Health Information and Quality Authority

An tÚdarás Um Fhaisnéis agus Cáilíocht Sláinte

Health technology assessment of the use of information technology for early warning and clinical handover systems

10 March 2015

Safer Better Care

About the Health Information and Quality Authority

The Health Information and Quality Authority (HIQA) is the independent Authority established to drive continuous improvement in Ireland's health and personal social care services, monitor the safety and quality of these services and promote person-centred care for the benefit of the public.

The Authority's mandate to date extends across the quality and safety of the public, private (within its social care function) and voluntary sectors. Reporting to the Minister for Health and the Minister for Children and Youth Affairs, the Health Information and Quality Authority has statutory responsibility for:

- **Setting Standards for Health and Social Services** – Developing person-centred standards, based on evidence and best international practice, for those health and social care services in Ireland that by law are required to be regulated by the Authority.
- **Social Services Inspectorate** – Registering and inspecting residential centres for dependent people and inspecting children detention schools, foster care services and child protection services.
- **Monitoring Healthcare Quality and Safety** – Monitoring the quality and safety of health and personal social care services and investigating as necessary serious concerns about the health and welfare of people who use these services.
- **Health Technology Assessment** – Ensuring the best outcome for people who use our health services and best use of resources by evaluating the clinical and cost effectiveness of drugs, equipment, diagnostic techniques and health promotion activities.
- **Health Information** – Advising on the efficient and secure collection and sharing of health information, evaluating information resources and publishing information about the delivery and performance of Ireland's health and social care services.

Foreword

In support of sustainable integration and implementation of National Clinical Effectiveness Committee (NCEC) quality assured National Clinical Guidelines, information technology has the potential to offer innovation in improving quality, safety and standardisation of care for patients. The benefits, risks and costs of such technology are considered in this HTA to assist a coordinated evidence-based approach for integration of information technology into clinical effectiveness processes.

The Health Information and Quality Authority (the Authority) received a request from the Department of Health to conduct a health technology assessment (HTA) of the use of information technology for early warning and clinical handover systems. The Authority conducted a systematic review of the literature to identify and critically appraise the evidence on the use of this information technology to assist with the timely identification of the deteriorating patient. In addition the Authority examined the key determinants of efficient implementation of such systems and the likely associated costs.

Work on the HTA was undertaken by an Evaluation Team from the HTA Directorate of the Authority. A multidisciplinary Expert Advisory Group (EAG) was convened to advise the Authority during the conduct of this assessment. The Authority would like to thank its Evaluation Team, the members of the EAG and all who contributed to the preparation of this report.

Dr Máirín Ryan

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Health Information and Quality Authority

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List of abbreviations used in this report

CBA	Controlled before-and-after study
CI	Confidence interval
DNR	Do Not Resuscitate
ECHOS	Electronic Clinical Handover System
EEWS	Electronic Early Warning System
EHR	Electronic Health Record
EMR	Electronic Medical Record
EPOC	Effective Practice of Care Cochrane Group
EPSS	Electronic Physiological Surveillance System
EWS	Early Warning System
HIQA	Health Information and Quality Authority
HSE	Health Service Executive
ISRCTN	International standard randomised controlled trial number
LOS	Length of stay
NCEC	National Clinical Effectiveness Committee
NRCT	Non-randomised controlled trial
OR	Odds ratio
PICO	Population - Intervention - Comparator - Outcomes
QoL	Quality of life
RCT	Randomised controlled trial
RRT	Rapid response team
SD	Standard Deviation

Acknowledgements

The Authority would like to thank all of the individuals and organisations who provided their time, advice and information in support of this health technology assessment (HTA).

Particular thanks are due to the Expert Advisory Group (EAG) and the individuals within the organisations listed below who provided advice and information.

The membership of the EAG was as follows:

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Ms Mary Tierney	Patient Representative, member of Patients for Patients' Safety Group
Mr Fran Thompson	Head of ICT Services, HSE
Prof Michael Turner	National Clinical Lead, National Clinical Programme for Obstetrics and Gynaecology, HSE

Organisations that assisted the Authority in providing information, in writing or through meetings, included:

Bedside Clinical
NHS Innovations Unit
NerveCentre
Syncho-Phi
The Learning Clinic
UPHS Center for Evidence-based Practice, University of Pennsylvania Health System

Members of the Evaluation Team:

Members of the Authority's Evaluation Team were Dr Patricia Harrington, Dr Mary O'Riordan, Shelley O'Neill, Patrick Moran, Dr Conor Teljeur, Gearóid Harrahill and Dr Máirín Ryan.

Conflicts of Interest

None reported.

Advice to the Minister for Health

This health technology assessment (HTA) examined the clinical and cost-effectiveness of electronic early warning and clinical handover systems. In addition, benefits and investment requirements were estimated and key themes for effective robust implementation were outlined.

Having concluded a systematic review of the clinical and cost-effectiveness literature, the key findings of this HTA which precede and inform the Authority's advice are as follows:

- A range of Information and Communications Technology (ICT) options are available to support detection of the deteriorating patient and to facilitate clinical handover of patients.

- The results of this systematic literature review indicate there is some evidence that the implementation of electronic early warning systems has contributed to reduced mortality rates. Change in general and ICU length of stay (LOS) varied from a minimal reduction up to 28.9% and 40.3% reductions, respectively. Improved efficiency and accuracy of recording vital sign parameters, compliance with escalation protocols and significant user (clinician) satisfaction were also reported. However, as the quality of studies of effectiveness was variable and the interventions performed in a range of healthcare jurisdictions with a variety of outcomes measured, the ability to generalise the findings to the Irish healthcare context may be limited.

- The quality of studies on the clinical effectiveness of electronic clinical handover systems were hampered by poor study design, small sample size and unspecified follow-up. The trend of results showed increased accuracy of recording handover, efficiency gains for staff and positive clinician user perception of improved patient safety due to better handover communication processes. However, a face-to-face element to clinical handover was identified as an important part of patient care.

- Cost-effectiveness data was minimal however; there was some evidence of a positive return on investment with continuous monitoring implementation for one US-based study. Due to the significant difference between US and Irish healthcare provision models, the ability to generalise this return-on-investment to the Irish context is uncertain.

- The benefits estimated are indicative only. The move from paper-based recording of vital sign parameters to an electronic early warning system could mean a potential reduction of general and ICU LOS of as much 28.9% (95%CI 18.6%-40.3%) and 40.3% (95%CI4.6% - 76%), respectively. Such reductions would translate to a potential national hospital capacity gain of 802,096 bed days per annum and 30,628 ICU bed-days per annum. Although indicative estimates only, if these hospital capacity gains were to be even partially realized, it would allow for more efficient utilisation of acute hospital beds, reduced pressure on Emergency Departments, reduced waiting times for elective surgeries and ultimately more appropriate and timely access to acute hospital services.

- Other potential benefits include increased efficiencies gained from reduced vital sign recording time, as much as 1.6 times faster than that of a paper-based system. This means more available clinician time to deliver care to patients. When this efficiency gain is coupled with improved accuracy of recording of vital signs and handover information, the potential gains realised through a safer patient environment are important contributions to be noted.

- However, a significant capital investment is required for these potential gains. Estimated total five year investment requirements for a local 530 bed hospital have been estimated between €1m-1.3m. At a national level, five year investment requirements have been estimated between €40.1m to €51.4m.

- A survey to ascertain current diffusion of this technology in Ireland showed almost no deployment of these systems in publically funded hospitals currently.

- All electronic early warning and clinical handover systems should be developed in line with National Clinical Effectiveness Committee (NCEC) quality assured National Clinical Guidelines. Computer learning algorithms and software driving the system should be developed with due consideration to the clinical parameters that have proven effectiveness. National Clinical Guidelines quality assured by NCEC and published by the Department of Health have been developed for use in healthcare organisations in Ireland only, taking into account specific requirements for the Irish healthcare setting.

- The potential benefit to patients is appropriate escalation of care and improved patient safety. Strong leadership and adequate resources, such as the appropriate level of trained staff to manage the identified deteriorating patient are critical to successful implementation and improvements in patient outcomes. Investment in electronic early warning systems should be linked with a training

programme for assessing and treating the acutely deteriorating patient. To maximise the effectiveness of implementation the employment of human factors analysis would help to create work environments that boost productivity while minimizing risks to patient safety.

- The full potential of the system should be realised by taking advantage of the large amounts of clinical data collected to assist in service planning, audit and governance functions.

- The implementation of ICT to support electronic early warning and clinical handover systems should be considered in the context of a standards based approach, the wider ICT agenda and the eHealth Strategy, for example, timing of implementation may be part of a larger move towards electronic health record systems.

Arising from the findings above, the Authority's advice to the Minister for Health is as follows:

The evidence to support the introduction of electronic early warning and clinical handover systems is of variable quality. Some reduction in mortality and hospital length of stay has been reported. The introduction of electronic early warning and clinical handover systems has been shown to be an efficient, accurate and auditable way of recording patient vital sign parameters.

Implementation will require significant capital investment, but has the potential to improve safety and efficiency of care and increase acute hospital bed capacity.

The potential benefit to patients is appropriate escalation of care and improved patient safety. Outcomes and implementation success are highly dependent on strong leadership, a multidisciplinary approach and linkage to a training programme for assessing and treating the deteriorating patient.

Executive Summary

1. Introduction

1.1 Background

As part of the programme for sustainable integration and support of implementation of the National Clinical Guidelines,[1] information technology has the potential to offer innovation in improving quality, safety and standardisation of care for patients. Following a request from Clincal Effectiveness Unit, Department of Health through the Chief Medical Officer, the Authority agreed to conduct a health technology assessment (HTA) of the use of information technology for early warning score and clinical handover systems. This HTA aims to examine evidence of clinical effectiveness and cost-effectiveness of electronic early warning systems and electronic clinical handover systems to inform decision-making regarding their implementation. This HTA was conducted using the general principles of HTA and employing the processes and practices used by the Authority in such projects.

In summary:

- The Terms of Reference of the HTA were agreed between the Authority and the Department of Health.
- An Expert Advisory Group (EAG) was established. An evaluation team was appointed comprising internal Authority staff.
- A systematic review of the evidence was carried out to summarise the available evidence on the effectiveness, safety, and cost-effectiveness of electronic early warning and clinical handover systems and to identify key determinants to support effective implementation.
- A survey of 32 hospitals was conducted to identify electronic systems currently in use
- A review of manufacturer dossiers and interviews with key stakeholders and industry were performed to identify common emergent themes that support an effective electronic early warning and clinical handover system achieving successful outcomes.
- Based on a systematic review of the available literature on the clinical effectiveness of electronic early warning and clinical handover systems and discussion with manufacturers and international stakeholders, the resource

[1] *National Clinical Guideline No. 1, National Early Warning Score (NEWS), National Clinical Guideline No. 4 Irish Maternity Early Warning System (IMEWS), National Clinical Guideline No. 5 Clinical Handover in Maternity and National Clinical Guideline No. 6 Sepsis Management. For further information see www.health.gov.ie/patient-safety/ncec*

implications and the associated costs of any potentially clinically effective electronic early warning and clinical handover systems were identified.

2. Technology description

There are a number of different types of Information and Communications Technology (ICT) options to consider for detection of the deteriorating patient. The main areas for consideration are:

1. Electronic early warning systems
2. Electronic clinical handover systems
3. Continuous patient monitoring *without* electronic early warning system integration
4. Continuous monitoring *integrated with* electronic early warning systems.
5. Electronic physiological surveillance systems that incorporate more patient and hospital variables than electronic early warning score calculation alone.

While commercial electronic early warning systems may comprise a wide range of features, there are four core elements that are common to all systems including information capture, automated calculation of the early warning score, escalation triggered by pre-determined thresholds and subsequent communications of actions taken to respond to the deteriorating patient.

Electronic clinical handover systems are often web-based electronic software systems or applications that are derived from the electronic health record. They may also form part of the functional ability of an electronic early warning system or may operate as a stand-alone system.

While electronic systems are tools to facilitate the identification of the deteriorating patient, to be effective, they must impact patient outcomes. External system factors such as strong leadership, a supportive infrastructure and the availability of appropriately trained responders are integral to the successful management of the deteriorating patient rather than simply the deployment of an electronic tool.

3. Clinical effectiveness and safety

The systematic review, examining literature up to end Dec 2014, yielded 10 studies on electronic early warning systems and 17 studies on electronic clinical handover systems.

The results of this systematic literature review indicate there is some evidence that the implementation of electronic early warning systems has contributed to reduced

mortality rates. Change in general and intensive care unit (ICU) length of stay (LOS) varied from a minimal reduction up to 29% and 40% reductions, respectively. Improved efficiency and accuracy of recording vital sign parameters, compliance with escalation protocols and significant user (clinician) satisfaction were also reported. However, as the quality of studies of effectiveness was variable and the interventions performed in a number of healthcare jurisdictions with a range of outcomes measured, the generalisability to the Irish healthcare context may be limited.

The majority of published studies on electronic clinical handover systems were unblinded, before-and-after studies with short or unspecified follow-up periods. Reported outcomes tended to focus on information transfer and clinician experience. Mortality and impact on ICU LOS were not reported on. As with electronic early warning systems, electronic clinical handover systems used a variety of platforms (electronic patient record systems, stand-alone systems, and web-based modules) and collected a variety of data which makes synthesis of information difficult.

Time efficiency gains were reported in rounding and sign-out processes. Clinician experience of electronic clinical handover systems was positive with a perceived reduction in workload burden, clearer medical plans and discharge summaries, and improved patient safety as a result of more accurate and legible documentation. In one study, length of stay on general wards was shown to be significantly reduced with electronic clinical handover systems.

4. Benefits and investment requirements

Cost and resource use data reported in the literature are minimal. No cost-effectiveness studies, one return-on-investment study and two studies reporting resource utilisation were retrieved. With regards to electronic clinical handover systems, no cost-related studies were retrieved. The limited economic literature available suggest that, based on one US study, a continuous monitoring system offers a favourable return on investment, with the cost of installing and maintaining the system offset by reductions in LOS and ICU LOS. However, given the differences in US hospital funding and administration practices the relevance of these cost data to the Irish healthcare setting is not known.

The resource gains and investment requirements of potentially implementing an electronic early warning system into a representative Model 4, 530-bed teaching hospital in Ireland were estimated. The population and setting was limited to the acute hospital, adult in-patient services excluding maternity and paediatrics. The benefit estimates presented are not based on independent economic modeling, but

rather extrapolated results from a study identified in the systematic review that most closely represented the Irish context and which reported on the impact on length of stay. Benefits were only found in studies with robust and sustained escalation policies in response to the patient deterioration alerts. The indicative estimates should be considered with this in mind.

