chemistry and haematology departments, that combined accounted for 70% of the add-on test volume, were 2.56% and 0.69%, respectively.

Proportion of Tests Accounted for by Add-on Tests (Number of Add-on Tests/Number of all Tests)			
Hospital		**Department**	
		Andrology/Seminology	0% (0/797)
		Bone Marrow	0% (0/237)
		Clinical chemistry	2.56% (8300/324178)
		Cytology	0% (0/3095)
		Endocrinology	6.33% (1358/21455)
		Genetics	0.29% (7/2396)
		Haematology	0.69% (1527/222374)
A	2.04% (3654/178819)	**Histopathology**	0.05% (1/1868)
B	0.61% (189/31130)	**Immunology**	7.22% (1199/16613)
C	1.29% (632/49168)	**Microbiology**	0.10% (98/97904)
D	2.22% (1103/49615)	**Non-gynae cytology**	0.65% (9/1381)
E	1.92% (4569/238164)	**Serology**	7.78% (1300/16700)
F	2.24% (3796/169151)	**Virology**	2.04% (144/7049)
Overall			*1.95% (13943/716047)*

Table 13. The proportion of pathology tests accounted for by add-on tests, the add-on test volume, and the total test volume, at each of the six study hospitals (left-side) and each of the ten departments within the pathology service (right-side) for the two-month period of August-September 2011.

Repeat testing

Assessing the appropriateness of test ordering is a complex process, not least because test ordering decisions are made according to nuances of each patient's condition.[38] Appropriateness of test ordering relates to both overuse and under-use, although most commentary has focused on overuse, occurring when a test has been ordered without a clinical indication or within a time frame that is unlikely to provide additional diagnostic information.[31 32]

The clinical decision support features that can be included in electronic ordering systems have the potential to reduce the repeat test order rate by notifying clinicians when there is an existing identical test order, for that patient, already recorded within the EMR. Clinicians can then choose not to proceed with the order or, if clinically appropriate, to override the alert and proceed with the order. On the other hand, it is much more difficult for a paper order to be identified as a repeat test and, therefore, clinicians have reduced access to information that could assist them make effective decisions. Reductions in the rate of unnecessary repeat tests can result in reductions in patient phlebotomies and workload in the laboratory.[40 41]

We compared the rates of repeat EUC testing within one-hour and within 24-hours of the previous test, for electronic and paper test orders. The pattern of data shown in Table 14 shows that the proportion of repeat EUC testing in 2011 that occurred within one hour of the previous EUC test was greater for tests ordered using the paper system than those ordered with the EMR (0.69% and 0.25%, respectively), a significant difference (χ^2=40.95, p< .001). While, for tests ordered within 24 hours, there was a lower proportion of repeat tests with paper orders than for electronic orders (11.68% and 34.04%, respectively), also a significant difference (χ^2=8534.37, p< .001).

Repeat EUC orders created electronically within 24-hours of the previous EUC order for the same patient triggered a Duplicate Order Alert that had to be acknowledged for the order to be created. The finding that 33.79% (the difference between 34.04% of orders within 24 hours and 0.25% of orders within 1 hour) of electronically-ordered repeat EUC tests occurred between one and 24-hours suggests that ordering clinicians were prepared, in many cases, to proceed with a repeat EUC order despite encountering a Duplicate Order Alert. The relative infrequency of electronically-ordered EUC orders within one hour of the previous order may be a consequence of ordering clinicians' decisions being influenced by their ability to access data on their computers screens about what EUC tests had been ordered in the very recent past. In addition, while the proportion of repeat EUC tests occurring within one-hour of the previous test decreased with time for electronically-ordered tests (overall: 0.40% in 2009, 0.31% in 2010, and 0.25% in 2011), the pattern was not consistent for EUC tests ordered with the paper system (Overall: 0.63% in 2009, 0.56% in 2010, and 0.69% in 2011).

		Year							
		2008		2009		2010		2011	
Hosp	Time Delay	EMR	Paper	EMR	Paper	EMR	Paper	EMR	Paper
A	<1 Hr n=	.	0.77% 86	.	0.77% 91	0.49% 52	1.58% 28	0.24% 27	1.37% 30
								χ^2=53.62, p< .001	
	<24Hrs n=	.	36.79% 4131	.	32.53% 3821	32.70% 3489	12.51% 221	32.43% 3574	12.75% 280
								χ^2=1829.34, p< .001	
	Repeat Tests		11230	0	11746	10669	1767	11022	2196
	Total Tests		17542	0	17254	14729	2894	14945	3474
B	<1 Hr n=	.	0.30% 4	.	0.29% 4	0.30% 3	0.00% 0	0.21% 2	1.30% 3
								χ^2=too few events	
	<24Hrs n=	.	39.29% 523	.	37.84% 518	39.13% 394	16.03% 38	34.74% 330	12.55% 29
								χ^2=186.87, p< .001	
	Repeat Tests		1331	0	1369	1007	237	950	231
	Total Tests		1968	0	2019	1303	486	1260	465
C	<1 Hr n=	.	0.53% 13	.	0.42% 12	0.29% 8	0.00% 0	0.12% 3	0.26% 1
								χ^2=too few events	
	<24Hrs n=	.	41.52% 1016	.	41.99% 1190	43.63% 1196	26.49% 89	39.09% 955	16.54% 63
								χ^2=620.34, p< .001	
	Repeat Tests		2447	0	2834	2741	336	2443	381
	Total Tests		4018	0	4111	3794	611	3306	678
D	<1 Hr n=	.	0.46% 12	0.28% 7	0.00% 0	0.18% 5	2.52% 4	0.41% 12	0.32% 1
								χ^2=too few events	
	<24Hrs n=	.	31.29% 811	29.91% 752	20.50% 33	30.26% 821	18.87% 30	27.77% 805	11.78% 37
								χ^2=326.64, p< .001	
	Repeat Tests		2592	2514	161	2713	159	2899	314
	Total Tests		4591	4106	338	4358	306	4648	633

		Year							
		2008		2009		2010		2011	
Hosp	Time Delay	EMR	Paper	EMR	Paper	EMR	Paper	EMR	Paper
E	<1 Hr n=	.	0.53% 82	0.49% 68	0.75% 20	0.24% 37	0.29% 10	0.27% 48	0.56% 13
								χ^2=5.69, p< .05	
	<24Hrs n=	.	37.17% 5802	38.92% 5367	11.94% 320	37.29% 5661	19.56% 680	37.40% 6573	9.82% 228
								χ^2=3987.71, p< .001	
	Repeat Tests		15609	13790	2679	15181	3476	17577	2322
	Total Tests		22911	18256	4445	19640	4954	21984	3698
F	<1 Hr n=	.	0.50% 63	0.33% 37	0.31% 8	0.26% 28	0.25% 7	0.22% 25	0.25% 6
								χ^2=0.16, *n.s.*	
	<24Hrs n=	.	35.99% 4530	36.13% 4102	8.50% 216	31.90% 3382	7.82% 220	30.91% 3568	11.64% 281
								χ^2=1734.58, p< .001	
	Repeat Tests		12586	11353	2542	10601	2815	11543	2415
	Total Tests		18949	15207	3888	14474	3946	15322	3267
Overall	<1 Hr n=	.	0.57% 260	0.40% 112	0.63% 135	0.31% 133	0.56% 49	0.25% 117	0.69% 54
								χ^2=40.95, p< .001	
	<24Hrs n=	.	36.71% 16813	36.96% 10221	28.59% 6098	34.82% 14943	14.54% 1278	34.04% 15805	11.68% 918
								χ^2=8534.37, p< .001	
	Repeat Tests		45795	27657	21331	42912	8790	46434	7859
	Total Tests		69979	37569	32055	58298	13197	61465	12215

Chi-square (χ^2) tests of independence; *n.s.*: Not Significant

Table 14. A comparison, between hospitals and between years, of the proportion and volume of paper- and electronically-ordered (EMR) and repeat EUC tests (in the clinical chemistry department) whose specimens arrived in the CSR within 1- and 24-hours of the previous EUC test, for the same patient.

SECTION VI: TURNAROUND TIMES

Introduction

The measurement of test turnaround times (TATs) involves consideration of multiple sequential steps that make up the pathology test process.[42] The start time for TAT calculation can be defined at a variety of time points including the time a pathology test is ordered by the authorised clinician, the time a specimen is collected, received at the CSR of the pathology service, when the laboratory test process was undertaken, right through to the time a result was issued or a clinician accessed the result.[8] TAT provides one measure of the effectiveness of a laboratory, provided it is linked to clinical need, and is often used as a key indicator of laboratory performance.[43 44] TAT has the potential to affect the length of stay in wards and the ED, where delays in obtaining pathology test results may delay diagnosis, treatment and the transfer or discharge of the patient from ED.[45-47]

Methods

TAT analysis for this section utilised the linked and verified dataset as described in Section V. This enabled examination of the following two measures:

- the data entry phase undertaken within CSR measured from the time a specimen is received in the CSR to when the specimen leaves CSR (Data entry time).
- Total Laboratory TAT measured from the time a specimen is received in the CSR to the time a verified result is available (Total Laboratory TAT).

Data were extracted from the LIS for all six study hospitals for the months August and September for each of the years from 2008 to 2011. The tests selected were limited to high-volume tests (EUC [electrolytes, urea, creatinine] in the clinical chemistry department and Automated Differential [including full blood count] in the haematology department).

Results

Our analyses showed that the median data entry time for all hospitals combined was three minutes faster for electronic than for paper orders for each year; a significant difference. This significant difference was consistent for both tests (EUC and Automated Differential) across 2010 and 2011 (see Tables 15a and 15b). This faster data entry time translated into significantly lower median Total Laboratory TATs for

electronic orders than for paper orders (for EUC tests the difference in medians was 12 minutes in 2010 and six minutes in 2011; for Automated Differential tests, the difference in medians was four minutes in 2010 and two minutes in 2011). In January 2011, the chemistry analyser in the clinical chemistry department servicing Hospitals A, B, and C, was replaced with an instrument with a longer analytical cycle time. This was the reason for an increased Total Laboratory TAT in 2011.

Clinical chemistry			2008		2009		2010		2011	
Hosp	**EUC**		**EMR**	**Paper**	**EMR**	**Paper**	**EMR**	**Paper**	**EMR**	**Paper**
A	**Median TAT (mins)**	**Data Entry**	.	14	.	9	5	8	5	8
							z=25.56, *p*<.001		*z*=17.77, *p*<.001	
		Total Lab	.	42	.	47	43	56	58	64
							z=20.53, *p*<.001		*z*=15.72, *p*<.001	
	Test Count		.	20325	.	19757	16926	3058	17252	3616
B	**Median TAT (mins)**	**Data Entry**	.	12	.	9	6	8	5	6
							z=7.36, *p*<.001		*z*=2.88, *p*<.01	
		Total Lab	.	42	.	49	44	51	61	65
							z=5.39, *p*<.001		*z*=3.38, *p*<.01	
	Test Count		.	2152	.	2205	1486	504	1435	481
C	**Median TAT (mins)**	**Data Entry**	.	10	.	9	5	8	5	8
							z=12.13, *p*<.001		*z*=12.76, *p*<.001	
		Total Lab	.	40	.	51	43	59	64	70
							z=12.51, *p*<.001		*z*=6.02, *p*<.001	
	Test Count		.	4953	.	5142	4475	663	3886	714
D	**Median TAT (mins)**	**Data Entry**	.	1	10	12	6	8	4	9
					z=4.06, *p*<.001		*z*=4.03, *p*<.001		*z*=12.64, *p*<.001	
		Total Lab	.	52	66	74	68	74	59	70
					z=5.10, *p*<.001		*z*=3.38, *p*<.01		*z*=10.13, *p*<.001	
	Test Count		.	5160	4560	357	4880	321	5134	646
E	**Median TAT (mins)**	**Data Entry**	.	10	10	15	10	15	7	13
					z=20.22, *p*<.001		*z*=25.70, *p*<.001		*z*=27.04, *p*<.001	
		Total Lab	.	50	52	58	79	89	67	81
					z=16.38, *p*<.001		*z*=14.33, *p*<.001		*z*=22.60, *p*<.001	
	Test Count		.	24266	19459	4482	20798	5071	23179	3747
F	**Median TAT (mins)**	**Data Entry**	.	12	14	12	9	9	6	7
					z=0.48, *n.s.*		*z*=0.56, *n.s.*		*z*=7.47, *p*<.001	
		Total Lab	.	65	65	72	87	88	61	65
					z=16.69, *p*<.001		*z*=3.95, *p*<.001		*z*=12.43, *p*<.001	
	Test Count		.	19517	15776	3950	15503	4017	16418	3345
Overall	**Median TAT (mins)**	**Data Entry**					7	10	6	9
							z=35.16, *p*<.001		*z*=33.56, *p*<.001	
		Total Lab					66	78	62	68
							z=29.67, *p*<.001		*z*=30.45, *p*<.001	
	Test Count						64068	13634	67304	12549

Mann-Whitney U tests of significance; *n.s.*: Not Significant

Table 15a. A comparison, between electronic-orders (EMR) and paper-orders, for EUC in the clinical chemistry department, of the median test TATs for the pre-analytic data entry phase and the laboratory test process from the time a specimen was received in CSR until a result was available.

Haematology			2008		2009		2010		2011	
Hosp	**Automated Diff**		**EMR**	**Paper**	**EMR**	**Paper**	**EMR**	**Paper**	**EMR**	**Paper**
A	**Median TAT (mins)**	**Data Entry**	.	14	.	9	5	9	5	8
							z=28.69, *p*<.001		*z*=20.29, *p*<.001	
		Total Lab	.	45	.	33	28	32	29	30
							z=11.34, *p*<.001		*z*=5.77, *p*<.001	
	Test Count		.	19561	.	19121	15836	3160	16237	3771
B	**Median TAT (mins)**	**Data Entry**	.	16	.	9	6	7	6	8
							z=7.28, *p*<.001		*z*=7.45, *p*<.001	
		Total Lab	.	51	.	35	32	32	30	31
							z=0.04, *n.s.*		*z*=2.57, *p*<.05	
	Test Count		.	3087	.	2996	1642	1333	1647	1376
C	**Median TAT (mins)**	**Data Entry**	.	12	.	9	5	9	4	9
							z=17.46, *p*<.001		*z*=15.81, *p*<.001	
		Total Lab	.	46	.	36	33	33	32	32
							z=0.70, *n.s.*		*z*=0.81, *n.s.*	
	Test Count		.	3963	.	3809	3378	636	3056	751
D	**Median TAT (mins)**	**Data Entry**	.	1	10	12	6	7	4	9
					z=3.80, *p*<.001		*z=4.42*, *p*<.001		*z*=12.35, *p*<.001	
		Total Lab	.	29	42	47	43	50	26	33
					z=3.60, *p*<.001		*z*=3.01, *p*<.01		*z*=6.30, *p*<.001	
	Test Count		.	4979	4419	346	4744	329	5231	688
E	**Median TAT (mins)**	**Data Entry**	.	10	10	15	10	15	7	13
					z=21.06, *p*<.001		*z*=25.55, *p*<.001		*z*=26.59, *p*<.001	
		Total Lab	.	45	43	47	38	44	37	44
					z=10.19, *p*<.001		*z*=18.54, *p*<.001		*z*=18.27, *p*<.001	
	Test Count		.	22367	17305	4791	19490	5453	21473	4373
F	**Median TAT (mins)**	**Data Entry**	.	12	13	12	9	8	6	6
					z=2.41, *p*<.05		*z*=0.21, *n.s.*		*z*=5.56, *p*<.001	
		Total Lab	.	74	71	73	78	78	58	64
					z=1.57, *n.s.*		*z*=0.06, *n.s.*		*z*=2.57, *p*<.05	
	Test Count		.	20139	15838	4662	15811	4417	16717	3733
Overall	**Median TAT (mins)**	**Data Entry**					7	10	6	9
							z=34.41, *p*<.001		*z*=35.35, *p*<.001	
		Total Lab					40	44	36	38
							z=12.79, *p*<.001		*z*=11.70, *p*<.001	
	Test Count						60901	15328	64361	14692

Mann-Whitney U tests of significance; *n.s.*: Not Significant

Table 15b. A comparison, between electronic-orders (EMR) and paper-orders, for Automated Differential in haematology, of the median test TATs for the pre-analytic data entry phase, and the laboratory test process from the time a specimen was received in CSR until a result was available.

SECTION VII: PATIENT OUTCOME – EMERGENCY DEPARTMENT (ED) LENGTH OF STAY

Aims

This analysis examined the relationships between the performance of the pathology service (e.g., number of pathology departments involved, number of tests, test turnaround time and whether test orders were paper or electronic) and patient length of stay in emergency departments (ED LOS).

Data background

As described earlier (see Section V), pathology test order data from the LIS were linked with ED admission, discharge, and triage data (from the EDIS) for patients who presented at an ED during the period August-September of 2008 to 2011. Four adult hospitals with EDs were included. The linked ED pathology dataset, contained information for 397,639 tests ordered for 55,933 patients (with 67,246 patient presentations) who had at least one pathology test ordered during their stay in the ED.

Data inclusion criteria

In the linked dataset, 57% of ED presentations involved a single pathology test order episode; 43% of ED presentations involved multiple test order episodes (up to 17 test order episodes). There was a median of seven tests in each test order episode (inter-quartile range: 5 to 10 tests). Sometimes, a subsequent test order episode occurred before all the results of a preceding test order episode were available to clinicians. In addition, tests from a single test order episode were often processed in different departments of the pathology service and therefore test results become available at different times. These issues had the potential to confound statistical analyses.

In order to simplify the data analysis, we included only presentations with a single pathology test order episode (57% of ED presentations); and utilised the maximum test TAT before patient discharge (i.e., the test TAT for the slowest test result that was available before the patient was discharged from the ED).

There were 31,214 presentations, for 28,191 patients, which met the criteria stated above (presentations that had only one test order episode, had a valid laboratory test TAT, and presented at the ED of one of the hospital sites).

Comparison of ED LOS between this study dataset and Bureau of Health Information ED Quarterly report (July-Sep 2011)

The Bureau of Health Information (BHI) published a report on the performance of emergency departments across NSW for the July-September quarter of 2011.[48] As shown in Figure 2, the distribution of patients across triage categories in the BHI report was significantly different to the distribution of patients across triage categories in this study dataset (i.e., presentations with only one test order episode; χ^2=5295, df=4, p<0.0001). More presentations were triaged as potentially life threatening (triage category=3) in this dataset (47%) than that in the BHI dataset (32%) and fewer presentations were triaged as less urgent (triage category=5) in this dataset (2%) than those in the BHI dataset (14%). A potential explanation for this difference is that this study dataset analysis only included those ED patients who had pathology tests during their stay. Additionally, patients who did not have any pathology tests might be more likely to be triaged into the "Less urgent (5)" category and, therefore, be excluded from this study dataset.