Using data derived from the systematic review and applying this to the Irish healthcare setting, potential benefits from implementing a move from paper-based recording of vital sign parameters to an electronic early warning system could mean a potential resource gain for the Irish healthcare setting being realised through a reduction in general and ICU LOS of 28.9% (95%CI 18.6%-40.3%) and 40.3% (95%CI 4.6% - 76%), respectively. This translates to a capacity gain at a national level of 802,096 hospital bed days per annum (of a total of 2.8 million bed days per annum) and 30,628 ICU bed-days per annum (of a total of 76,000 ICU bed days per annum assuming 90% occupancy).This potential substantial resource gain would assist the efficient utilisation of acute hospital beds and result in reduced pressure on Emergency Departments, reduced waiting times for elective surgeries and ultimately more appropriate and timely access to acute hospital services.

Other potential benefits include increased efficiencies gained from reduced vital sign recording time, as much as 1.6 times faster than that of a paper-based system. This means more available clinician time to deliver care to patients. When this efficiency gain is coupled with improved accuracy of recording of vital signs and handover information, the potential gains realised through a safer patient environment are important contributions to be noted.

However, for these gains to be realised, a significant initial and ongoing maintenance investment is required. Based on indicative investment requirements from the UK, total five-year investment for a single local site has been estimated between €1.0m and €1.3m. At a national level, the five-year investment has been estimated between €40.1m and €51.4m. These indicative investment requirements will be subject to local tendering and contract arrangements.

5. Key Implementation Themes

Themes to assist implementation of electronic early warning and clinical handover systems were extrapolated from the findings in the systematic review and a series of semi-structured interviews carried out, both in person and over the telephone, with national stakeholders and international manufacturers and agencies that have been involved in the implementation of these systems.

All electronic early warning and clinical handover systems should be developed in line with National Clinical Effectiveness Committee (NCEC) quality assured National Clinical Guidelines. Computer learning algorithms and software driving the system should be developed with due consideration to the clinical parameters that have proven effectiveness. National Clinical Guidelines quality assured by NCEC and published by the Department of Health have been developed for use in healthcare organisations in Ireland only, taking into account specific requirements for the Irish healthcare setting.

The potential benefit to patients is appropriate escalation of care and improved patient safety. Strong leadership and adequate resources, such as the appropriate level of trained staff to manage the identified deteriorating patient are critical to successful implementation and improvements in patient outcomes. To maximise the effectiveness of implementation the employment of human factors analysis would help to create work environments that boost productivity while minimizing risks to patient safety. In addition, the full potential of the system should be realised by taking advantage of the large amounts of clinical data it collects to assist in audit and governance functions. The implementation of ICT to support electronic early warning and clinical handover systems should be considered in the context of a standards based approach, the wider ICT agenda and the eHealth Strategy, for example, timing of implementation may be part of a larger move towards electronic health record systems.

Conclusion

In summary, the evidence to support the introduction of electronic early warning and clinical handover systems is of variable quality. Some reduction in mortality and hospital length of stay has been reported. The introduction of electronic early warning and clinical handover systems has been shown to be an efficient, accurate and auditable way of recording patient vital sign parameters.

Implementation will require significant capital investment, but has the potential to improve safety and efficiency of care and increase acute hospital bed capacity.

The potential benefit to patients is appropriate escalation of care and improved patient safety. Outcomes and implementation success are highly dependent on strong leadership, a multidisciplinary approach and linkage to a training programme for assessing and treating the deteriorating patient.

1. Introduction

1.1 Background to request

Following a request from the Clincal Effectiveness Unit, Department of Health through the Chief Medical Officer in October 2014, the Health Information and Quality Authority (the Authority) agreed to undertake a health technology assessment (HTA) of the use of information technology for early warning score and clinical handover systems. This was to inform a policy decision as to whether such systems should be deployed in the Irish healthcare system.

1.2 Terms of Reference

Following an initial scoping of the technology, the terms of reference for this assessment which were agreed between the Authority and the Department of Health were:

- To review the international clinical evidence on the effectiveness and safety of electronic early warning and clinical handover systems.
- To review the available literature on the cost-effectiveness of electronic early warning and clinical handover systems.
- To examine and outline key determinants and common emergent themes that support an effective electronic early warning and clinical handover system achieving successful outcomes.
- To identify electronic early warning and clinical handover systems that are currently in use nationally.
- To identify the resource implications and the associated costs of any potentially clinically effective electronic early warning and clinical handover systems.

1.3 Overall approach

The Authority convened an expert advisory group (EAG) comprising representation from relevant stakeholders including clinical specialists, information technology (IT) specialists, a representative of a patient organisation, the Department of Health (DoH) and the Health Service Executive (HSE). The role of the EAG was to inform and guide the process, provide expert advice and information and to provide access to data where appropriate. A full list of the membership of the EAG is available in the acknowledgements section of this report.

The Terms of Reference of the EAG were to:

- Contribute to the provision of high quality and considered advice by the Authority to the Minister for Health.
- Contribute fully to the work, debate and decision-making processes of the group by providing expert guidance, as appropriate.
- Be prepared to provide expert advice on relevant issues outside of group meetings, as requested.
- Provide advice to the Authority regarding the scope of the analysis.
- Support the Evaluation Team led by the Authority during the assessment process by providing expert opinion and access to pertinent data, as appropriate.
- Review the project plan outline and advise on priorities, as required.
- Review the draft report from the Evaluation Team and recommend amendments, as appropriate.
- Contribute to the Authority's development of its approach to HTA by participating in an evaluation of the process on the conclusion of the assessment.

The Authority appointed an Evaluation Team comprising internal staff from the HTA Directorate to conduct the assessment.

The terms of reference of the HTA were agreed by the EAG. The final report was approved by the Authority prior to its submission as advice to the Minister for Health.

2. Information technology for early warning systems and clinical handover

2.1 Description of the concepts

As part of the programme for sustainable integration and support of implementation of the National Clinical Guidelines,[2] it was recognised that information technology has the potential to offer innovation in improving quality, safety and standardisation of care for patients. However, the benefits, risks and costs of such technology need to be considered in a systematic way to assist a coordinated evidence-based approach for integration of information technology into clinical effectiveness processes.

Failure to identify the acutely deteriorating patient is considered a major cause of avoidable morbidity and mortality.(1;2) In Ireland, a National Early Warning Score (NEWS)(3) is a multi-parameter aggregate weighted scoring system which assists with the early detection of patient deterioration and subsequent escalation of care using a graded response with the primary aim of reducing adverse patient outcomes.

Traditionally, these vital sign parameters have been recorded through paper-based systems. In an attempt to improve recording processes and appropriate escalation of care, electronic versions of early warning scores have been introduced into the healthcare setting.(4)

Over the past decade, there has been considerable focus on the identification and response to unexpected clinical deterioration occurring in hospitalised patients.(1;2) Despite efforts, the detection of patients who are deteriorating in hospital is often later than it should be.(2) Much of this work has been prompted by studies demonstrating that many deteriorations are not detected in a timely fashion, leading to unplanned admissions to the intensive care unit or to cardiac arrest, which could have been avoided had appropriate care been instituted at an earlier stage.(5) Therefore, there has been a move to consider how recent technological developments could improve the identification of patients who are deteriorating. These trends in technological developments include advances in physiological sensor monitoring,(6) the adoption of mobile technologies,(7) the improvement in computer-based learning algorithms to support clinical decision making(8) and the increasing roll-out of electronic patient records.(9)

[2] *National Clinical Guideline No. 1, National Early Warning Score (NEWS), National Clinical Guideline No. 4 Irish Maternity Early Warning System (IMEWS), National Clinical Guideline No. 5 Clinical Handover in Maternity and National Clinical Guideline No. 6 Sepsis Management.*

As part of quality improvement and patient safety initiatives, one of the central processes to assist with delivery or safe care is clinical handover. Clinical handover has been defined as 'the transfer of professional responsibility and accountability for some or all aspects of care for a patient, or groups of patients, to another person or professional group on a temporary or permanent basis'.[10] Information technology can also be considered for use in clinical handover. Electronic versions aim to make these processes more effective and efficient.

2.2 Description of the technology

There are a number of different types of Information and Communications Technology (ICT) options to consider for detection of the deteriorating patient. The main areas for consideration are:

1. Electronic early warning systems
2. Electronic clinical handover systems
3. Continuous patient monitoring *without* electronic early warning system integration
4. Continuous monitoring *integrated with* electronic early warning systems.
5. Electronic physiological surveillance systems that incorporate more patient and hospital variables than electronic early warning score calculation alone.

2.2.1 Electronic early warning systems

While commercial electronic early warning systems may comprise a wide range of features, there are four core elements that are common to all systems. Table 2.1 outlines the four key elements of an electronic early warning system.

Table 2.1: Core elements of electronic early warning systems

1. Electronic reporting (information capture) of vital sign parameters at the bedside using a mobile, user-friendly platform.
2. Computer learning systems that calculate the early warning score
3. Escalation of care when appropriate
4. Communication of the actions to be taken/or have been taken to address deteriorating vital sign and patient parameters.

When an electronic early warning system is introduced into a setting, the threshold parameters are usually set in line with national or local guidelines for early warning scores and escalation protocols. Despite the commonalities outlined in Table 2.1, comparing effectiveness of various electronic systems poses a challenge because the same software/hardware system may be implemented in two settings, but each

jurisdiction may have different early warning score thresholds, escalation protocols, baseline supporting infrastructure (rapid response teams [RRTs], ICT support) and resources for education of staff to use the new systems, all of which influence the various outcomes.

2.2.2 Electronic clinical handover systems

These are often web-based electronic software systems or applications that are derived from the electronic health record. They may also form part of the functional ability of an electronic early warning system or may operate as a stand-alone system. The usual variables that are incorporated in an electronic clinical handover system include patient demographics, admission and clinical team responsibility linkage, clinical update information and handover governance.

2.2.3 Continuous monitoring with or without electronic early warning systems

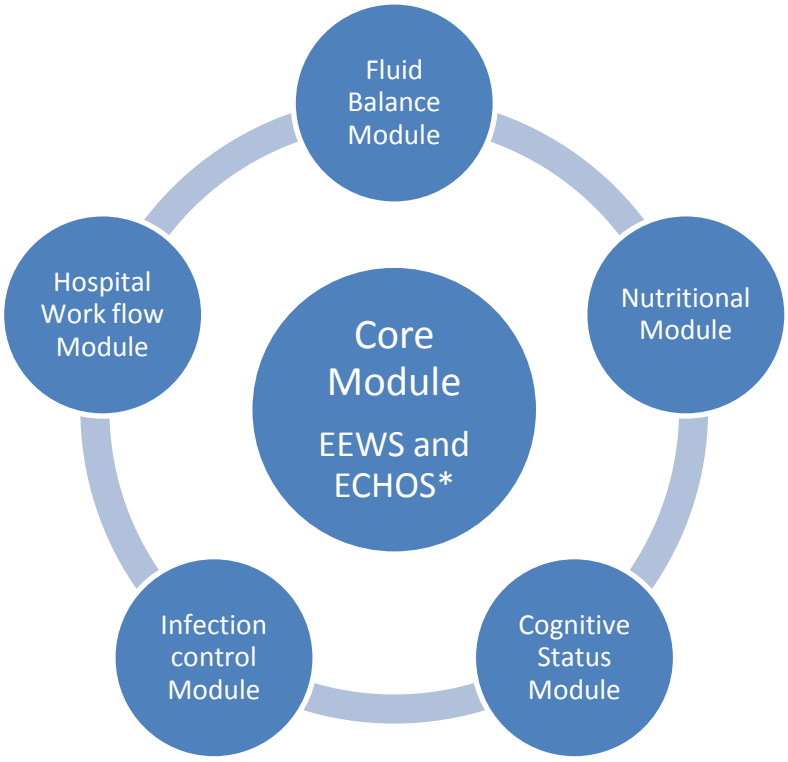
'Smart patient monitoring' technology is another subgroup of patient monitoring systems. These systems include automated physiological data feeds that are displayed at a central monitoring area with this information potentially also used to generate early warning scores and escalate care as outlined in Table 2.1. The systems that incorporate this automated monitoring with electronic early warning systems are more recent to the market.

2.2.4 Electronic physiological surveillance systems

Electronic physiological surveillance systems describe a broader category of electronic monitoring (see Figure 2.1). These systems include more complex data than just early warning score calculations based on vital sign parameters. They may have additional modules to assist patient care and workflow processes, for example, monitoring of fluid balance, nutritional and cognitive status as well as monitoring of infection control.

In attempting to identify the deteriorating patient by collecting vast quantities of physiological data, these systems have included functions to enable the assessment of hospital work flow and staffing levels, so that the clinical capacity of an area can be matched to the areas of greatest need in terms of patient care. Although stand-alone electronic clinical handover tools can support services, integration of the handover tool with other core ICT functions may offer more benefits, for example, the coordination of electronic physiological surveillance systems and clinical handover tools.[(11)]

Figure 2.1: An example of an electronic physiological surveillance system with a selection of possible additional modules.

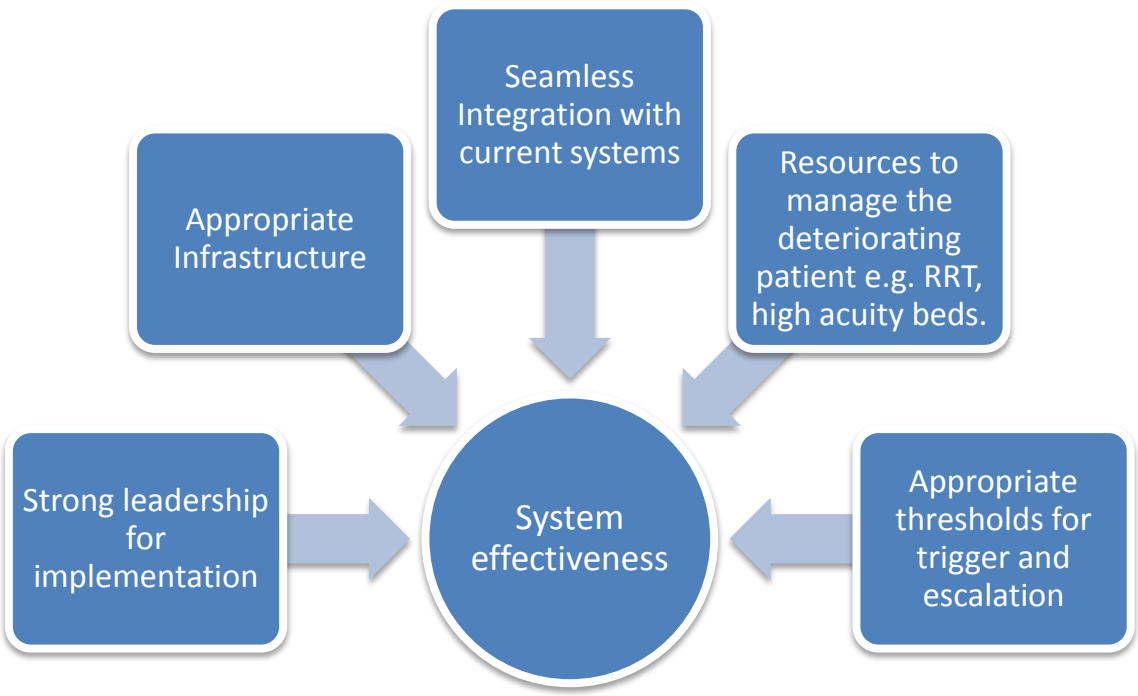


*EEWS (electronic early warning system), ECHOS (electronic clinical handover system). This graphic is based on the VitalPAC™ system

2.3 Factors affecting assessment of clinical effectiveness

While electronic systems are tools to facilitate the identification of the deteriorating patient, to be effective, they must impact patient outcomes. Figure 2.2 illustrates the external factors that influence the clinical effectiveness of ICT solutions in identifying the acutely deteriorating patient. These external factors are explored further in Chapter 5 which reviews key implementation themes.

Figure 2.2 External factors that impact electronic early warning system effectiveness



*RRT: Rapid Response Team

Not only can electronic systems vary in terms of early warning score thresholds and escalation parameters (even if the technology is from the same manufacturer); different brands of system will vary in terms of interface, usability and functionality. To complicate matters further when comparing the effectiveness of various systems, the success of any system will be strongly influenced by the level of supportive infrastructure, a robust implementation plan and the level of development resource that is available to the organisation. In addition, once the deteriorating patient is identified, having the resources to respond to the identified patient in a timely, clinically adequate way, such as with rapid response teams, appropriate transfer and availability of higher acuity beds, will impact on overall clinical outcomes.

It is important that any new technology can integrate seamlessly within existing clinical practice and that the system is designed in a way that does not add to workload, interfere with clinical tasks, or compromise patient safety and quality of care. It is also critical that these systems are developed in line with National Clinical Effectiveness Committee (NCEC) quality-assured National Clinical

Guidelines on Early Warning Scores and Clinical Handover [3] and that any updates to these guidelines can be incorporated with ease into the electronic system. Finally, the ultimate clinical decision making lies with the healthcare professional. Electronic systems should be viewed as aids to decision making and not a replacement for clinical decision making.

In this systematic review, the electronic systems are examined in isolation; however, the reader must remain cognisant of the external factors outlined above that influence the effectiveness of any new ICT programme.

2.4 Diffusion of the technology

Internationally, there are several commercially available electronic early warning systems. Appendix A provides a list of some of these systems. The US has seen a rise in the use of electronic health care records (EHR) from approximately 20% to 80% of acute hospitals in recent years with some linkage of vital sign monitoring to information in the electronic health record.[9] Other jurisdictions such as the UK and Canada have not had widespread adoption of the electronic health record; however the use of electronic early warning systems and electronic physiological surveillance systems, such as VitalPAC™, NerveCentre and Patientrack™ has been adopted across many local and regional services, particularly in the UK. Electronic clinical handover systems tend to be developed in-house using the electronic health record; this can be as part of an electronic early warning system function, or as a stand-alone system such as the Australian OpenKIMS or the US-based UWCores system.

Use of electronic early warning or clinical handover systems in the general acute hospital setting (that is, excluding ICU monitoring systems) in Ireland is minimal. Of 38 publically-funded hospitals that provided information regarding availability of these systems in their hospital, only two reported some use, but this was limited to the Emergency Department (ED) or Acute Medical Assessment Unit (AMAU) only. Five other hospitals reported that they were considering different options around electronic monitoring systems, but implementation was not imminent.

With regards to electronic innovations in maternity early warning systems in Ireland, the Maternal and Neonatal Clinical Management System (MN-CMS) is under development. This is the design and implementation of an electronic health record for all women and babies in maternity services in Ireland. Implementation of this system which will incorporate the Irish Maternity Early Warning System (IMEWS)

[3] *National Clinical Guideline No. 1, National Early Warning Score (NEWS), National Clinical Guideline No. 4 Irish Maternity Early Warning System (IMEWS), National Clinical Guideline No. 5 Clinical Handover in Maternity and National Clinical Guideline No. 6 Sepsis Management.*

and clinical handover is set to begin in late 2015. The aim of the project is to create a maternity and neonatal management system that will interface with other patient-based clinical and administrative systems ensuring a complete clinical management system ideally from the first positive pregnancy test, through referral, antenatal care, intra-partum, postnatal care and discharge.

2.5 Summary

- A range of Information and Communications Technology (ICT) options are available to support detection of the deteriorating patient and to facilitate clinical handover of patients.
- To be effective, electronic early warning systems must impact patient outcomes. However, assessment of their impact is complicated; while electronic early warning systems have a number of core features, they vary in their programmed identification and escalation thresholds as well as how the data generated are used to inform decision making.
- The effectiveness of any system will depend on the ability to seamlessly integrate it into existing infrastructure that has been trained and resourced to respond to the data generated.
- A national survey revealed minimal current investment in electronic early warning and clinical handover systems.

3. Clinical Effectiveness and Safety

A systematic review of electronic clinical handover and electronic early warning score systems was carried out to identify, appraise and synthesise the best available evidence on the clinical effectiveness and safety of these interventions.

This review included:

- development of a literature review protocol with the input of the EAG
- contact with device manufacturers to request company submissions in support of clinical and cost-effectiveness
- contact with leading authors to request information on any relevant planned or ongoing studies
- appraisal and synthesis of all available evidence in line with international best practice in systematic reviews of interventions.

3.1 Literature review

A search for studies comparing paper-based recording systems (current practice) of early warning systems and clinical handover with electronic systems was conducted in Embase, Medline and CINAHL. The Current Controlled Trials (ISRCTN) register and the Cochrane Central Register of Controlled Trials and the Cochrane library (Database of Abstracts of Reviews of Effects [DARE], Cochrane Database of Systematic Reviews [CDSR] and Health Technology Assessment Database [HTA]) were also searched. No date or language restrictions were applied. All searches were carried out up to the end of December 2014. A search of reference lists of relevant studies and previous review articles was also performed. Eight device manufacturers and three leading authors in this area were contacted to identify other relevant published or unpublished studies, as well as ongoing or planned studies. The criteria for including studies are shown in Table 3.1. Full details of the search strings used and the retrieved results are provided in Appendix B.

Preliminary screening of all returned results was carried out by a single person to eliminate studies that were clearly not relevant. Assessment of eligibility of studies and identification of multiple reports from single studies was carried out independently by two people. Any disagreements were resolved by discussion.

Data extraction was performed independently by two people, with disagreements resolved by discussion. Assessment of the risk of bias of included studies was performed by two people independently. The Cochrane risk of bias tool[12] was chosen to assess randomised controlled trials (RCT). Non-randomised controlled trials (NRCT) and controlled before-and-after (CBA) studies were assessed using the nine-item checklist developed by the Cochrane Effective Practice and Organisation of Care (EPOC) group.[13]

Table 3.1 PICO criteria for study eligibility

Population	All hospital in-patients and staff who are involved in delivering the intervention. Subpopulations include pregnant adult and paediatric in-patients
Intervention	Electronic/automated/computerised, Early Warning OR Track and Trigger Score/System/Tool/Chart Electronic /automated/computerised clinical handover/handoffs Electronic /automated/computerised escalation
Comparator	Paper-based recording systems (current practice) and/or Different electronic systems.
Outcomes	**Primary outcome** ▪ Mortality **Secondary outcomes** ▪ ICU LOS ▪ ICU admission ▪ Cardio-pulmonary arrest ▪ Adverse incidents (rates of non-escalation when there should have been escalation, IT failures, loss of data) ▪ Usability ▪ Patient experience ▪ Efficiency in work processes ▪ Change of investigations/interventions rates, workload responding to alerts, (Sensitivity/Specificity)

Study design	Randomised controlled trials (RCTs), non-randomised control trials (NRCTs) and controlled before-and-after (CBA) studies were considered the best source of evidence for the effectiveness of this treatment. Cohort studies, trials with historical controls, cross-sectional studies and case series provide less reliable information on the effects of such interventions, primarily due to the inability to control allocation or ensure that treatment and comparison groups are equivalent in terms of their prognosis at baseline. However, findings from these types of studies were synthesised and discussed in the absence of better evidence, with due consideration of their methodological limitations. Studies that were only reported as conference abstracts were excluded.

3.2 Results

The search (see Figure 3.1 and 3.2) identified 28 completed studies that met the inclusion criteria:

- Electronic early warning systems: n=8
- Continuous monitoring systems without automated early warning score calculation: n=2
- Continuous monitoring systems with integrated electronic early warning system: n=1
- Electronic clinical handover systems: n=17.

Figure 3.1. Flowchart of electronic early warning systems/continuous monitoring studies inclusion and exclusion

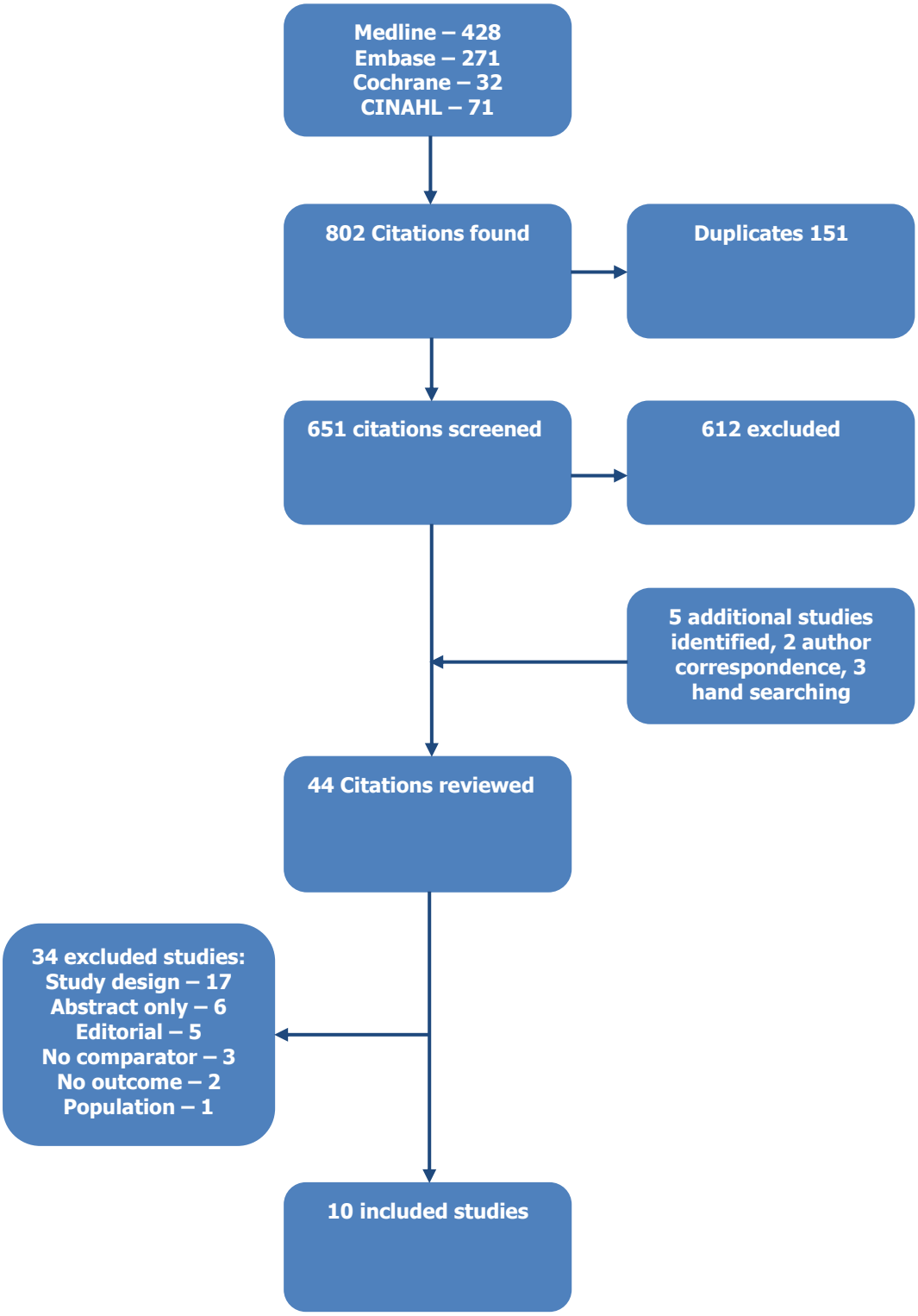
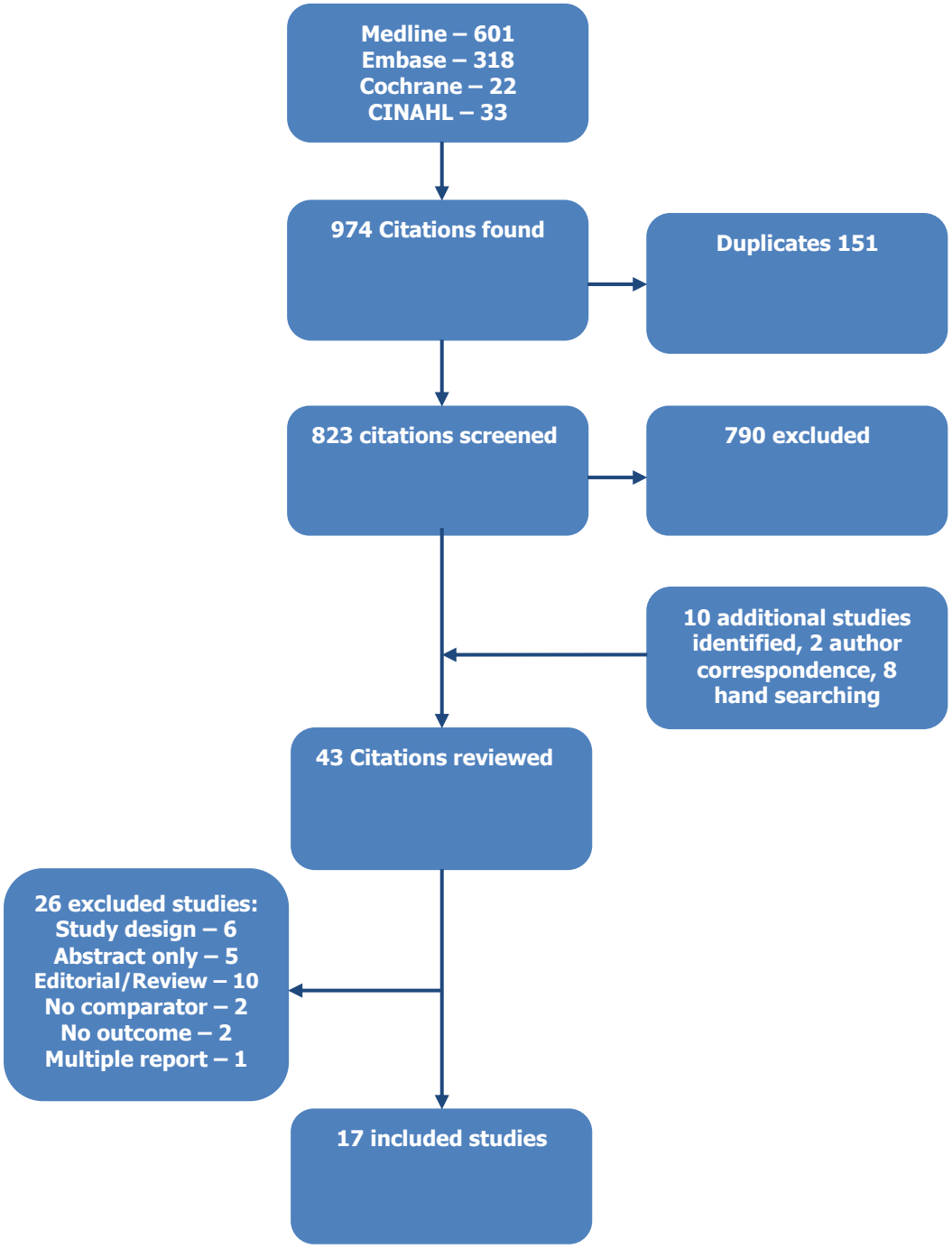