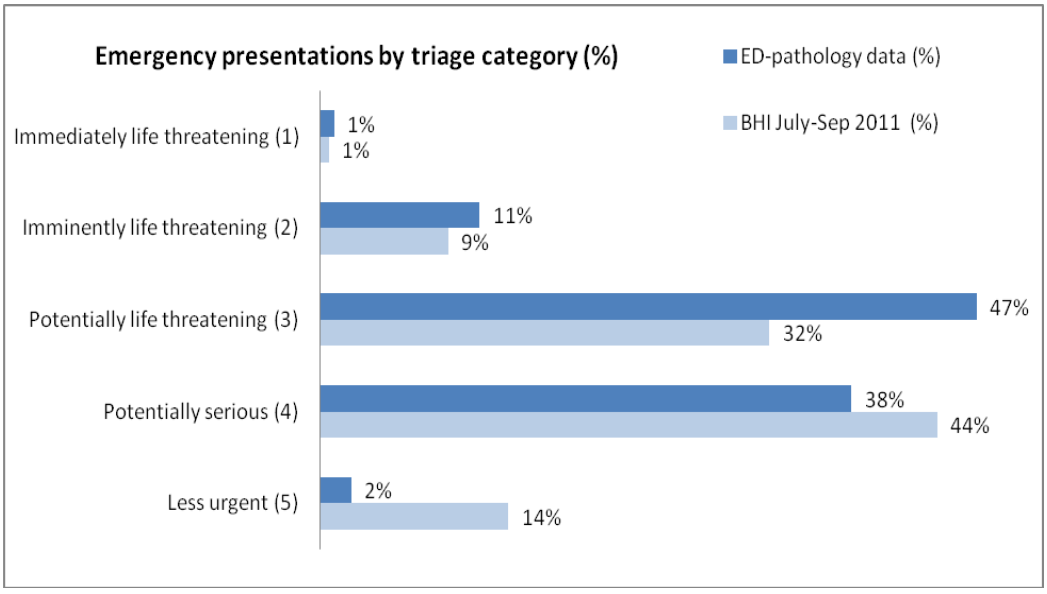


Figure 2. Comparison between this study dataset and the data reported by BHI of the proportion of ED presentations accounted for by each triage category.

The median ED LOS for all emergency and non-emergency presentations with recorded discharge time at the EDs across all NSW hospitals, as shown in the BHI report, was 7 hours and 3 minutes. The median ED LOS for the same categories of ED presentations

in this study dataset was 6 hours and 37 minutes. Potential reasons for this difference include:

1) LOS in our analysis was calculated from the available triage time to discharge time, not from the patients' actual arrival time (a systematically longer time);
2) Our analysis excluded ED presentations with more than one test order episode, which would seem more likely to have a longer LOS than presentations with only one test order episode.

Methods

Multilevel linear regression modelling was applied to identify the factors affecting ED LOS taking into account the correlation between patients' presentations at the same hospital in the same calendar year. Our analysis examined the available data on ED patients' demographics (i.e., age and gender) and information related to ED presentation characteristics (i.e., triage category, and ED mode of separation). Data extracted from the LIS provided pathology test information related to ED presentations, such as number of tests, number of pathology departments involved, order type (paper, EMR, or both), and laboratory TAT. The distribution of ED length of stay was found to be skewed and, therefore, a logarithmic transformation was applied. Model building was performed using StataCorp Stata version 12 software.[49] The following data include only ED presentations that met the inclusion criteria described above.

Results

There was a greater proportion of female patients in the dataset than males (47.1% males, χ^2=95, df=1, p<0.0001). This pattern was consistent across each of the four hospitals (χ^2=4.1, df=3, p=.25). The median age of patients at the first presentation (in cases where multiple presentations occurred within the analysis period) was 51 years (IQR: 31-72).

ED length of stay (ED LOS)

The median LOS was 5 hours and 35 minutes (IQR: 3 hours and 39 minutes to 7 hours and 51 minutes). Overall, 74.53% of the presentations had a stay longer than 4-hours (95% CI 74.05% to 75.02%). The duration of the 95th percentile ED LOS was 878 minutes (14 hours and 38 minutes). Among the four hospitals, the median ED LOS was consistently the shortest at Hospital A and, with the exception of 2008, consistently the longest at Hospital F (Table 16).

Year	Hospital	Number of ED presentations meeting criteria	Median LOS (minutes)	Median TAT (minutes)	Median number of tests
2008	A	1932	308	49	4
	D	1116	351	68	6
	E	2612	326	51	5
	F	2199	349	68	5
2009	A	2105	296	48	4
	D	1095	367	72	6
	E	2406	312	48	4
	F	2040	385	69	5
2010	A	2208	323	46	4
	D	1166	355	72	6
	E	2472	349	63	4
	F	1981	367	77	5
2011	A	2140	301	53	4
	D	1255	332	53	5
	E	2473	325	55	4
	F	2014	382	66	5

Table 16. Median LOS, TAT, and number of tests by hospital and year.

Pathology testing characteristics

Maximum test TAT before discharge

The median maximum test TAT before discharge from ED was 58 minutes (IQR: 40-88 minutes). The duration of the 95th percentile maximum test TAT was 3 hours and 40 minutes. There was a moderate positive correlation between maximum TAT and LOS (ρ=0.42; 95% CI: 0.39-0.41). The median TAT at Hospital A was the shortest and at Hospital F it was the longest among four hospitals (see Table 16). This was the same pattern observed for LOS.

Number of tests

Half the presentations involved a minimum of four pathology tests (IQR: 3-6 tests). The number of tests varied more between the calendar years for Hospitals D and E than Hospitals A and F (Table 16). There was a weak positive correlation between the number of tests in a test order episode and ED LOS (ρ=0.14; 95% CI: 0.12-0.15).

Number of pathology departments involved

Of the presentations meeting the inclusion criteria, 77.52% included tests from two pathology departments, most often clinical chemistry and haematology. The results in Table 17 suggest that, as more pathology departments were involved in fulfilling the test order, both the maximum test TAT and the ED LOS were longer.

Number of labs	Number of test order episodes	Median TAT (minutes)	Median LOS (minutes)
1	1857	43	280
2	24197	56	335
3	4760	77	360
4	381	84	379
5	17	91	409
6	2	104	548

Table 17. The number of test order episodes which involved one through six different pathology departments, and the associated median TAT and LOS.

Test order type

EMR was implemented through 2008 and 2009, and became available at Hospital A in 2010, while at Hospitals D, E, and F it was also available for the 2009 period. Each test order episode could be created exclusively using the paper system, exclusively using the EMR system, or using a combination of the two systems. After the implementation of EMR was complete at all hospital EDs, (i.e., 2010), around 74% (in 2010) to 76% (in 2011) of test order episodes were created using EMR; around 2% (in both 2010 and 2011) used only the paper system; and 22% (in 2011) to 24% (in 2010) used a combination of both EMR and paper systems (Figure 3).

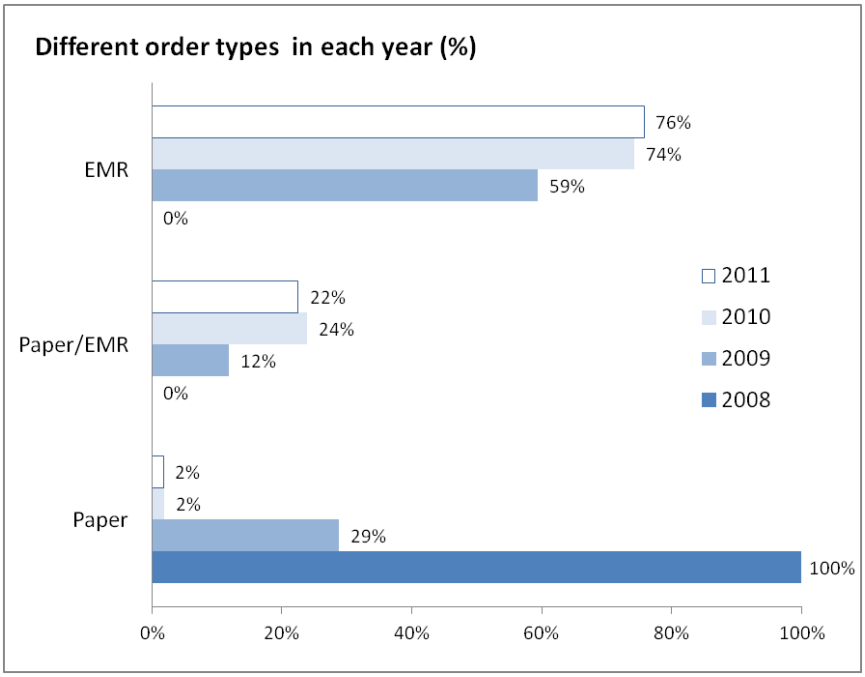


Figure 3. Percentage of test order episodes of each order type across the study period.

Across all hospital EDs the median TAT and ED LOS were longest for presentations where the test order episode was created using both the paper and EMR systems compared to presentations where the test order episode was created using the paper or EMR system exclusively (Table 18).

Hospital	Order Type	Number of ED presentations meeting criteria	Median TAT (minutes)	Median LOS (minutes)
A	**Paper**	4080	48	302
	Paper/EMR	960	83	354
	EMR	3345	47	301
D	**Paper**	1159	68	353
	Paper/EMR	798	101	384
	EMR	2675	59	335
E	**Paper**	2818	50	323
	Paper/EMR	1388	82	378
	EMR	5757	52	319
F	**Paper**	2289	69	351
	Paper/EMR	1400	105	429
	EMR	4545	65	363

Table 18. Median LOS and TAT by hospital and order type.

ED presentation characteristics

Triage category

More than 85% of presentations were triaged as potentially life threatening or potentially serious (categories 3 and 4, respectively). Figure 4 shows that the distribution of patient volume between triage categories was not uniform across the four hospitals (χ^2=815, df=12, p<0.0001).

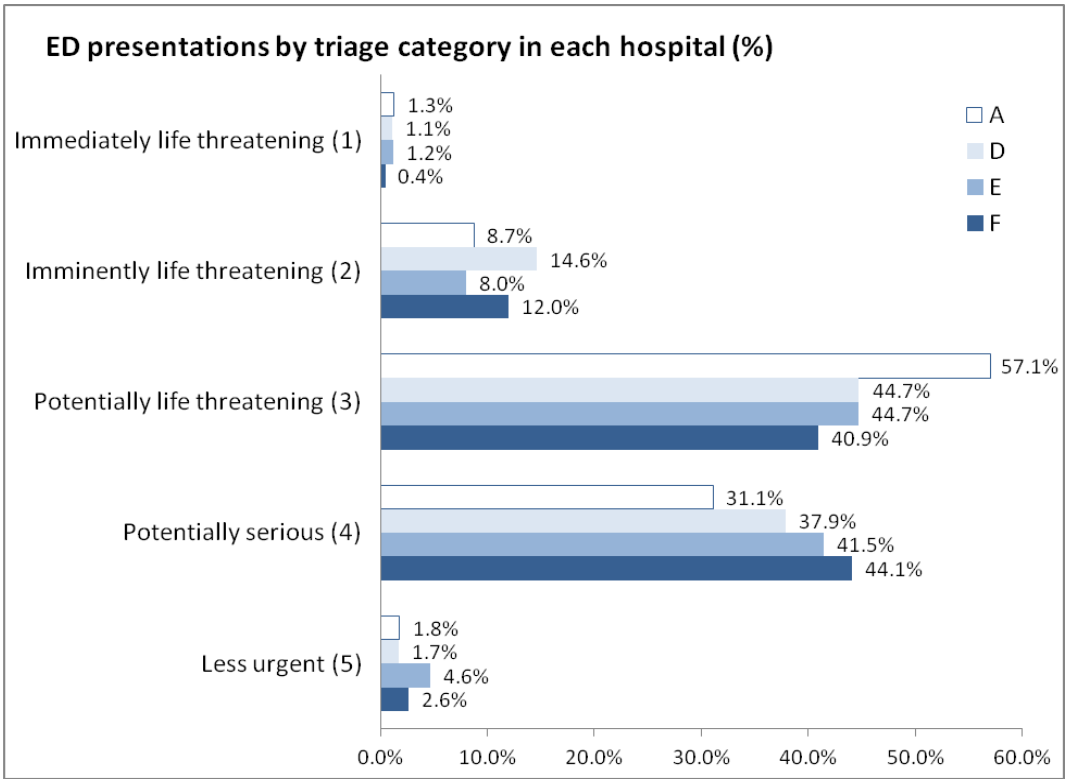


Figure 4. Percentage of ED presentations by triage category in each hospital.

The median test TAT and ED LOS were shorter for presentations with the triage category of immediately life threatening (category 1) than for presentations in the other four triage categories (Table 19).

Triage	Number of ED presentations meeting criteria	Median TAT (IQR) (minutes)	Median LOS (IQR) (minutes)
Immediately life threatening (1)	309	54 (36, 77)	271 (175, 418)
Imminently life threatening (2)	3541	60 (43, 89)	293 (209, 410)
Potentially life threatening (3)	14682	58 (40, 89)	335 (240, 471)
Potentially serious (4)	11928	56 (39, 86)	353 (250, 490)
Less urgent (5)	754	53 (36, 82)	317 (220, 452)

Table 19. Median LOS and TAT by triage category.

Mode of separation

Of the presentations meeting the inclusion criteria, 41.70% had their treatment completed within the ED and were discharged to home, and 56.17% of patients were eventually admitted or transferred to another ward or hospital (Table 20). The median TATs of the different modes of separation varied from 49 to 65 minutes and the median LOS ranged from 246 to 395 minutes (Table 20). Both median TAT and median LOS were longer for patients who were admitted and discharged as an inpatient within ED than for patients with another mode of separation.

ED mode of separation	Number of ED presentations meeting criteria	Median TAT (minutes)	Median LOS (minutes)
Admitted/transferred to another ward/hospital	17534	62	395
Admitted: Died in ED	40	65	302
Departed: Treatment Completed	13015	54	282
Left at own risk	625	49	246

Table 20. Median LOS and TAT by ED mode of separation.

The relationship between ED LOS and the pathology service

Table 21 shows the factors which make significant contributions to the changes of ED LOS with consideration of the correlation between presentations at the same hospital in the same calendar year. The model accounts for 24% of the variation in ED LOS. The inclusion of TAT and the number of tests ordered in the model explains more than 10% of the variation in ED LOS.

Table 21 shows that, everything else being equal, every 60 minute increase in maximum test turnaround time was, on average, associated with a 9.84% increase in ED LOS (95% CI: 9.49% to 10.19%; $p<.0001$). This constitutes strong evidence that the pathology test turnaround time affects patients' length of stay within the ED when controlling for patient age, triage category, number of tests conducted during the ED stay and ED mode of separation and taking into account the correlation between presentations at the same hospital in the same calendar year. Another important factor related to the pathology testing revealed by this analysis is the number of tests ordered for each presentation. Each additional five tests ordered within a presentation was, on average, associated with a 2.84% increase in ED LOS after adjustment for the other factors in the model, a small but significant effect (95% CI: 1.68% to 4.29%; $p<.0001$).

Variables		**% change[#]^ (95% CI)**	***p*-value**
Age (for each additional 5 years)		1.14(1.03, 1.25)	<.0001
Triage category	**Immediately life threatening (1)**	1.00	
	Imminently life threatening (2)	11.30(5.73, 16.87)	<.0001
	Potentially life threatening (3)	33.84(27.49, 40.19)	<.0001
	Potentially serious (4)	32.99(27.57, 38.41)	<.0001
	Less urgent (5)	40.70(35.25, 46.15)	<.0001
TAT (Max, for each additional 60 minutes)		9.84(9.49, 10.19)	<.0001
# of tests (for each additional 5 tests)		2.84(1.54, 4.15)	<.0001
Mode of separation	**Admitted/transferred to another ward/hospital**	1.00	
	Admitted: Died in ED	-1.23(-16.12, 13.67)	0.87
	Departed: Treatment completed	-30.90(-32.04, -29.77)	<.0001
	Left at own risk	-43.26(-47.04, -39.49)	<.0001
^The percent change in the LOS for one defined unit increase in the independent variable while all other variables in the model are held constant			

Table 21. The relationship between ED LOS and TAT: model results.

The model helps us understand of the contribution of pathology testing, TAT and the number of tests in particular, to ED LOS. However, a large proportion of variation in ED LOS is not accounted for by the model and more information, such as patients' condition, treatment received, and clinical staffing levels, would greatly assist further investigation of this issue.

SECTION VIII: BENEFITS REALISATION FRAMEWORK

This project has delivered a large body of empirical findings assessing the impact of the EMR on key performance dimensions of the pathology ordering process including: a) the quality of the test ordering process e.g., labelling, patient and specimen identification; b) the effectiveness of the orders (test volumes, DRG casemix, add-on testing and repeat test rates; c) the impact on laboratory processes as measured by turnaround times; and d) patient outcomes – the impact on length of stay within the ED.

Laboratory test order errors

Our retrospective audit of the error log compared the number and frequency of errors logged during the first half of 2009 (when it was a paper based system), and the period between 1 March 2010 and 9 October 2011 (when it was a computerised system). There was a major increase in the number and frequency of errors logged in the system when measured as a rate per 1000 test order episodes increasing from 9.66 in 2009 to 12.67 in 2010 and 13.48 in 2011. The great majority of errors responsible for this increase were attributable to new or changed processes associated with the introduction of EMR, which included errors categorised as "Other," "No specimen received," "Test set" and "EMR test order problem." Closer analysis of the "EMR test order problem" errors revealed that 66.72% of cases were related to an alteration made on a print-out of an electronic test order where a new test order should have been created. Other reasons included the presence of duplicate forms, add-on tests, or an incorrect EMR order.

A cross-sectional analysis of the error log data comparing paper test orders with EMR test orders across the three years found that the rate of errors recorded in the IIMS (for the categories "Mislabelled specimen", "Mismatched specimen" and "Unlabelled specimen") were significantly fewer for EMR orders than for paper orders. The findings across categories related to efficiency and effectiveness (e.g., "Accident to specimen; "Insufficient specimen" and "Patient detail problem") were variable. Process maps were utilised to identify the source of errors recorded as "EMR test order problem" and to help quantify their impact on laboratory processes. Our analysis showed that the median turnaround time (from receipt at the CSR to test result) of test orders with an "EMR test order problem" was 181 minutes (3 hours) longer than the equivalent median for all test order episodes.

Effectiveness of the test order process

We undertook a series of analyses at each of the six hospital sites to compare test volumes. Our findings showed that when comparing the periods before and after the implementation of EMR, the mean number of tests ordered in each test order episode decreased significantly at all hospitals. The overall rate across all hospitals fell from 4.63 in 2008 to 4.36 in 2011 ($p<.001$). When test numbers were analysed according to the number of tests per patient admission they were found to be higher in 2011 compared to 2008 for some hospitals (e.g., A and E) but lower in other hospitals (e.g., C and D). However, the mean length of stay for admitted patients was consistently shorter in 2011 than 2008.