Figure 3.2. Flowchart of electronic clinical handover systems study inclusion and exclusion



3.2.1 Electronic early warning/continuous monitoring systems

Of the ten studies examining clinical effectiveness of electronic early warning systems or continuous monitoring systems there were two RCTS,[14;15] two randomised controlled cross-over studies,[16;17] one CBA,[18;19] and five before-and-after trials. [4;19-22]

The level of bias in the two RCTs[14;15] was considered low and moderate (due to unblinded nature of the trial), respectively. Likewise, for the two randomised controlled crossover studies[16;17], bias level was considered low and moderate, respectively. Historically controlled before-and-after trials were judged to have a high level of bias. Of the ten studies, outcome data reported included mortality, cardio-pulmonary arrests, length of stay (LOS) in general wards, intensive care unit (ICU) LOS, ICU admissions, adverse events, change in work processes and clinician experience. See Table 3.2 and 3.3 for the summary of studies and risk of bias.

Table 3.2. Electronic early warning system: summary of studies

Author	Study type	Bias	System
Kollef et al.[14] 2014, US	RCT	Low	In-house electronic alert system
Watkinson et al.[15] 2006, US	RCT	Moderate	Continuous monitoring without Electronic Early Warning system
Bailey et al.[16] 2013, US	Randomised, controlled cross-over study	Low	In-house electronic alert system
Prytherch et al.[17] 2006, UK	Randomised Crossover Study, classroom setting.	Moderate	VitalPAC™
Bellomo et al.[18] 2012, Multi-site US, UK, Sweden, Australia	Controlled Before-and-after trial	High	Continuous monitoring with integrated Electronic Early Warning System
Brown et al.[19] 2014, US	Before-and-after trial	High	Continuous monitoring without Electronic Early Warning system
Dawes et al.[20] 2014, UK	Before-and-after trial	High	VitalPAC™ system linked with Worthing predictive tool as the underlying algorithm.
Jones et al.[21] 2011, UK	Before-and-after trial	High	Patientrack™
Schmidt et al.[4] 2014, UK	Before-and-after trial	High	VitalPAC™
Mohammed et al.[22] 2009, UK	Before-and-after trial	High	VitalPAC™

*Level of bias determined using EPOC 9 criteria

Table 3.3. Risk of bias assessment for randomised trials

	Kollef[14]	Watkinson[15]	Bailey[16]	Prytherch[17]	Bellomo[18]
Was the allocation sequence adequately generated?	low	low	low	unclear	high
Was the allocation adequately concealed?	low	unclear	low	high	high
Were baseline outcome measurements similar?	low	low	low	low	low
Were baseline characteristics similar?	low	low	low	low	low
Were incomplete outcome data adequately addressed?	unclear	unclear	unclear	unclear	unclear
Was knowledge of the allocated interventions adequately prevented during the study?	low	high	low	high	high
Was the study adequately protected against contamination?	low	low	low	unclear	unclear
Was the study free from selective outcome reporting?	low	low	low	low	low
Was the study free from other risks of bias?	low	low	low	low	low

The majority of studies were examining electronic early warning systems only, however three studies[15;18;19] looked particularly at continuous monitoring effects without electronic early warning score calculation and one study examined continuous monitoring with electronic early warning score calculation. See Table 3.4 for a summary of study outcomes.

Table 3.4. Summary of clinical outcomes data reported for electronic early warning systems/continuous monitoring

Study	Mortality	Cardio-Pulm. Arrest	LOS	ICU LOS	ICU Admissions	Adverse Events	Change in work processes	Clinician Experience	Costs
Bellomo R[18] (CBA)	X	X	X		X		X		X
Bailey TC[16] (Randomised Crossover)	X		X		X		X		
Brown H[19] (CBA)	X	X	X	X	X				
Dawes TR[20] (Before-after)	X		X						
Jones S[21] (Before-after)	X	X	X	X	X	X	X		
Kollef MH[14] (RCT)	X		X	X	X		X		
Mohammed MA[22] (Before-after)							X	X	
Prytherch DR[17] (Randomised Crossover)							X	X	
Schmidt PE[4] (Before-after)	X								X
Watkinson PJ[15] (RCT)	X	X	X		X	X			

*Adverse events are those that were averted OR occurred as a result of the introduction of the electronic system.
X represents when data in a particular domain are present in the study.

Mortality

Eight studies reported mortality outcome data (two RCTs[14;15], one randomised controlled crossover study,[16] one CBA [18] and five before-and-after trials).[4;19-21] These studies included a mixture of manual and automated monitoring and early warning score calculations. Table 3.5 summarises the study details of those reporting mortality outcomes.

Table 3.5. Summary of studies reporting mortality outcomes

Author	Study Design	Study Quality	Patients	System	Follow-up	Outcomes reported
Electronic early warning systems						
Kollef 2014, US	RCT	Low risk of bias	Patients: Intervention n=285, Baseline n=286	Follow on from Bailey 2013 study using in-house development of real-time alerts, but this time sent to RRT nurse.	Not reported	Crude mortality reduction of 7.7% (control) to 7.3% (intervention) p<0.865, odds ratio: 0.947
Bailey 2013, US	Randomised controlled cross-over study	Low risk of bias	Intervention n=9,911 Control n=10,120	In-house development of real-time alerts system to predict ICU transfer risk. Alerts sent to charge nurse.	Not reported	Patients with alerts were at 8.9-fold greater risk of death (95% CI: 7.4-10.7) than those without alerts (244 of 2353 [10.4%] vs. 206 of 17678 [1.2%]). Among patients identified by the early warning system, there were no differences in the proportion of patients who died in the intervention group as compared with the control group. Alerts occurred a median of 8 hours prior to death (interquartile range, 4.09-15.66).
Dawes 2014, UK	Before/ after trial	High risk of bias	3,184 patients included (3,020 survived, 164 died)	VitalPAC™ system linked with Worthing predictive tool as the underlying algorithm.	Not reported	Reduction of observed mortality rate; 8.3% to 5.2% over 5 years (p=0.29 post adjustment for disease severity)
Jones 2011, UK	Before/- after trial	High risk of bias	1,481 patients included	Patientrack™	Not reported	Deaths in study population (baseline 67 (9.5%) vs. alert 59 (7.6%) p=0.19)

Schmidt 2014, UK	Before/ after trial	High risk of bias	2 large unconnected hospital settings (>1,000 bed hospitals) both with VitalPAC™ established for >5 years.	VitalPAC™	Not reported	Crude mortality reduction in the 5 year study period Hospital 1: 7.75% to 6.42% (p<0.001) (estimated 397 fewer deaths) Hospital 2: 7.57% to 6.15% (p<0.001) (estimated 372 fewer deaths). Seasonally-adjusted mortality was predominantly above the 7-year mean (Hospital 1, 30/47 (63.8%) months; Hospital 2, 45/57 (78.9%)), whereas afterward introduction, it was seldom so (Hospital 1, 4/37 (10.8%) months; Hospital 2, 2/27 (7.4%))
Continuous monitoring without electronic early warning system integration						
Watkinson 2006, UK	RCT	Moderate risk of bias	402 total high risk medical and surgical patients 201 in each group.	Continuous monitor Propaq, Welch Allyn.	30 days	No difference in mortality rate between intervention and control group. 34 (17%) monitored patients and 35 (17%) control patients died within 30 days. The 96-h mortality was slightly higher in the monitored (15/201, 7.5%) than in the unmonitored arm (11/201, 5.5%). Acute hospital mortality 34 (17%) intervention vs. 36 (18%) control.
Brown 2014, US	Before/ after trial (9-month pre, 9-month post)	High risk of bias	Chart review: Intervention, n=2,314 Charts Control n=5,329 Charts	Continuous monitoring system using EarlySense technology	1 month	Overall mortality was low in both the control (2 non-DNR deaths) and intervention period (1 non-DNR).
Continuous monitoring with electronic early warning system integration						
Bellomo 2012, Multi-site	Controlled Before/ after trial	High risk of bias	Intervention n=8,688 Controls n=9,617	Intellivue System, Philips Medical	90 day post discharge	No overall change in in-hospital mortality control 174 (1.8%) vs. intervention 174 (2.0%) Survival immediately after rapid response team treatment, to hospital discharge or 90 days increased from 86% to 92% (difference [95% CI] 6.3 [0.0–12.6]; p=0.04). Improved in-hospital survival among RRT call patients, adjusted OR during the intervention period was 0.47 (95% CI 0.23–0.97; p=0.04).

Key ICU: Intensive care unit; **RRT**: Rapid Response Team; **CI:** Confidence Interval; **EWRS:** Early Warning Response System; **DNR:** Do Not Resuscitate; **OR:** Odds Ratio**; RCT:** Randomised Control Trial

Of the eight studies reporting mortality outcomes, five examined electronic early warning systems.[4;14;16;20;21] Three of these studies, [4;20;21] all before-and-after trials, examined the move from a paper-based early warning system to an electronic version. The move from a paper-based early warning system to an electronic version most closely reflects the Irish context. Two RCT studies[14;16] compared an electronic alert system with no electronic alerts. For the remainder of the studies, one RCT[15] and one before-and-after trial[19] studied continuous monitoring without an integrated electronic early warning system and one CBA study examined a continuous monitoring system with integrated electronic early warning system.[18]

Paper-based to electronic early warning systems

The trial by Schmidt et al.[4] showed a significant crude mortality reduction in the five year study period using VitalPAC™. In hospital one, this was reported as a reduction in crude mortality from 7.75% to 6.42% ($p<0.001$) (estimated 397 fewer deaths) and hospital two as a reduction from 7.57% to 6.15% ($p<0.001$) (estimated 372 fewer deaths). In addition, cumulative sum control chart (CUSUM) analysis revealed an abrupt and sustained reduction in mortality in both hospitals which coincided with the deployment of the electronic physiological surveillance system. Of note however, there is international evidence to suggest that all hospital mortality has been decreasing year-on-year [23] thought to be due to overall improved ICU care. This could account for the decrease in mortality reported by Schmidt et al..[4] The studies by Dawes et al.[20] (VitalPAC™) and Jones et al.[21] (Patientrack™) showed no significant reduction in observed mortality rate.

Electronic alerts versus no electronic alerts

The randomised controlled crossover trial by Bailey et al.[16] reported on the effects of implementation of an in-house real time alert system. This system used a specially developed algorithm to predict ICU transfer risk and used data from the electronic patient record. The alert was sent to the charge nurse on the ward who was then responsible for escalating care as per local protocols. The alert itself was shown to be highly specific for identifying clinical deterioration and showed that patients with alerts were at an 8.9-fold greater risk of death than those without alerts; however, there were no differences in reported mortality between intervention and control groups.

The RCT by Kollef et al.[14] was a follow-on study from the Bailey trial and used the same in-house prediction algorithm and real-time alert system. The main differences in methodology were that instead of the real-time alerts being sent to the charge nurse, the alert was sent to a rapid response team (RRT). As a result of the findings

from the Bailey trial, the premise emerged that sending real time alerts to the charge nurse only, was not sufficient to influence patient outcomes and involving the RRT was a more appropriate course of action. However, the results by Kollef et al. showed no reduction in mortality between intervention and control group. In their discussion they highlight their next steps to determine if the combination of utilising electronic patient record data with continuous monitoring and real-time streaming of vital sign data will not only improve prediction of deterioration, but also deliver improved clinical outcomes.

Continuous monitoring without electronic early warning system integration

An RCT by Watkinson et al.[15] (Propaq monitor, Welch Allyn) examined automated monitoring only without early warning score calculations and found no difference in overall mortality between the intervention and control groups.

Continuous monitoring with integrated electronic early warning system

In a controlled before-and-after study by Bellomo et al.[18] (Intellivue System, Philips Medical), there was no overall change to in-hospital mortality; however, survival to hospital discharge or 90 days increased in those patients who received rapid response team treatment from 86% to 92% post intervention, p=0.04. They also reported an improved in-hospital survival amongst RRT call patients during the intervention period (OR 0.47, p=0.04).

Length of stay (LOS) on general wards

There was a substantial difference in pre-intervention LOS ranging from 4.0-10.1 days. This may reflect the heterogeneity in the patient population or differences in country specific healthcare infrastructure. The reduction that was achieved ranged from one to 2.8 days although interpretation is complicated by the variation in baseline LOS. See Table 3.6 for a summary of LOS outcomes.