Our comparison of the number of tests undertaken per admission and grouped into DRG categories provided examples such as A06B (Tracheostomy w/ventilation >95hrs) where the mean number of tests per admission fell from 181.10 in 2008 to 156.77 in 2011, but where the corresponding mean length of stay rose from 646 hours to 696 hours. Alternatively, for E62A (Respiratory infections) the numbers increased from 40.60 to 42.81 for mean number of tests and decreased from 305 to 289 hours for mean length of stay. Our analysis of the test ordering profiles for the DRG of F74Z (Chest pain) at four hospital EDs highlighted some common test ordering patterns (e.g., Troponin, EUC, and Automated Differential tests were consistently the most frequently ordered tests) but also revealed some major differences between hospitals and for the period before and after the introduction of EMR. The mean number of C-Reactive protein tests per ED presentation varied both between hospitals and between years. At three of the EDs the mean number of C-Reactive protein tests per ED presentation was higher in 2011 than in 2008 (Hospital ED "A": from a mean of 0.02 C-Reactive protein tests per ED presentation, in 2008, to a mean of 0.08 tests per presentation; Hospital ED "D": from a mean of 0.24 tests to 0.31 tests; and Hospital ED "F": from a mean of 0.13 tests to 0.21 tests), while the opposite was true for the ED at Hospital ED "E" (from a mean of 0.11 tests to 0.06 tests).

The introduction of EMR across all the hospitals made it possible to compare add-on testing rates both between hospitals and between pathology departments. Our analysis showed that there was variation between hospitals that ranged from 0.61% in Hospital B (specialist hospital) to 2.24% in Hospital F (metropolitan hospital). Clinical chemistry and haematology were the pathology departments that accounted for the

highest volume of add-on tests; in those departments, add-on tests accounted for 2.56%, and 0.69%, respectively, of all ordered tests.

Assessing the appropriateness of test ordering is a complex process. The National Coalition of Public Pathology describes appropriateness as a multifaceted concept which requires consideration of a number of factors usually unique to every individual context.[38] Generally, test inappropriateness is assumed to be synonymous with "overuse" and occurs when a test has been ordered without a clinical indication or within a time frame which provides no additional information and therefore provides no value in the diagnosis or treatment of the patient.[50 51] These situations are determined by expert consensus based on evidence-based guidelines.[38] In this project, we compared the rate of paper and EMR-ordered EUC tests which were ordered within 1-hour and 24-hours of the previous EUC test. In 2011, the proportion of repeat EUC testing occurring within one hour of the previous EUC test was significantly greater for tests ordered with the paper system than electronically-ordered tests (0.69% and 0.25%, respectively). Conversely, a significantly smaller proportion of paper-ordered tests was ordered within 24 hours than for electronically-ordered tests (11.68% and 34.04%, respectively).

Timeliness of the test ordering process

Turnaround times (TAT) are one of the most frequently used measures of laboratory performance,[43] and often a central criteria of how clinicians judge the quality of a pathology service.[44] TAT partly reflects the efficiency of the laboratory workflow in regard to the use of time but it also includes processes outside the laboratory's control (e.g., analytical cycle time). TAT can be considered by type of test (e.g., EUC), its priority (e.g., urgent or routine) or via different stages of the testing process (e.g., ordering, collection, identification, transportation, preparation, analysis, reporting, interpretation, action).[52] In this project, we incorporated an examination of the data entry time; that is, the time from when a specimen arrives in the CSR to the time that it leaves the CSR, often referred to as the laboratory pre-analytical stage. This provided a means of comparing the impact of EMR (relative to the paper-based status quo) on data entry processes within the CSR. The median data entry time for EMR orders was three minutes shorter than it was for paper-orders. We also examined the Total Laboratory TAT. This measure allowed us to test if any time savings from the data entry process

impacted on a measure of the entire laboratory process; significant differences in the median Total Laboratory TAT were demonstrated.

Patient outcomes – ED length of stay

The impact that improved TATs have on patient outcomes is difficult to establish because of the unique work processes and contextual make up of each healthcare setting.[44] Critical care settings and EDs are areas where shorter TATs may be expected to contribute to the improvement of patient flows and reduction of length of stay.[53] There are studies that have investigated the effect that improved TATs and the volume of tests have on reducing length of stay in the ED which can be expected to affect overcrowding and the quality of patient care.[45 47 54] This project used multilevel linear regression modelling to examine the relationship between TAT and the number of tests and the length of stay in the ED. Our analysis produced a model that accounted for 24% of the variation in ED LOS and indicated that the ED LOS, on average, increased by 9.84% for every 60 minute increase in the test turnaround time (95% CI: 9.5% to 10.2%; $p<0.0001$). After adjusting for patient age, triage category, and number of tests conducted during the ED stay and eventual ED mode of separation, the model provided strong evidence that test turnaround time affects patients' length of stay in the ED.

Performance indicators of the impact of EMR on the quality of pathology services

This research was underpinned by an imperative to carefully monitor the impact that electronic ordering has on the functioning of pathology laboratory services and their contribution to safe and quality patient care.[55] It highlights the importance of using quantitative analyses built upon robust evidence-based performance indicators as a means of encouraging transparency and clarity about what is being achieved and the desired outcome.[56] The comparative empirical findings that emerge from the benefits realisation framework can identify what works best, where, and in what circumstances, as a means of enhancing the implementation and sustainability of electronic ordering systems and maximising their contribution to safe and high quality patient care.

Contribution to evidence-based practice: Evidence-based medicine has meant a shift in the culture of health provision away from decisions based on opinion, past practices and precedent towards a system that better utilises science, research and evidence to guide decision making.[57] For pathology, this has inspired a new emphasis on its role in the whole patient journey beginning with asking the right clinical questions about the

selection of the most appropriate test or investigation to diagnose a problem, to the interpretation and provision of clinical advice, and treatment across the whole spectrum of clinical specialties involved in the patient pathway.[58]

Quality and safety of patient care: The World Health Organization's World Alliance for Patient Safety has highlighted the importance of pathology services to the global patient safety agenda emphasising the role of the laboratory in: i) ensuring reliable and accurate results delivered in a timely fashion; ii) informing clinical management decisions; and iii) the safe administration of blood products and medications.[59] The main sources of laboratory errors arise within the pre-analytic (clinician's test order and CSR) and post-analytic (laboratory report to the clinician) phases of the process. It is in these areas where electronic ordering can have a major positive impact. Electronic decision support functions can assist clinicians to improve the quality of test ordering, for example selecting appropriate tests, accurately specifying all aspects of the test order including relevant clinical information, and indicating clinical urgency. It can also help to promote appropriate test ordering and utilisation that facilitates quality decision making and health benefit for the patient.[9]

Effectiveness of pathology services: There is some evidence, from general practice and acute care settings over the last decade, of the potential for electronic ordering to improve the effectiveness of health care,[60-62] promote compliance with evidence-based guidelines[63] and accentuate the use of evidence to support clinical decision making.[64] However, the utilisation of electronic ordering in Australia and overseas has yet to extend beyond a small number of hospitals and the utilisation of decision support functions has not been extensive.[11] Moreover, the implementation of electronic ordering represents a potential high risk for hospitals[65] that can lead to unexpected outcomes[66] and test ordering errors including the over-utilisation or inappropriate ordering of tests.[67] One of the main gaps within the existing literature is that it often neglects to compare different applications over time in order to identify the features that contribute to their success or otherwise.[11] It also often fails to account for the crucial role that factors like education, feedback and quality improvement can have on the success and sustainability of decision support features.[68 69] This means that there is an insufficient understanding of why a system may be useful and effective in one setting but not another.[70]

The evidence provided by this research has led to a set of indicators that can be used to monitor various aspects of electronic ordering and its effect on the laboratory processes (predominantly the pre-analytical processes). These indicators can be used for comparisons between hospitals, wards etc., to help improve the overall safety of the patient, efficiency in the wards and help improve the quality and value of pathology provided. Tables 22a-22f provide a summary of these indicators which make up the key elements of the Benefits Realisation Framework.

Quality of pathology test orders and specimens	
Definition	Quality pathology testing requires accurate patient and test order information as well as safe collection and transport of all specimens to the pathology service.
Aim	To accurately document the type of pre-analytical errors (e.g., mislabelled specimens, patient detail problems or unmet collection requirements) and to use this information to address the cause of the errors and to improve the quality of pathology provided by the pathology service.
Rationale	Patient safety may be compromised by pre-analytical errors that can occur at any of the many steps that a specimen and test order form take before specimen processing and analysis actually begins.[25 71] Electronic ordering has been introduced with the purpose of improving the quality of information provided to the laboratory thus enhancing the safety of the patient and improving efficiency and effectiveness in the laboratory.
Potential uses	The measurement of errors can be performed as part of an overall assessment between hospitals, between wards or across time. A comprehensive evaluation of errors allows for complex issues to be assessed and provides a valuable quality improvement tool.
Potential confounders	Documentation of errors needs to be part of the routine laboratory procedure. Classification of the various errors is subject to a range of interpretations so clear unambiguous definitions are required.
Data sources	All pathology services are required to collect and report laboratory errors as part of the NATA medical testing accreditation requirements.[72] Computerised error logs provide data in digital form that is generally more amenable to validity and integrity checks and statistical analyses. The manual intervention required to audit a paper error log is associated with the need for a much greater investment of time and resources.

Table 22a. Benefits realisation framework: Quality of pathology test orders and specimens.

Test volumes	
Definition	The total number of tests ordered for a given period measured through a variety of methods e.g., per test order episode, per patient admission, per Diagnosis-related Group (DRG), per patient admission, and per specific test type (e.g., Troponin).
Aim	To compare and monitor test volumes using the metrics described above.
Rationale	Clinical decision support components of electronic ordering have the potential to improve the appropriateness of pathology test ordering. Alternatively, the ease with which an order can be made may also increase the risk of over-ordering pathology tests. The impact of excessive ordering is not just financial; it may lead to an increase in false positives resulting in unnecessary and expensive diagnostic examinations and treatments.[73]
Potential uses	Assessing test volume using a variety of metrics (described above) allows for a comprehensive analysis of test utilisation in the pathology service. For example, assessing test volume per test order episode informs whether changes that make test ordering more accessible (i.e., electronic ordering) are associated with over-ordering; and assessing test volume per patient admission per DRG allows test volume assessments to control for the type, severity, and complexity of the patients' condition.
Potential confounders	Research in this field shows that the volume of test ordering may be affected by a variety of factors including, the type of hospital (i.e., teaching or non-teaching), seniority and position of clinical staff and even by the number of clinicians who see a patient.[74] There is often a direct relationship between patient length of stay and the number of tests per patient admission. Test volume for electronic and paper orders cannot be directly compared because, when both methods of ordering are available, they may be used differently in different clinical contexts (i.e., different wards, or patients of differing diagnostic complexity).
Data sources	Analyses of test volume per test order episode can be conducted using data extracted from a LIS; however, analyses using other metrics (patient admission and DRG categories) will require a LIS dataset that has been linked with admission, discharge, and DRG data extracted from the PAS and EDIS.[75]

Table 22b. Benefits realisation framework: Test volumes.

Add-on test rates	
Definition	Add-on tests are tests performed on an existing specimen previously submitted to the pathology service with an earlier test order.[34 35]
Aim	To assess the volume and distribution of add-on tests.
Rationale	Add-on tests are labour-intensive and interruptive of the workflow in the laboratory. Add-on test utilisation places a disproportionate burden on laboratory resources.[33]
Potential uses	Understanding the utilisation of add-on testing can assist in decisions regarding the allocation of resources and, potentially, changes in the processes used for add-on testing.[39]
Potential confounders	An add-on test rate can be defined in two ways: (1) the number of add-on tests as a proportion of all tests, and (2) the number of add-on test order episodes (that may contain requests for multiple add-on tests) as a proportion of all test order episodes.
Data sources	Data extracted from LIS are sufficient to conduct analyses of add-on test volumes and rates. Analyses are rendered much easier if the LIS supports a binary flag or checkbox to identify add-on tests (rather than free-text).

Table 22c. Benefits realisation framework: Add-on test rates.

Test appropriateness	
Definition	While there are many pathology tests that are conducted repeatedly in order to monitor a condition or treatment, when a repeat test is ordered within a brief time frame there is a high likelihood that it will be redundant and will provide no additional information.[60 76]
Aim	To identify the proportion of repeat tests ordered within different time-frames and compare these proportions for paper- and electronically-ordered repeat tests at each hospital.
Rationale	Electronic ordering systems allow ordering clinicians to see what tests have already been ordered. They can also provide on-screen warnings suggesting that a repeat test order has been made within an inappropriate time frame. Such information may lead clinicians to decide not to order a repeat test that they otherwise would have ordered.
Potential uses	Reduce the rate of inappropriate test orders.
Potential confounders	Inappropriate testing is generally used to refer to the ordering of tests without a clear clinical indication or performed at the wrong time or too frequently to be of value in diagnosis or clinical management in line with evidence-based guidelines and expert consensus.[38]
Data sources	One aspect of test appropriateness can be assessed by looking at the temporal properties of repeat testing. For this type of analysis, data extracted from LIS are sufficient, but the analysis should select specific tests and clinical settings.

Table 22d. Benefits realisation framework: Test appropriateness.

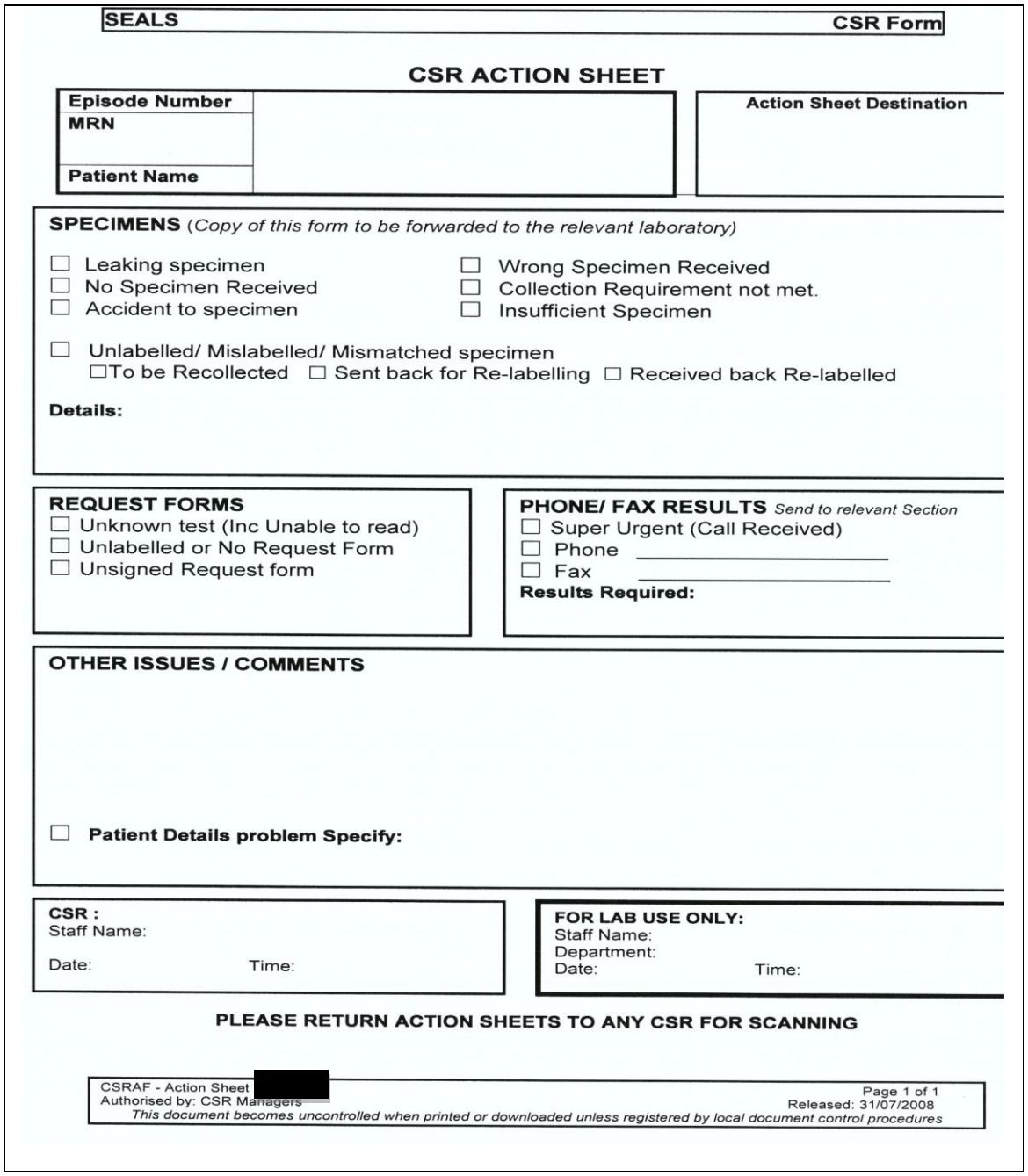
Turnaround Times	
Definition	Laboratory turnaround time (TAT) is the time taken by the laboratory to complete the testing process (from when the specimen arrives in the CSR to when a result is available to the clinician). It is also possible to analyse the data entry time (from receipt of the specimen at CSR to when the specimen is ready to leave CSR for processing and analysis).
Aim	Comparisons between electronic and paper orders of both data entry times and Total Laboratory TAT.
Rationale	Clinical satisfaction with pathology services is related to the timeliness of test results because of its effect on time to patient diagnosis and/or treatment.[77]
Potential uses	Electronic ordering is most likely to directly affect the data entry time but may also have flow-on effects on Total Laboratory TAT.
Potential confounders	TAT can be affected by a number of factors including the type of test being ordered and transportation requirements.
Data sources	Data extracted from LIS should be sufficient for turnaround time analyses.

Table 22e. Benefits realisation framework: Turnaround times.

Impact on patient outcomes (ED length of stay):	
Definition	Length of stay (LOS) represents the amount of time a patient remains in ED from triage to discharge.
Aim	To understand what factors associated with pathology testing play a role in a patient's LOS in the ED.
Rationale	EDs are a high-activity and high-demand component of the hospital.[78] ED LOS is one of the major factors contributing to hospital overcrowding[53] and laboratory TAT is one of the many contributing factors to ED LOS.[79] Shorter stays in the EDs are also indicative of efficient diagnosis and stabilisation of the patient condition and, therefore, of the ED's performance as a whole.[47 80 81]
Potential uses	Quantifying benefits, in patient-experience terms, aids in the resource-allocation strategies in the hospital.
Potential confounders	Many ED visits will involve multiple pathology tests ordered across multiple test order episodes. Each of those tests will influence more-or-less strongly the clinicians' diagnostic decision and treatment; therefore, care should be taken to consider how analyses can utilise the turnaround time of the decision-critical tests.
Data sources	Analyses of the impact of various factors on length of stay in ED will require a LIS dataset that has been linked with admission, discharge, triage, and demographic data extracted from the EDIS.