Table 3.6. Summary of studies reporting length of stay outcomes (LOS)

Author	Study Design	Study Quality	Patients	System	Follow-up	Outcomes reported
Electronic early warning systems						
Bailey 2013, US	Randomised controlled cross-over study	Low risk of bias	Intervention n=9,911 control n=10,120	In-house development of real-time alerts system to predict ICU transfer risk. Alerts sent to charge nurse.	Not reported	No difference in LOS between intervention and control group (specific data not reported)
Kollef 2014, US	RCT	Low risk of bias	Patients: Intervention n=285, Baseline n=286	Follow on from Bailey 2013 study using in-house development of real-time alerts but this time sent to RRT nurse.	Not reported	9.4 days (control) v. 8.4 days (intervention) p=0.038
Dawes 2014, UK	Before/ after trial	High risk of bias	3184 patients included (3020 survived, 164 died)	VitalPAC™ system linked with Worthing predictive tool as the underlying algorithm.	Not reported	Reduction from 4 to 2 days in 5 years (not statistically significant after adjustment for admission Worthing PSS score)
Jones 2011, UK	Before/ after trial	High risk of bias	patients included n=1,481	Patientrack™	Not reported	Reduced LOS (in implementation arm) 9.7days v. 6.9 days p<0.001

Continuous monitoring without electronic early warning system integration						
Brown 2014, US	Before/after trial (9-month pre, 9-month post)	High risk of bias	Chart review: Intervention n=2,314 Charts, /control n=5,329 Charts	Continuous monitoring system using EarlySense technology	1 month	Average LOS 3.6 days (post intervention) vs. 4.0 (pre intervention in case unit) p<0.05
Continuous monitoring with electronic early warning system integration						
Bellomo 2012, Multi. US, UK, Sweden, Australia	Controlled Before-and-after trial	High risk of bias	Intervention n=8,688 Controls n=9,617	Intellivue System, Philips Medical	90 day post discharge	Significant reduction in LOS 4(before) [2–6.7] and 3[2–6] (after) p<0.0001, Hospital length of stay (days)

Three studies reported a statistically significant reduction in LOS. [14;18;21] Two before-and-after studies[20;21] examined a move from a paper-based system to an electronic early warning system. One of these studies, by Jones et al.[21] showed a statistically significant decrease in LOS post intervention by 2.8 days, however, the study by Dawes et al. showed no significant reduction in length of stay post adjustment for patient severity on admission.

Two studies compared the effect of electronic alerts with no electronic alerts. The RCT by Kollef et al.[14] showed a significant reduction of LOS by one day, however, the randomised controlled cross-over study by Bailey et al.[16] found no difference in LOS in the intervention arm.

One study by Brown et al.[19] that examined continuous monitoring without integrated electronic early warning system showed a significant decrease in length of stay in the intervention arm (from 4.0 to 3.6 days; p <0.05). Another study by Bellomo et al.[18] showed a significant reduction in LOS of one day post introduction of a continuous monitoring system with an integrated electronic early warning system.

Intensive care unit length of stay (ICU LOS)

A before-and-after study[21] by Jones et al., that examined the move from a paper-based to electronic early warning system, showed a statistically significant reduction

in ICU LOS during the study periods: (pre-intervention) 14 patients (51 critical care bed-days) and (post intervention) 5 patients (26 critical care bed-days) (p=0.04).

The RCT by Kollef et al., [14] that compared electronic alerts system with no alerts, showed no reduction in ICU LOS.

The study of continuous monitoring by Brown et al.[19] showed a significant reduction in total ICU days in the intervention unit post-implementation (63.5 vs. 120.1 per 1,000 patients, p=0.04). See Table 3.7 for a summary of ICU LOS outcomes.

Table 3.7. Summary of studies reporting ICU length of stay

Author	Study Design	Study Quality	Patients	System	Follow-up	Outcomes reported
Electronic early warning systems						
Kollef 2014, US	RCT	Low risk of bias	Patients: Intervention n=285, Baseline n=286	Follow on from Bailey 2013 study using in-house development of real-time alerts but this time sent to RRT nurse.	Not reported	5.8 days (control) v. 4.8 (intervention) p=0.812.
Jones 2011, UK	Before-and-after trial	High risk of bias	patients included n=1,481	Patientrack™	Not reported	The LOS in critical care during the study periods were 14 patients (51 bed-days) and 5 patients (26 bed-days), respectively (p=0.04).
Continuous monitoring without electronic early warning system integration						
Brown 2014, US	Before-and-after trial (9-month pre, 9-month post)	High risk of bias	Chart review: Intervention n=2,314 Charts, control n=5,329 Charts	Continuous monitoring system using EarlySense technology	1 month	63.5 intensive care unit days Post intervention vs. 120.1 pre-intervention per 1,000 patients, p=0.04).

Unplanned ICU admissions

Seven studies reported unplanned ICU admissions outcomes.[14-16;18;19;21] Results of the studies are summarised in Table 3.8. One before-and-after study by Jones et al.[21], that examined the move from a paper-based to electronic early warning system, showed that there was a significant reduction in unplanned critical care admissions following the implementation of an electronic early warning system (14 admissions to 5 admissions p=0.04; study size n=1,481 included patients).

For those studies that examined either a new electronic alert system or continuous monitoring, none of the RCTs or randomised cross over studies[14-16] reported a significant difference in unplanned ICU admissions between the intervention and control groups. However, the CBA study by Bellomo et al.,[18] showed that in the US arm of the study, there was a significant increase in the proportion of RRT call patients who were transferred to a higher acuity ward, but that there was no significant difference in the unplanned ICU transfer rate.

Table 3.8. Summary of studies reporting ICU admission/transfer

Author	Study Design	Study Quality	Patients	System	Follow-up	Outcomes reported
Electronic early warning systems						
Bailey 2013, US	Randomised controlled Cross-over study	Low risk of bias	Intervention n=9,911 control n=10,120	In-house development of real-time alerts system to predict ICU transfer risk. Alerts sent to charge nurse.	Not reported	No difference in ICU transfer between intervention and control groups.
Kollef 2014, US	RCT	Low risk of bias	Patients: Intervention n=285, Baseline n=286	Follow on from Bailey 2013 study using in-house development of real-time alerts but this time sent to RRT nurse.	Not reported	ICU transfer (17.8% vs. 18.2%; odds ratio: 0.972; 95% CI: 0.635–1.490)
Jones 2011, UK	Before-and- after trial	High risk of bias	1,481 patients included	Patientrack™	Not reported	Reduced critical care bed days 14 admissions to 5 admissions p=0.04)
Continuous monitoring without electronic early warning system integration						
Watkinson 2006, UK	RCT	Moderate risk of bias	402 total high risk medical and surgical patients 201	Continuous monitor Propaq, Welch Allyn.	30 days	Unscheduled ICU / CCU admission 10 mandatory monitoring, 10

			in each group.			usual care patients
Brown 2014. US.	Controlled before-and-after trial (9-month pre, 9-month post)	High risk of bias	Chart review: Intervention n=2,314 Charts, Control n=5,329 Charts	Continuous monitoring system using EarlySense technology	1 month	Rate of transfer to the ICU did not change p=0.19, 26.52 cases pre intervention) 25.93 post intervention case /1,000 patients
Continuous monitoring with electronic early warning system integration						
Bellomo 2012, Multi. US, UK, Sweden, Australia.	Controlled Before-and- after trial	High risk of bias	Intervention n=8,688 Controls n=9,617	Intellivue System, Philips Medical	90-day post discharge	A non-significant increase in the proportion of RRT call patients who were transferred to a greater acuity ward from 75 (41%) to 96 (49%); p=0.13, which achieved significance in US hospitals from 52 (54%) to 70 (69%); difference (95% CI) 15.7% (1.3–30.1); p=0.03

Cardio-pulmonary arrest

Four studies[15;18;19;21] reported findings on cardio-pulmonary arrest events. Table 3.9 gives a summary of the study outcomes.

Table 3.9. Summary of studies reporting cardio-pulmonary arrest outcomes

Author	Study Design	Study Quality	Patients	System	Follow-up	Outcomes reported
Electronic early warning systems						
Jones 2011, UK	Before-and-after trial	High risk of bias	1,481 patients included	Patientrack™	Not reported	Reduced Cardio-Pulm arrest 3 (0.4%) to 0, p=0.21)
Continuous monitoring without electronic early warning system integration						
Watkinson 2006, UK	RCT	Moderate risk of bias	402 total high risk medical and surgical patients 201 in each group.	Continuous monitor Propaq, Welch Allyn.	30 days	Cardiac arrest calls: 6 mandatory monitoring, 1 usual care patients
Brown 2014, US	Before-and-after trial (9-month pre, 9-month post)	High risk of bias	Chart review: Intervention n=2,314 Charts, Control n=5,329 Charts	Continuous monitoring system using EarlySense technology	1 month	Rate of code blue events decreased following the intervention from 6.3 to 0.9 per 1,000 patients (p=0.02).
Continuous monitoring with electronic early warning system integration						
Bellomo 2012, Multi	Controlled Before-and-after trial	High risk of bias	Intervention n=8,688 Controls n=9,617	Intellivue System, Philips Medical	90 day post discharge	34 cardiac arrests (before) and 24 (after) p=0.34.

The before-after-trial by Brown et al.[19], examined the effect of continuous monitoring on patient outcomes by comparing a 33-bed medical-surgical unit (intervention unit) with another control unit for a 9-month pre-implementation and a 9-month post-implementation period, (n=7,643 patient charts). Their reported rate of cardio-pulmonary ('code blue') events decreased following the intervention, from 6.3 to 0.9 (post intervention) per 1,000 patients (p = 0.02).

The RCT by Watkinson et al. [15] examined the effect of continuous monitoring (without EWS calculation and relying on the charge nurse to log the deterioration and escalate according to clinical judgement). They noted that arrest calls increased in the first 96 hours after randomisation with six calls in the mandatory monitoring arm compared with one call in usual care patients.

Adverse Events

Adverse event reporting was minimal. In a before-and-after study by Jones et al.,[21] it was noted that in phase 1 of their study, when data were checked manually, there were 12 instances out of 567 early warning score calculations where the recorded score was underestimated and the actual score would have triggered a clinical response as per the early warning score protocol.

In the RCT by Watkinson et al.,[15] technical problems with the device prevented complete recording for the whole monitoring period for 33 of 257 monitored patients. In 30 of these episodes, motion artifact gave a spurious abnormal reading.

Change in work processes

Seven studies[14;16-18;21;22] reported on the effect of the intervention on work processes (see Table 3.10). The changes in work processes included efficiency gains, improved accuracy of recording vital signs and early warning score calculations, compliance with early warning guidelines and protocols, and improved clinical attendance to the deteriorating patient.

The RCT by Kollef et al.[14] reported on changes in clinical care processes. The authors report that the intervention group was significantly more likely to have telemetry and oximetry started while the control group was more likely to have antibiotics commenced within 24 hours of the alert. They also describe a 97% specificity and 40% sensitivity of alert threshold as giving a 'manageable' alert rate for staff, i.e. 1-2 alerts per nursing unit. This threshold was also used by Bailey et al.[16] for their randomised cross-over study.

The CBA study by Bellomo et al.[18] reported a reduction in vasopressor use ($p=0.02$) in the intervention group, a 52% relative increase in proportion of RRT calls triggered by respiratory criteria and a decrease in abnormal physiological criteria present at the time of the call.

In terms of efficiency gains, a classroom-based randomised crossover study, by Prytherch et al.[17] showed that vital sign data entry using the VitalPAC™ system was 1.6 times faster than pen and paper with a reduction in erroneous data entry and incorrect clinical actions in the intervention group. The studies by Bellomo et al.[18] and Mohammed et al.[22] confirmed the efficiency gains from using electronic vital sign monitoring, showing a significant reduction in vital sign recording of 1.6 minutes and 13.9 seconds per set of recordings, respectively. The variation in time to record the set of vital sign parameters may be due to the different types of system that were being examined. The study by Bellomo et al.[18] was using continuous

monitoring with electronic early warning system integration while the other system examined the time taken for manual input of vital sign parameters. The before-and-after study by Jones et al.[21] also found that accuracy of recording was significantly improved from 81% pre intervention to 100% post intervention.

Table 3.10. Summary of studies reporting changes in work processes

Author	Study Design	Study Quality	Patients	System	Follow-up	Outcomes reported
Electronic early warning systems						
Kollef 2014, US	RCT	Low risk of bias	Patients: Intervention n=285, Baseline n=286	Follow on from Bailey 2013 study using In-house development of real-time alerts but this time sent to RRT nurse rather than the ward charge nurse.	Not reported	Intervention group was more likely to have telemetry (69.2% v. 61.8% p<0.05) and oximetry (7% v.2.1% p<0.005) started. Control group was more likely to have new antibiotic orders started within 24 hours of the alert 42.5% v. 32.2% p=0.011). The number of RRT calls initiated by the primary care team was similar for the intervention and control groups (19.9% vs. 16.5%; odds ratio: 1.260; 95% CI: 0.823-1.931).
Bailey 2013, US	Randomised controlled Cross-over study	Low risk of bias	Intervention n=9,911 control n=10,120	In-house development of real-time alerts system to predict ICU transfer risk. Alerts sent to charge nurse.	Not reported	A threshold of 0.976 for specificity was chosen to achieve a sensitivity of approximately 40%. These operating characteristics were chosen in turn to generate a manageable number of alerts per hospital nursing unit per day (estimated at 1–2 per nursing unit per day).
Prytherch 2006, UK	Randomised Crossover Study, classroom setting.	Moderate risk of bias	Nurses n=21	1) traditional pen and paper method 2) VitalPAC™	Not reported	Incorrect entries or omissions: 29% (24/84) Paper vs. 10%(8/84) VitalPac™ Incorrect clinical actions:14% Paper (12/84) vs. 5% (4/84) VitalPac™ The mean time (±SD) taken for participants to calculate and chart a set of weighted values and early warning score using the pen/paper method was 67.6±35.3 s (n = 84). The corresponding time taken to enter a set of physiological data using the VitalPAC was 43.0±23.5 s (n=84).

Jones 2011, UK	Before-and-after trial	High risk of bias	n=1481 patients included	Patientrack™	Not reported	Accuracy of recording improved 81% to 100%, Clinical attendance improved (EWS 3, 4, and 5) 29% to 79%; EWS level >5 from 67% to 96% (p<0.001). Complete compliance with the early warning score protocol for EWS 3, 4 or 5 (i.e., recheck EWS within 1 hour and if still EWS 3, 4 or 5 then clinical response within the next hour) could not be determined in the baseline group due to poor documentation of attendance times in the medical record.
Mohammed 2009, UK	Before-and-after, classroom setting phase I & II, with phase III ward environment (3 phases)	High risk of bias	Nurses n=26 Phase I (classroom), n=20 nurses phase III (ward)	Phase I early warning score calculated pen and paper; Phase II (classroom) using VitalPAC™, Phase III (ward) VitalPAC™	Not reported	Accuracy: Paper based 58% vs. electronic classroom 96% CI 95% 31-44% (P<0.0001), Phase 3: Electronic classroom 96% vs. Electronic Ward 88% p=0.006 Efficiency: Paper based 37.9s vs. Electronic classroom 35.1s (p=0.016) vs. Electronic Ward 24.0s (p<0.0001)
Continuous monitoring with electronic early warning system integration						
Bellomo 2012, Multi	Controlled Before-and-after trial	High risk of bias	Intervention n=8,688 Controls n=9,617	Intellivue System, Philips Medical	90 day post discharge	The time required to complete and record a set of vital signs decreased from 4.1 ± 1.3 mins to 2.5 ± 0.5 mins (difference [95% CI] 1.6 [1.4–1.8]; p < 0.0001); Intervention change: Reduction in vasopressor use p=0.02; Intervention led to a 52% relative increase in proportion of RRT calls triggered by respiratory criteria and a decrease in abnormal physiological criteria present at the time of the call.

Clinician Experience

Two studies specifically explored clinician experience with the electronic early warning systems. Mohammed et al.[22] found that at first in the paper phase of the study, nurses favoured paper-based records over the electronic system in all respects except accuracy. In phase 2 (the classroom experience with an electronic early warning system) the nurses' views shifted to favour hand-held computer recordings. In phase 3 (ward setting for electronic early warning systems) nurses continued to prefer using the hand-held computer.

Prytherch et al.[17] also examined pen and paper versus electronic early warning systems in a classroom setting. Completing a questionnaire using a five-point Likert scale (1 = strongly favours pen and paper, 5 = strongly favours VitalPAC™), the participants showed a preference for the VitalPAC™ across all five questions:

- Pen and paper method is more accurate 3.86 (1.35 SD)
- Pen and paper allows easier detection of errors 3.76 (1.26 SD)
- Pen and paper method is simpler 3.52 (1.50 SD)
- Pen and paper method is quicker 3.43 (1.60 SD)
- Pen and paper method is more convenient 3.33 (1.56 SD).

3.2.2 Electronic clinical handover systems

Of the 17 included studies examining electronic clinical handover systems, two were prospective randomised cross-over studies[24;25], one was a controlled trial[26] and the remainder were before-and-after studies. The two cross-over studies were considered to have moderate levels of bias as the method of randomisation was not well described, concealment of treatment allocation was not clear and it was not certain if baseline characteristics or outcomes were similar. All other studies were classified as having high bias due to the before-and-after nature of the trials. See Tables 3.11 and 3.12 for a summary of studies and risk of bias.

For data collection, the studies tended to use surveys, questionnaires or informal discussions with audit. The information collected by the studies was diverse, however it can be grouped into discrete domains: information transfer, clinician experience with use, compliance, efficiency in processes/quality improvement, length of stay, and adverse incidents. The majority of findings related to information transfer, clinician experience with use and change in work processes as a result of the intervention. There were no studies that reported change in mortality, cardio-pulmonary arrest rates or ICU admissions. See Table 3.13 for a summary of outcomes.

Table 3.11. Electronic clinical handover systems summary of studies

Country of origin	
US	9
UK	4
Australia	1
Ireland	1
Spain	1
Denmark	1
Total studies	17
Type of trial	
Prospective randomised cross-over study	2
Controlled trial	1
Before-and-after study	14
Level of bias*	
Prospective randomised cross-over studies	Moderate
Controlled trial, before-and-after trials	High
Data collection tool/method	
Survey or questionnaire	16
Informal discussion with audit	1

*Level of bias determined using EPOC 9 criteria.

Table 3.12. Randomised controlled crossover trial assessment of risk of bias for electronic clinical handover

	Van Eaton 2005[24]	Van Eaton 2010[25]
Was the allocation sequence adequately generated?	unclear	unclear
Was the allocation adequately concealed?	unclear	unclear
Were baseline outcome measurements similar?	low	low
Were baseline characteristics similar?	low	low
Were incomplete outcome data adequately addressed?	unclear	unclear
Was knowledge of the allocated interventions adequately prevented during the study?	unclear	unclear
Was the study adequately protected against contamination?	unclear	unclear
Was the study free from selective outcome reporting?	low	low
Was the study free from other risks of bias?	low	low

Table 3.13. Summary of clinical outcomes data reported for electronic clinical handover systems

Study	Information transfer	Clinician Experience with use	Length of Stay	Adverse Events*
Ahmed J[27] (Before-and-after)	X			
Barnes SL[28] (Before-and-after)	X	X		
Craig SR[29] (Before-and-after)				X
Govier M[30] (Before-and-after)		X		
Graham KL[31] (Before-and-after)	X	X		X
Hertzum M[32] (Before-and-after)		X		
Kochendorfer KM[33] (Before-and-after)	X	X		
Oroviogoicoechea C [34] (Before-and-after)		X		
Palma JP[35] (Before-and-after)	X	X		
Panesar RS[36] (Before-and-after)	X			
Patel VP[37] (Before-and-after)	X	X		
Payne CE[26] (Controlled trial)	X	X		
Raptis DA[38] (Before-and-after)	X			
Ryan S[39] (Before-and-after pilot study)			X	
Van Eaton EG (2005)[24] (Prospective randomised cross-over study)	X	X		
Van Eaton EG (2010)[25] (Prospective randomised cross-over study)				X
Wohlauer MV[40] (Before-and-after)	X			

*Adverse events are those that were averted OR occurred as a result of the introduction of the electronic system. **X** indicates where data was present in a particular domain.

Information Transfer

The main areas of change related to the introduction of electronic clinical handover systems were in accuracy and in the scope of the information that was handed over, and a reduction in the time for handover to occur, see Tables 3.14 and 3.15. Four of five studies[24;33;35;40], which included one randomised controlled cross-over study by Van Eaton et al., reported on efficiency outcomes and indicated that the introduction of electronic clinical handover systems reduced the time taken to perform ward rounds, handover or sign-out.

Eight studies[24;26;27;30;31;37;38;40] including the randomised controlled cross-over study by Van Eaton et al. reported an improvement in the accuracy of information transferred and also in the quality of the documentation. One before-and-after study by Panesar et al. reported on improved multidisciplinary communication with the introduction of an electronic SBAR tool.[36]

Table 3.14. Summary of time efficiencies reported with electronic clinical handover systems

Domain	Author	Study Design	Study Quality	Patients	System	Follow-up	Outcomes
Time efficiency changes	Van Eaton et al. 2005, US	Randomised crossover study	Moderate risk of bias	Two sites: Surgical and internal medicine residents (n=161)	Centralised, web-based computerised ward-round and sign-out system (UWCores)	6 week run-in period. 5-month study period. Study ended post intervention	Reduced time spend pre-handover (copying data from EHR). Use of UWCores reduced the mean portion of prerounding time spent hand-copying vital signs and laboratory values data from 24% to 12% (p <0.0001) Reduced handover duration (1.5mins per patient p<0.0006)
	Kochendorfer et al. 2010, US	Before-and–after	High risk of bias	Inpatient wards Residents, faculty members (n=53/93 respondents before; n=62/108 respondents after). Only 18 residents and 15 attendees completed both surveys.	A standard, in-house, computer-generated document for daily ward rounds.	5 month study period. No follow-up post end of trial	Time saving: 44 mins less on rounding post implementation.
	Palma et al. 2010, US	Before-and-after	High risk of bias	US: Single site Neonatal ICU (NICU) Multidisciplinary neonatal care staff (n=52 respondents	Electronic Medical Record (EMR) - integrated Neonatal ICU specific handoff tool, compared to a	6 month study period. No follow-up post end of	Updating sign-off information pre (11-15mins/day) post (16 to 20 mins/day), p=0.026, Median reported percentage Sign-

				before; n=46 respondents after)	standalone Microsoft access-based handoff tool	this period.	out preparation time pre (25-49%) post (<25%) p=0.0006.
	Ryan et al. 2010, Ireland	Before-and-after (pilot)	High risk of bias	Surgical staff (no number reported) 47 paper based reports, 41 electronic reports.	A standard, in-house, computer-generated document for daily ward rounds.	Two separate two week before-and-after study periods.	No significant difference in the time taken to obtain the first intervention when both time periods were analysed before-and-after the introduction of the electronic handover (P=0.059, 21.2 (10.3) versus 28.2 (7.8) h (mean SEM)).
	Wohlauer et al. 2012, US	Before-and-after	High risk of bias	Survey method of junior doctors. Pre-implementation n=168 Post-implementation n=83	In-house computerised ward-round and sign-out (CSO) programme to automate collection of clinical information in addition to a brief narrative describing ongoing care issues.	9 month study period. No further follow-up after post intervention survey.	11 fewer minutes in pre-round (p<0.006)

Table 3.15. Summary of details of information transfer post electronic clinical handover system introduction

Domain	Author	Study design	Study Quality	Setting	System	Follow-up	Reported Outcomes
Demographic patient details	Ahmed et al. 2012, UK	Before-and-after	High risk of bias	Acute surgical ward NCHDs (no number reported) (n=137 admissions before; n=155 admissions after)	In-house computerised handover template	8 week study period. No further follow-up post intervention audit.	Patient number documented: 84(61%) vs. 132 (85%) p<0.001, Date of birth 124(91%) vs. 158(98%) p<0.005
	Patel et al. 2009, UK	Before-and-after	High risk of bias	Trauma and orthopaedic unit NCHDs (n=43), 350 patient paper based, 357 patients web-based.	In-house computerised handover template vs. paper-based system	6 month study period. No further follow-up post intervention	Improved information transfer post intervention: • missing demographic data reduced 35.1% to 0.8% p<0.0001 • missing patient location reduced from 18.6% to 3.6% p<0.0001 • missing consultant information reduced from 12.9% to 2.0% p<0.0001
	Raptis et al. UK, 2009	Before-and-after	High risk of bias	Acute hospital (600 beds) Medical interns (no number reported) (n=773 handovers before; n= 872 handovers after)	In-house computerised handover template vs. paper-based system	Four month study period. No further follow-up post intervention	Patient details recorded improved post intervention: • Overall 34% vs. 100% p=0.0001 • Patient location 86% vs.96% p=0.001
Compliance	Govier et al. UK, 2012	Before-and-after	High risk of bias	Weekend on-call doctors (no number	In-house electronic spreadsheet	Weekend audit. No further	First audit cycle: 86% had some form of written handover. Second audit cycle (post intervention with

				reported)	system for written weekend handover.	follow-up post intervention	an electronic list with minimal dataset): 100% having a written handover, 86.3% was electronic list based.
Clinical details recorded	Ahmed et al. 2012, UK	Before-and-after	High risk of bias	As above	As above	As above	Number of records with past medical history documented: Pre intervention 39 (28%) vs. post intervention75 (48%), p<0.001
	Graham et al. 2013, US	Before-and-after	High risk of bias	Primary and night-time covering interns (n=39) at a US hospital (n=200 written handoff reviewed), 9,200 day to night handoffs	In-house electronic template for the day-to night handoff	Four month study period. No further follow-up post intervention	Handoff content: ▪ Active problem list pre(74%) post(96%) p<0.001 ▪ Current clinical status pre(46%) post(96%) p<0.001, ▪ Anticipatory guidance pre (53%) post (86%) p<0.001.
	Patel et al. 2009, UK	Before-and-after	High risk of bias	As above	As above	As above	Missing diagnosis reduced from 11.7% to 0.8% (p<0.0001). Missing data on side was reduced from 31.4% to 0.8% (p<0.0001). Missing information on anatomical site 13.7% vs. 1.1%. Treatment plan included in pre (52.3%) and post (94.7%) (p<0.0001). On 96.6% of paper ad hoc handovers it was not stated whether the injury was 'closed' or 'open', whereas in the electronic group this information was evident in 100%
	Payne et al. 2012, US	Before-and-after	High risk of bias	Internal medicine 12 resident teams	Web-based application designed to standardise	1 month intervention 4 month follow-up	Increase in the completeness of information handed over. Code Status 100% (post) vs. 55%(pre) p<0.01, Problem List 100% (post) vs. 48% (pre) p<0.01, Medication

				(n=80 respondents before; n=161 respondents after)	information exchange	period.	List 100%(post) vs. 11%(pre) p<0.01
	Raptis et al. 2009, UK	Before-and-after	High risk of bias	As above	As above	As above	Improvement in recording post intervention: ▪ Primary diagnosis 85% vs. 91%, p=0.002 ▪ Current problem 86% vs. 93%, p=0.001 ▪ Day team details 52% vs. 96%, p=0.001 ▪ Plan of action 93% vs. 97%, p=0.002
Quality improvement	Van Eaton et al. 2005 US	Prospective Randomised crossover study	Moderate risk of bias	As above	As above	As above	Reduced number of reported patients missed out during handover rounds among the intervention group (2.5 vs. 5 patients/team/month (p=0.0001)
	Wohlauer et al. 2012, US	Before-and-after	High risk of bias	As above	As above	As above	Reported 'No missed' patients increased post intervention (pre 56.5% to post 69.9% p<0.01)
	Ahmed et al. 2012, UK	Before-and-after	High risk of bias	As above	As above	As above	Patient assessment by senior clinician 3 (2%) vs. 125(85%) p<0.001

Clinician Experience

Ten studies[24;26;28;30-35;37] examined clinician experience regarding the introduction of electronic clinical handover systems. All studies reported improved overall satisfaction with the electronic system of handover. Perceived improvements from the clinician perspective included clearly outlined medical plans, readable discharge summaries, clearer discharge plans and easier access to patient information in the file.

Reduced workload burden was also reported and many of the respondents felt that clinically relevant errors were less likely post implementation and that they received more clinically relevant information during the sign-out process. The perception was that electronic clinical handover systems improved quality of care, sign-out quality and continuity of care.

Length of Stay (LOS)

Only one before-and-after study reported on the effect of electronic clinical handover in an acute surgical setting, on LOS. In a study carried out in Ireland, Ryan et al.[39] showed that there was a reduction in median patient LOS in the two week post-intervention period, from five to four days (p=0.047).