Table 22f. Benefits realisation framework: Impact on patient outcomes (Length of stay in ED).

Appendix I – CSR error log sheet used for the paper-based documentation of errors (in use until 21 September 2009)



SEALS CSR Form

CSR ACTION SHEET

Episode Number	
MRN	
Patient Name	

Action Sheet Destination

SPECIMENS (*Copy of this form to be forwarded to the relevant laboratory*)

- ☐ Leaking specimen
- ☐ No Specimen Received
- ☐ Accident to specimen
- ☐ Wrong Specimen Received
- ☐ Collection Requirement not met.
- ☐ Insufficient Specimen
- ☐ Unlabelled/ Mislabelled/ Mismatched specimen
  - ☐To be Recollected ☐ Sent back for Re-labelling ☐ Received back Re-labelled

Details:

REQUEST FORMS
- ☐ Unknown test (Inc Unable to read)
- ☐ Unlabelled or No Request Form
- ☐ Unsigned Request form

PHONE/ FAX RESULTS *Send to relevant Section*
- ☐ Super Urgent (Call Received)
- ☐ Phone _____
- ☐ Fax _____

Results Required:

OTHER ISSUES / COMMENTS

☐ **Patient Details problem Specify:**

CSR :
Staff Name:
Date: Time:

FOR LAB USE ONLY:
Staff Name:
Department:
Date: Time:

PLEASE RETURN ACTION SHEETS TO ANY CSR FOR SCANNING

CSRAF - Action Sheet [redacted]
Authorised by: CSR Managers
Page 1 of 1
Released: 31/07/2008
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Appendix II – Daily summary log sheet for paper-based documentation of errors (in use until 21 September 2009)

[redacted] CSR - [redacted] CSR Forms

CSR INCIDENT LOG

Trouble Shooter: _____ Date: _____

Patient Detail (Episode No./MRN/Name)	Patient Location Or Ward/Clinic Specimen Collected in	Raised By (Dept other than CSR)	Problem					Action Taken	Episode Note	initial
			Unlabeled/ Mislabeled Specimen	Leaking Specimen	Missing/ Wrong Specimen Type	Test Set	Others			

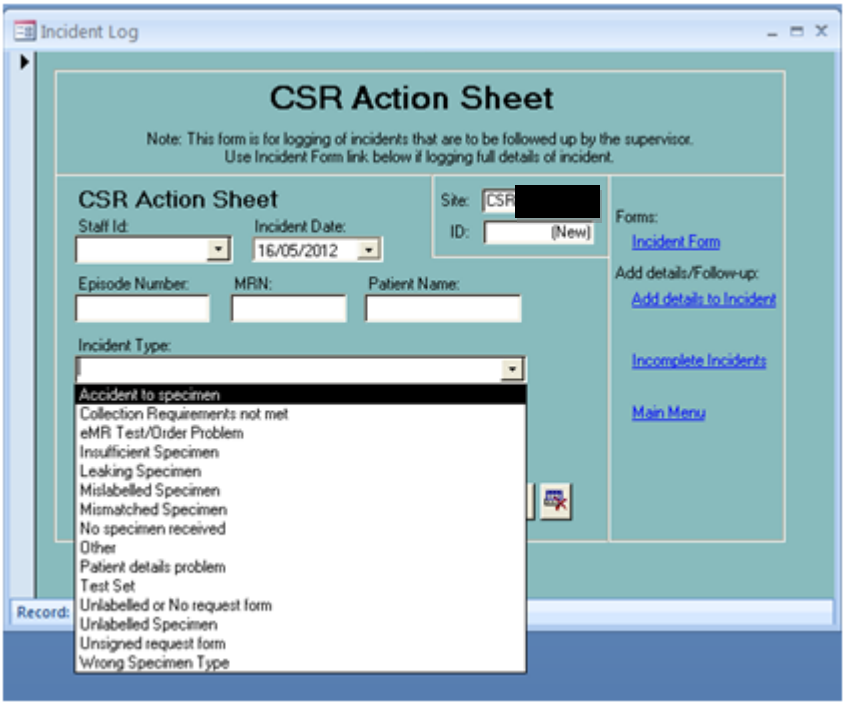
Reviewed by: _____ Date: _____

Comments:

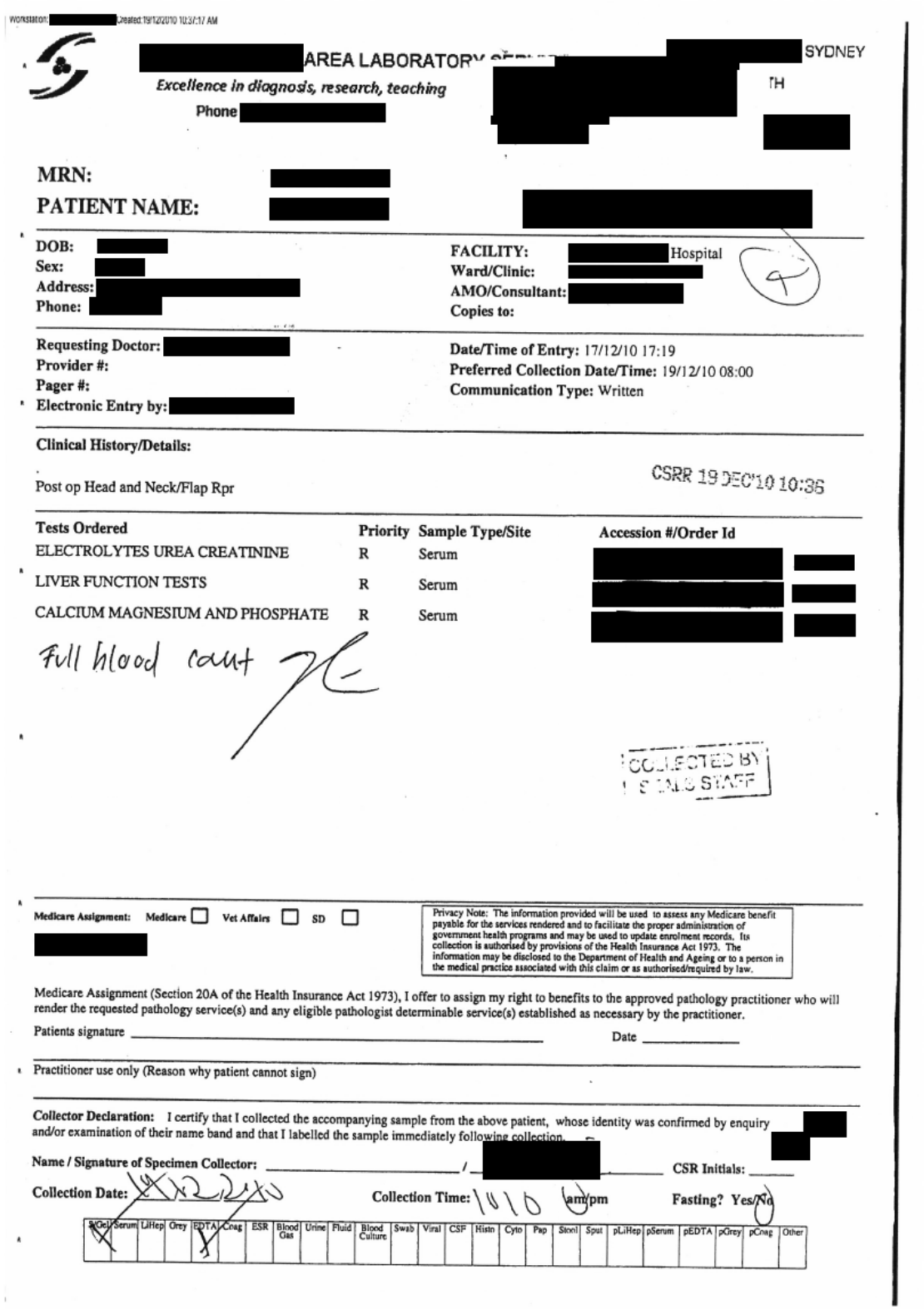
CSRRF - CSR Incident Log - 07
Authorised by: [redacted]

Page 1 of 1
Released : 21/01/2011

Appendix III – Screenshot of the revised computerised error log interface showing the list of possible error categories (in use from 1 March 2010)



Appendix IV– A sample EMR test order form print-out which was manually altered (requesting an additional Full Blood Count test), resulting in an "EMR test order problem" error



Workstation: [redacted] Created: 19/12/2010 10:37:17 AM

[redacted] AREA LABORATORY [redacted] SYDNEY

Excellence in diagnosis, research, teaching

Phone [redacted]

[redacted] TH

[redacted]

MRN: [redacted]

PATIENT NAME: [redacted]

DOB: [redacted]
Sex: [redacted]
Address: [redacted]
Phone: [redacted]

FACILITY: [redacted] Hospital
Ward/Clinic: [redacted]
AMO/Consultant: [redacted]
Copies to:

Requesting Doctor: [redacted]
Provider #:
Pager #:
Electronic Entry by: [redacted]

Date/Time of Entry: 17/12/10 17:19
Preferred Collection Date/Time: 19/12/10 08:00
Communication Type: Written

Clinical History/Details:

Post op Head and Neck/Flap Rpr

CSRR 19 DEC'10 10:36

Tests Ordered	Priority	Sample Type/Site	Accession #/Order Id
ELECTROLYTES UREA CREATININE	R	Serum	[redacted]
LIVER FUNCTION TESTS	R	Serum	[redacted]
CALCIUM MAGNESIUM AND PHOSPHATE	R	Serum	[redacted]

Full blood count

COLLECTED BY [illegible] STAFF

Medicare Assignment: Medicare ☐ Vet Affairs ☐ SD ☐

[redacted]

Privacy Note: The information provided will be used to assess any Medicare benefit payable for the services rendered and to facilitate the proper administration of government health programs and may be used to update enrolment records. Its collection is authorised by provisions of the Health Insurance Act 1973. The information may be disclosed to the Department of Health and Ageing or to a person in the medical practice associated with this claim or as authorised/required by law.

Medicare Assignment (Section 20A of the Health Insurance Act 1973), I offer to assign my right to benefits to the approved pathology practitioner who will render the requested pathology service(s) and any eligible pathologist determinable service(s) established as necessary by the practitioner.

Patients signature _____ Date _____

Practitioner use only (Reason why patient cannot sign)

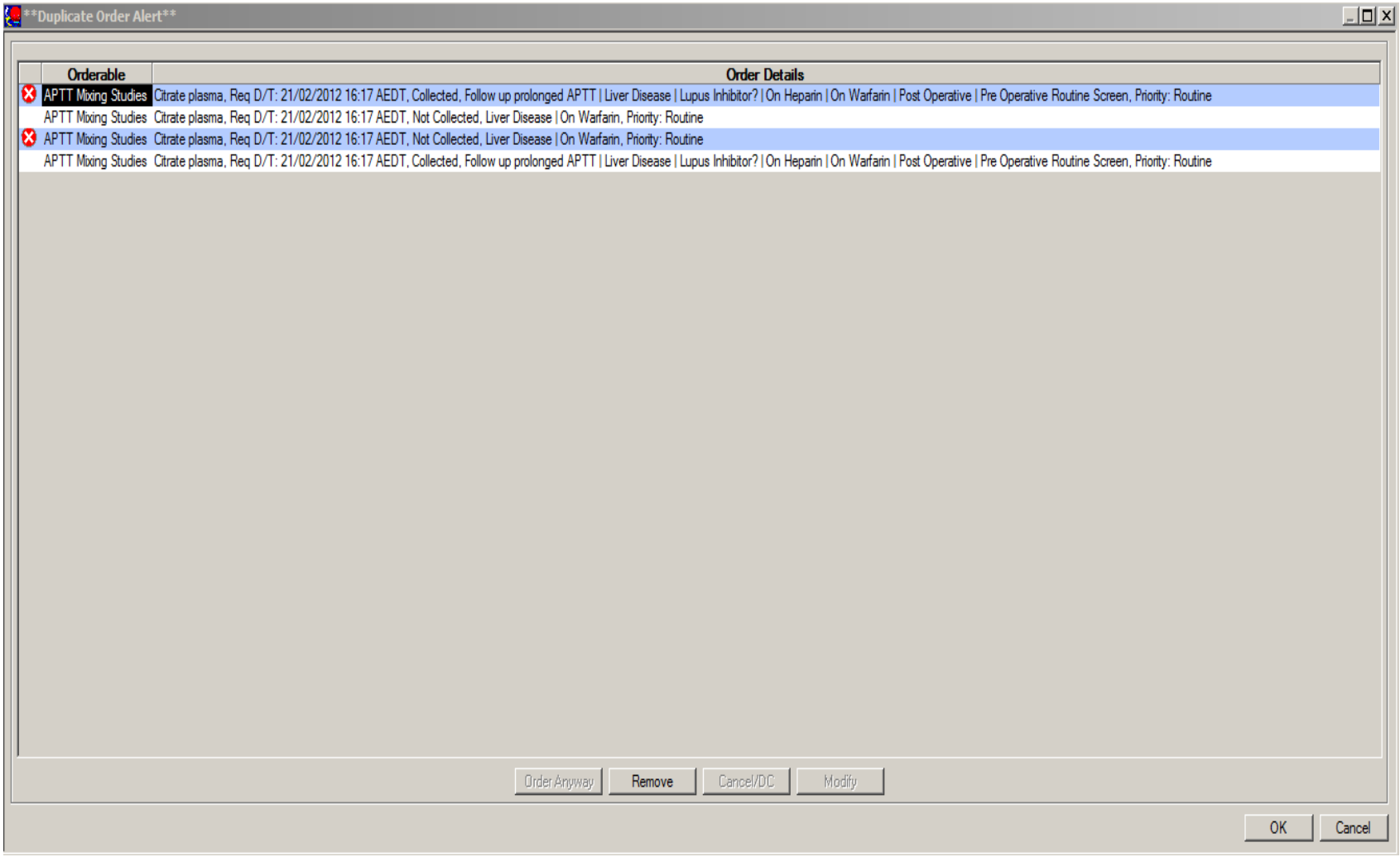
Collector Declaration: I certify that I collected the accompanying sample from the above patient, whose identity was confirmed by enquiry and/or examination of their name band and that I labelled the sample immediately following collection. [redacted]

Name / Signature of Specimen Collector: _____ / [redacted] **CSR Initials:** _____

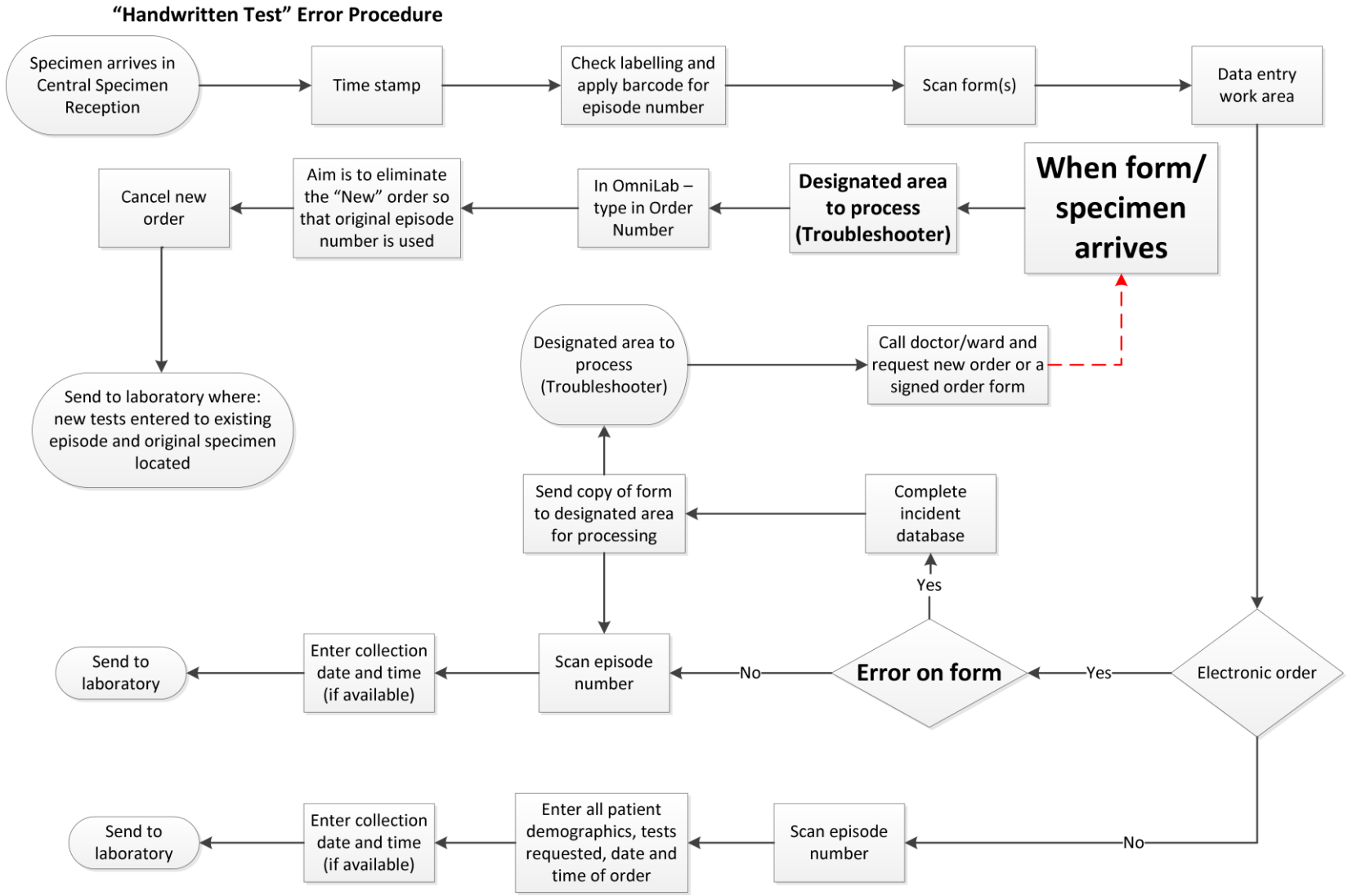
Collection Date: 19/12/2010 **Collection Time:** 1010 am/pm **Fasting? Yes/No**

S/Gel	Serum	LiHep	Grey	EDTA	Coag	ESR	Blood Gas	Urine	Fluid	Blood Culture	Swab	Viral	CSF	Histn	Cyto	Pap	Stool	Sput	pLiHep	pSerum	pEDTA	pGrey	pCoag	Other
X				X																				

Appendix V – Screenshot of a duplicate order alert in the EMR



Appendix VI – Flow diagram for handling of "handwritten request on an EMR order" errors in the CSR



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ISBN 978-0-7334-3194-4