Adverse Events

Three studies[25;29;31] reported on the impact of introducing an electronic clinical handover system on adverse event rates.

A US prospective, randomised crossover study by Van Eaton et al. [25] examined the safety of introducing an electronic clinical handover system and concluded that the introduction of an electronic handover/ward-round system (UWCores) did not worsen recording error rate and as a result was not shown to compromise patient safety (Mean number of errors reported 6.33 per 1,000 patient-days [control] vs. 5.61 per 1,000 patient-days [intervention], p=0.68); Reported overnight medical error under UWCores Odds Ratio [1.01, p=0.96]; Adverse Drug Events by the intervention team [OR 1.10 p=0.70]).

A before-and-after study by Graham et al.[31] show a reduction in critical data omission, near miss events and adverse events post intervention (critical data omission events pre (23) post (0) p<0.001, near misses pre (9) post (0) p<0.056, Adverse events pre (4) post (0) p<0.41.).

Another before-and-after study by Craig et al.[29] compared three phases of clinical handover: paper-based, electronic and face-to-face and found that medical interns

had a nine times greater risk of a reporting protocol failure with paper-based handover alone (95% CI 1.2-65.6, p=0.009), 7.4-fold risk (95% CI 1.1-54.1, p=0.016) with electronic handover alone, but no significant risk of protocol failure with face-to-face handover.

3.2.3 Subgroups analysis in paediatric and maternity patients

Few studies involving paediatric or maternity subpopulations were retrieved.

One before-and-after trial study by Palma et al.[35] was conducted to examine the effect of an electronic clinical handover tool in a newborn intensive care unit. It showed that the incorporation of a neonatal ICU (NICU)-specific handover tool into the EMR was perceived to improve sign-out accuracy, work-flow and provider satisfaction.

There were no studies retrieved that examined electronic early warning systems or electronic clinical handover systems involving the maternity population.

3.3 Discussion

Although this systematic review examines the clinical effectiveness of these electronic systems separately, it should be noted that this split is somewhat artificial. As innovations in this area continue to gain pace, both electronic early warning and electronic clinical handover systems are being incorporated into broader categories of systems termed electronic physiological surveillance systems. These systems not only consider the electronic collection of vital sign data, calculation of an early warning score and escalation of care, but in addition, the data is being used to generate handover templates and discharge summaries. Modules for harnessing more complex patient data such as fluid balance, nutritional status, tracking of infection control outbreaks and discerning patient acuity per staffing level, are also gaining in popularity.

Electronic early warning and continuous monitoring systems

Many of the published studies were suitably sized, however they were hampered by some degree of bias. The common early warning systems that were examined included the review of a move from a paper-based to electronic early warning systems, the comparison of a new electronic alerting system to no alerts and continuous monitoring systems either with or without the integration of an automated electronic early warning. The move from a paper-based to an electronic early warning system was the profile that most closely reflects the Irish context.

Table 3.16 summarises the main mortality and LOS findings in different categories of electronic early warning systems.

Table 3.16 Summary of mortality and LOS outcomes in different categories of electronic early warning system

Paper versus Electronic Early Warning System	Schmidt 2014 Dawes 2014 Jones 2011 (All before-and-after studies)	▪ Reduction in mortality shown by Schmidt et al. ▪ Reduction general and ICU LOS by Jones et al. ▪ No reduction in LOS by Dawes et al.
Continuous monitoring versus no continuous monitoring	Watkinson 2006 (RCT) Bellomo 2012 (CBA) Brown 2014 (B-and-A)	▪ No change in ICU transfer rate, Watkinson et al. ▪ Decreased general LOS Bellomo et al. ▪ Decreased general and ICU LOS Brown et al. ▪ Increased cardio-pulmonary arrest rate, Watkinson et al. ▪ Decreased cardio-pulmonary arrest rate, Brown et. Al
Electronic alerts versus no electronic alerts	Kollef 2014 (RCT) Bailey 2013 (Cross-over study)	▪ Reduction in general LOS by Kollef et al. ▪ No reduction in LOS by Bailey et al.
Manual versus electronic data input (Classroom based trials)	Prytherch 2006 (RCT) Mohammad 2009 (B-and-A)	▪ Fewer errors in computer-based systems ▪ Recording efficiency gains

B-and-A: Before-and-after study
RCT: Randomised controlled trial
CBA: Controlled before-and-after study

Although, at a high level, the interventions could be considered somewhat similar (that is, the introduction of some type of electronic early warning or continuous monitoring system), each system differed in terms of interface, structure, algorithms and pathways. In addition, the studies reported a variety of outcome measures. These issues made the synthesis of data difficult. The studies most commonly reported outcomes of mortality, cardiopulmonary arrest rates ('code blue' calls), length of stay changes and changes in work processes.

With regard to the effect of moving from paper-based to an electronic early warning system there was some level III-3[41] [4] evidence of a statistically significant reduction in crude mortality over a five year period of electronic early warning system use. Level III-3 evidence includes studies that are based on a before-and-after study design using historical controls so as a result there is an inherent high risk of bias. However, although there are some limitations in terms of study design, such as failure to measure all cause mortality and the possible effect of confounders, the investigators made strong efforts to mitigate the limitations. The study was carried out in two separate large hospitals (>1,000 beds each, located >200 miles apart). They also included seasonally-adjusted data and reported no major case-mix changes that might have impacted the observed reduction in mortality. The results showed an estimated 397 and 372 fewer deaths over five years in the two study sites, respectively. This large, well conducted study by Schmidt et al.[4] also reports that the reduction, which coincided with the introduction of an electronic early warning system, was both abrupt and sustained in both study sites. The positive effect of the electronic early warning system was thought to be due to improved accuracy and frequency of vital sign recording, increased delivery of decision support, and the enhanced usability of the system. This trend in improved accuracy of data recording and the optimisation of vital sign recording positively impacts on efficiency. These outcomes make a positive contribution to overall patient safety.

Regarding the effect on mortality of introducing an alerting system, neither the RCT by Kollef et al.[14] nor the randomised controlled cross-over study by Bailey et al.[16] showed a significant reduction. However, the Bailey study did show that patients with alerts had an 8.9 fold greater risk of death than those without alerts. The authors acknowledge that the failure of their system to positively impact on outcomes may have been due to the fact that alerted staff may not have made the appropriate patient-directed interventions despite the improved accuracy of detection of the deteriorating patient. The system relied strongly on the actions of a single alerted charge nurse to make clinical decisions. This reiterates the importance of adequate training of clinical staff in the management of the deteriorating patient. Without the appropriate number of properly trained staff to manage a particular unit and deliver the appropriate care to the newly identified deteriorating patient, the potential gains from an electronic system can never be fully realised. In addition, this study although well designed and of good quality, used a tool that was

[4] NHMRC Evidence Hierarchy: Level III-3- A comparative study without concurrent controls:
- Historical control study
- Two or more single arm study
- Interrupted time series without a parallel control group

developed solely for that specific local population and hence to generalise the results to other populations may not be reasonable.

Changes in general and ICU length of stay were reported by a number of studies. Baseline LOS varied broadly from 4-10 days across studies. This broad baseline range makes interpretation and applicability to the Irish context difficult. Irish average length of stay (ALOS) for the acute adult in-patient was reported as 5.9 days. [(42)] Different countries may have varying healthcare infrastructures that independently impact the LOS. This is particularly relevant if the studies have a high risk of bias that is inherent in a before-and –after study design. Of those studies reporting on outcomes related to the move from paper-based to electronic early warning systems, the large level III-3, before-and-after study by Jones et al.[(21)] reported a 29% reduction of LOS post intervention. The same study also showed ICU length of stay reduction of 40.3% and a significant reduction in ICU admissions (14 admissions to 5 admissions p=0.04) post introduction of their electronic early warning system when compared with a baseline paper record. Dawes et al., also reported a reduced length of stay post intervention of 2 days, however, this outcome lost significance once adjusted for severity of illness on admission.

In relation to studies that examined the impact of electronic alerts on general LOS, the RCT by Kollef et al. showed a significant reduction in LOS of one day in the post intervention arm. The larger randomised controlled cross-over study by Bailey et al. did not show any reduction in length of stay, however, as noted previously, the authors considered that the lack of appropriate resources to manage the identified deteriorating patient may have impacted the overall outcome measures.

The before-and-after study by Brown et al.[(19)] which examined the impact of continuous patient monitoring reported a significant reduction in cardio-pulmonary arrest rates. However, the RCT by Watkinson et al.[(15)] showed an increase in these calls in the first 96 hours after randomisation. However, this trial had a small size and it was unclear whether the study was adequately powered to reach a substantial conclusion. The mixed results also may point to the fact that the effectiveness of any continuous monitoring is intimately linked with the availability of resources to be aware of and appropriately respond to the changes in parameters and to have adequate interventions in place to treat the identified deteriorating patient.

The introduction of electronic early warning systems also appeared to positively impact work processes in terms of efficiency gains, improved accuracy of vital sign recording and improved clinical attendance to the deteriorating patient. Improvements of accuracy of vital sign recording, clinical attendance, compliance with early warning score protocols and reductions in incorrect clinical actions and

efficiency gains for staff post introduction of an electronic early warning system, offer positive contributions to a safer patient environment.

No adverse events or negative effects on patient safety were reported as a result of the introduction of electronic early warning systems. No outcomes from the patient perspective were recorded. This is a gap in the literature. All new interventions need to have a patient centred focus to ensure that from the patient perspective, their care is never compromised. All studies examining clinician experience with electronic early warning systems reported positive perceptions in terms of improved patient safety and accuracy of recording.

Electronic clinical handover systems

The majority of published studies on electronic clinical handover systems were unblinded, before-and-after studies with short or unspecified follow-up periods. Reported outcomes tended to focus on information transfer and clinician experience. Mortality and ICU LOS data were not reported. As with electronic early warning systems, electronic clinical handover systems used a variety of platforms (Electronic Patient Record systems, stand-alone systems, and web-based modules) and collected a variety of data which makes synthesis of information difficult.

Some time efficiency gains were reported in rounding and sign-out processes. Clinician experience of electronic clinical handover systems was positive with a perceived reduction in workload burden, clearer medical plans and discharge summaries, and improved patient safety as a result of more accurate and legible documentation. In one study, length of stay was shown to be significantly reduced with electronic clinical handover systems.

It was also reported that electronic clinical handover systems did not increase the adverse event rate in the clinical setting and that there was a reduction in critical data omission, near miss events and adverse events post introduction of the system. These positive impacts on the patient safety environment are important gains to be realised from electronic clinical handover systems. However, another study showed that face-to-face handover out-performed both paper-based and electronic handover (both the electronic and paper handovers were without any face-to-face handover). This highlights the point that electronic tools are best used as aids to the clinician rather than as substitutes for clinician-led care.

3.4 Summary

- The results of this systematic literature review indicates there is some evidence that the implementation of electronic early warning systems has

contributed to reduced mortality rates. Change in general and ICU LOS varied from a minimal reduction up to 29% and 40% reductions, respectively. Improved accuracy of recording, compliance with escalation protocols and significant user (clinician) satisfaction were also reported. However, as the quality of studies of effectiveness was variable and as the interventions were performed in a variety of healthcare jurisdictions with a variety of outcomes measured, therefore the generalisability to the Irish healthcare context may be limited.

- The quality of studies on the clinical effectiveness of electronic clinical handover systems were hampered by poor study design, small sample size and unspecified follow-up. The trend of results showed increased accuracy of recording handover, efficiency gains for staff and positive clinician user perception of improved patient safety due to better handover communication processes. However, a face-to-face element to clinical handover is still an important part of patient care.

- Systems that combine processes of electronic early warning systems and electronic clinical handover systems with other clinical data such as fluid balance, cognitive and nutritional status are gaining favour commercially because of the advantages of integration and analysis of complex data in one central repository with the resultant facility to use this information for many other hospital processes such as ward work-flow.

4. Benefits and investment requirements

4.1 Systematic review of costs and cost-effectiveness studies

4.1.1 Search strategy

A search was carried out in Medline, Embase, NHS Economic Evaluation Database (EED), Health Economics Evaluation Database (HEED) and the HTA database for economic analyses of electronic early warning and clinical handover systems. The search in Medline and Embase was carried out in tandem with the systematic review of clinical effectiveness detailed in Section 3.1. No methodology filters were used in that search so the returned results included economic analysis studies. These were identified and recorded during the screening and review process. Searches in NHS EED and the HTA database were performed in the Cochrane library and searches in HEED were performed in the HEED search portal (Wiley online library). No date or language restrictions were applied. All searches were carried out up to the end of December 2014.

4.1.2 Results

Cost and resource use data reported in the literature are minimal. No cost effectiveness studies, one return-on-investment study and two studies reporting resource utilisation were retrieved. With regards to electronic clinical handover systems, no cost-related studies were retrieved.

One US-based study by Slight et al.[43] reported a highly positive return-on-investment of implementing a continuous monitoring system in a general medical-surgical unit. Their data was based on the controlled before and after study (CBA) study by Brown et al.[19] For ease of review, all costs presented have been inflated using the local consumer price index for health to 2013 values and then converted to Irish Euro using the latest Purchasing Power Parities.[44] They compared two models, based on 2009-2010 cost data, (a base case model A and a more conservative model B) showing a net benefit range for intervention between €583,003 (model B) and €1,847,357 (model A) per annum with the hospital breaking even on the investment after 6 months and 9 months, respectively. The investment represented the cost of installing and maintaining the system and training staff to use the systems. The return was calculated on the basis of hospital LOS and ICU LOS for patients transferred from the medical-surgical unit. The average net benefit per patient ranged from €198 (model B) to €629 (model A). In addition, both models were subjected to a multiway sensitivity analysis of most and least favourable conditions. The most favorable conditions yielded a net benefit of €3,386,546 (model B) and €9,388,962 (model A) while the least favorable conditions yielded a net

benefit of €633,229 (model B) and €2,998,761 (model A). The return-on-investment was calculated to range from 25.4% per annum (model B) to 120.3% per annum (model A) for the least favourable conditions and 125.5% (model B) to 347.9% (model A) for the most favourable conditions.

The multi-centred trial by Bellomo et al. (2012) [18] reported acquisition costs for the continuous monitor that was used in their study of €4,673 (2012) per monitor with an additional 5% yearly maintenance cost. Post intervention they also estimated nursing time saved of 1,750 hours/year/ward, in the setting of 349 beds in 12 general medical wards.

In a UK study published in Schmidt et al.[4] indicated the staff resources that they enlisted to assist with the implementation of their trial. This was reported as 1.0 whole time equivalent (WTE) nurse (available for post support for 7 months), 0.25 WTE company trainer, 0.2 WTE physician to facilitate user training at site 1 (>1,000 beds).

To summarise, the limited economic literature available suggest that a continuous monitoring system offers a favourable return on investment, with the cost of installing and maintaining the system offset by reductions in LOS and ICU LOS and nursing time. However, given the differences in US hospital funding and administration practices the relevance of these cost data to the Irish healthcare setting is not known.

4.2 Estimated resource gains and investment requirements

In this section, the resource gains and the investment requirements of potentially implementing an electronic early warning system into a representative Model 4, 530-bed teaching hospital in Ireland were estimated. The population and setting was limited to the acute hospital, adult in-patient services excluding maternity and paediatrics (see Table 4.1 for hospital profile). The benefit estimates that are presented are not based on independent economic modeling but rather extrapolated results from a study identified in the systematic review that most closely represented the Irish context and which reported on the impact on length of stay. The estimates should be considered with this in mind.

Table 4.1. Level 1 hospital bed and ICU admission profile for cost analysis

Model 4 Hospital Profile	
Total beds	530
Total Beds (adult)	457
ICU Beds total (General and Cardiac) *	16
Acute Wards (Medical and Surgical)	18
ICU admissions 2014	178

*National Critical Care beds in Public Hospitals n=233

4.2.1 Estimated resource gains

The estimated resource gains were derived from a reduction in general and ICU LOS as per the findings in the systematic review. Four studies reported general reduced LOS. To ascertain the resource gains, studies that most closely resembled the Irish setting where chosen for the model. Regarding general LOS, two[14;16] of the four studies were excluded from the cost analysis because: they were US-based and were considered to have healthcare delivery structures that were too diverse from the Irish setting; their choice of early warning score underpinning the alert systems was not based on a nationally validated algorithm; they were assessing the introduction of an electronic alert system rather than the move from a paper-based to electronic early warning system; and had a different escalation process than the Irish setting. One UK study was excluded on the basis that it did not compare the introduction of the technology with a paper-based system.[20] Hence, estimations of the reduction in LOS were based on the study by Jones et al.[21] Although the baseline LOS reported by the Jones et al., was 9.7 days compared with ALOS of 7.0 days in the local Irish setting and the study design had a high risk of bias, this study was chosen because of its large sample size, the use of a paper-based comparator and national early warning score, and because it had escalation protocols and response systems that most resembled the Irish setting.

Irish data used for calculating benefits were as follows:

- Local Irish site: ALOS 7 days; ICU-beds n=16, ICU annual bed-days assuming 90% occupancy n=5,256;
- Nationally: ALOS 8.2 days, ICU beds n=233, ICU annual bed-days assuming 90% occupancy n=76,000

Tables 4.2 and 4.3 summarise some of the parameters for benefits calculation.

Table 4.2. Hospital Inpatient Enquiry: Activity data for local site and all hospitals nationally, 2013

	Hospital	Number of Cases	Bed Days	Average Length of Stay
All Inpatients (Excluding Maternity & Children)	Local Site	26,131	153,407	5.9
	Total for All Hospitals	409,430	2,843,675	7.0
Overnight Inpatients (Excluding Maternity & Children)	Local Site	21,279	148,555	7.0
	Total for All Hospitals	338,865	2,773,110	8.2
National ICU Bed days assuming 90% occupancy: 76,000				
Source: HIPE 2013 (accessed February 2015)				
Data exclude cases with admission type 6 (maternity) and age<18				
Overnight inpatient refers to inpatients with an overnight stay of at least one day, i.e. inpatients that were admitted and discharged on the same day are excluded.				

Table 4.3. LOS extrapolation, data from Jones et al.[21]

General Hospital Beds	
Original ALOS	9.7
Improved ALOS	6.9
Difference (days)	2.8
% Reduction	28.9%
ICU	
Original ICU Bed Days per 10,000 Bed Days	47.2
Improved ICU Bed Days per 10,000 Bed Days	28.2
% Reduction (proportion)	40.3%

*Original ICU LOS 51
*Improved ICU LOS 26

Applying the results of the Jones et al. study to the Irish setting could result in a potential reduction in general ALOS by 28.9% (CI 18.6%-40.3%) and ICU ALOS by 40.3% (4.6% - 76%), leading to additional national hospital capacity of 802,096 bed days per annum relative to a total capacity of 2.8 million acute hospital bed days per annum and 30,628 ICU bed-days per annum relative to a total capacity of 76,000 ICU bed days per annum. The wide confidence interval particularly for the ICU ALOS requires caution in interpretation of the true magnitude of the potential reduction; the most conservative reduction could be as little as 5% or 3,800 ICU bed days per

annum. However, if this resource gain was to be even partially realised, it would allow for more efficient utilisation of acute hospital beds, reduced pressure on Emergency Departments, reduced waiting times for elective surgeries and ultimately more appropriate and timely access to acute hospital services. This resource gain is not presented here as a monetary saving as beds that would become available with improved patient flow would be used more efficiently rather than provide an actual monetary saving. The potential benefit to patients is appropriate escalation of care and improved patient safety. Having the most appropriate level of care available according to need would be dependent on resources being reallocated to areas in which acutely deteriorating patients are detected, i.e. having a highly reactive system for allocating staff, which is not representative of current standard of care.

Other potential benefits include increased efficiencies gained from reduced vital sign recording time, as much as 1.6 times faster than that of a paper-based system. This means more available clinician time to deliver care to patients. When this efficiency gain is coupled with improved accuracy of recording of vital signs and handover information, the gains realised through a safer patient environment are important contributions to be noted.

4.2.2 Investment requirements

For the above benefits to be realised, approximate investment and resource requirements were estimated and are presented in Tables 4.4 and 4.5. The electronic early warning system investment outlined is for the core module alone, without any continuous monitoring provided; that is, a manual data input system that automatically calculates the early warning score which is escalated as appropriate in line with local protocols. The core module also includes an electronic clinical handover system. Costs related to additional modules that incorporate broader patient and hospital data such as infection control surveillance are not included. System supplier support for implementation and education of staff were also considered in the costs.

Two types of licensing agreements were considered. Type 1 is where a fee for the software license is paid for a certain timeframe (in this case for a five year period) in addition to any hardware yearly costs and maintenance. Type 2 is where a one-off payment for the software license is issued and maintenance and hardware costs are the only ongoing costs. The investment estimates were derived from indicative costs from suppliers and UK organisations and hospitals that have had experience in electronic early warning system implementation programmes. The cost of procuring and maintaining the systems may differ based on local tendering and procurement arrangements.

Implementation costs include training of staff in use of the system and also clinical and supplier staff required to assist with project implementation.

The opportunity cost of staff training was estimated to be 15 minutes training per healthcare worker. This cost was derived from UK pilot study data and will need to be adjusted for the Irish context as appropriate. This cost was estimated on the understanding that the roll-out had the following format; the training programme is ward based where staff are shown how to use the system which takes on average 15 minutes. This is followed by continued staff duty using the new electronic system with supervision by the supplier and hospital project managers. The roll-out per hospital can be from 3 to 6 months depending on hospital size. All healthcare workers would be required to have completed Compass™ training prior to use of the electronic early warning systems. If the training process deviates from the model outlined, further opportunity costs may need to be incorporated. Salary scales were taken as the mid-point of Health Service Executive pay range for staff nurses, NCHDs and Consultants.[45] These salary costs were adjusted to include imputed pension costs and overheads.[46] The annual hardware renewal rate was estimated at 30% based on supplier implementation experience and pilot study data from UK.

Inflation was calculated using UK consumer price index (CPI) for health, with an increase of 8.35% occurring from 2011 to 2014. Post-adjustment for country-specific inflation, conversion to Irish Euros was achieved using the purchasing price parity index as outlined in *HIQA Guidance on Budget Impact Analysis of Health Technologies in Ireland, 2015.*[44]

Table 4.4 Resource requirements for electronic early warning systems

Area	Resource
Technology	
Software	Annual license One-off license
Hardware	▪ Handheld devices ▪ Tablets ▪ Cases ▪ Multi device chargers
Integration fees	HL7 interoperability appears to be commercial system standard but each site requires baseline ICT infrastructure assessment prior to integration.
Implementation	
Project management staff*	▪ Supplier project manager (Year 1 and 2, €66,800 per annum and €26,720 year 3 and 4) ▪ Hospital project manager Year 1 (Nursing WTE 0.5)

Education of staff	Ward based and integrated with normal staff duties. Additional 15 minutes of demonstration with project manager support during the roll-out. COMPASS™ training required before use.
Clinical leadership staff	Clinical support Yr 1, Consultant (0.1 WTE), Nursing (WTE 1.25)

*Specifically for License Type 1. License Type 2 was shown to have an estimated amalgamated installation cost of €119,200 in Year 1. Education investment for Type 2 licensing was estimated to be the same as outlined for Type 1 license. All costs were derived from NHS pilot study data and will need to be adjusted appropriately for the Irish setting.

Table 4.5. Summary of approximate local site investments requirements for two license types of electronic early warning system (local 530 bed site) €

Costs	Year 1	Year 2	Year 3	Year 4	Year 5
License Type 1					
License fee per annum including maintenance costs	110,959	110,959	110,959	110,959	110,959
Hardware costs*	96,510	28,953	28,953	28,953	28,953
Implementation Costs					
Project management	147,293	26,720	26,720	26,720	-
Staff training	23,310	-	-	-	-
Total Type 1	**378,072**	**166,632**	**166,632**	**166,632**	**139,912**
Range of 20%	(336,578-419,565)	(138,650 – 194,614)	(138,650 – 194,614)	(138,650 – 194,614)	(138,650 – 194,614)
License Type 2					
License fee One-off payment	596,000	-	-	-	-
Maintenance costs		95,360	95,360	95,360	95,360
Hardware costs*	96,510	28,953	28,953	28,953	28,953
Implementation Costs					
Installation	119,200	-	-	-	-
Staff Training	23,310	-	-	-	-
Total Type 2	**835,020**	**124,313**	**124,313**	**124,313**	**124,313**
Range of 20%	(696,518 – 973,522)	(99,451-149,175)	(99,451-149,175)	(99,451-149,175)	(99,451-149,175)

*inclusive of VAT
Note: As the cost of license fees, maintenance and hardware are approximations, a range of 20% variation of the total is also presented. Initial cost estimates were derived from an NHS pilot study

Table 4.6. Summary of approximate National costs for two license types of electronic early warning system (€)

National Costs Type 1	Year 1	Year 2	Year 3	Year 4	Year 5
License fee per annum including maintenance costs	4,660,278	4,660,278	4,660,278	4,660,278	4,660,278
Hardware costs	2,294,610	688,383	688,383	688,383	688,383
Implementation Costs					
Project management	6,186,306	2,805,600	1,122,240	1,122,240	-
Staff training	286,126	-	-	-	-
Total Type 1	**14,549,560**	**8,154,261**	**6,470,901**	**6,470,901**	**5,348,661**
Range of 20%	(11.6m-17.5m)	(7.1m-9.2m)	(5.4m-7.5m)	(5.4m-7.5m)	(4.3m-6.4m)
National Costs Type 2	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**
License fee one-off payment	25,032,000	-	-	-	-
Maintenance costs		4,005,120	4,005,120	4,005,120	4,005,120
Hardware costs*	2,294,610	688,383	688,383	688,383	688,383
Implementation Costs					
Installation	5,006,400	-	-	-	-
Staff training	286,126	-	-	-	-
Total Type 2	**32,619,136**	**4,693,503**	**4,693,503**	**4,693,503**	**4,693,503**
Range 20%	(27.1m-38.0m)	(3.8m-5.6m)	(3.8m-5.6m)	(3.8m-5.6m)	(3.8m-5.6m)

*inclusive of VAT

Note: As the cost of license fees, maintenance and hardware are approximations, a range of 20% variation of the total cost is also presented.

4.3 Summary

- A range of investment requirements related to two types of licensing systems for electronic early warning systems are presented. These are indicative costs only which a formal tender process may substantially alter.

- Potential resource efficiencies are derived from reduction in general and ICU ALOS. There is considerable uncertainty in terms of both true benefits and investment requirements as investments may vary according to market forces and the resource gains are based on a single, historically controlled before-and-after study with a wide confidence interval on LOS reduction potential. A range of investment requirements and LOS reductions are presented to draw attention to this spectrum of uncertainty. Data from the systematic review of clinical effectiveness suggest that in addition to potential improvements in the patient safety, a move from paper-based recording of vital sign parameters to an electronic early warning system could mean a potential resource gain for the Irish healthcare setting realised as a reduction in general and ICU ALOS by 28.9% (95%CI 18.6%-40.3%) and 40.3% (95%CI4.6% - 76%), respectively. This would translate to a national hospital capacity gain of 802,096 bed days per annum and 30,628 ICU bed-days per annum.

- Regarding investment requirements, to purchase the license outright is a substantially greater investment in the first year (Type 2) however, the advantage is that it mitigates against future changes in license pricing. To offset the initial license costs of Type 2, maintenance costs appear lower compared with Type 1 licensing agreements, however these estimates may be subject to change and it is important to buffer against excessive variations in maintenance costs by requesting transparency from the suppliers regarding future expected maintenance cost changes.

- In the local site, overall five year investment requirements have been estimated as €1.0m and €1.3m for Type 1 and Type 2 licenses, respectively. On a national level, five year investment requirements have been estimated as €40.1m and €51.4m for Type 1 and Type 2 licenses, respectively.

5. Key Elements for Effective Implementation

5.1 Introduction

This chapter will outline the common themes to assist implementation of electronic early warning and clinical handover systems and also outline features that were identified by key stakeholders as being mandatory or desirable for the effective deployment of an electronic early warning and clinical handover system

5.2 Methodology

The themes to assist implementation of electronic early warning and clinical handover systems emerged from the findings in the systematic review and a series of semi-structured interviews carried out, both in person and over the telephone, with national stakeholders and international manufacturers and agencies that have been involved in the implementation of these systems.

5.3 Results

5.3.1 Electronic system requirements

Although systems come in various formats, some common themes to assist implementation can be extrapolated. In the first instance, all electronic early warning and clinical handover systems should be developed in line with NCEC quality assured National Clinical Guidelines. Computer learning algorithms and software driving the systems need to be developed with due consideration to the clinical parameters that have proven effectiveness. National Clinical Guidelines quality assured by NCEC and published by the Department of Health have been developed for use in healthcare organizations in Ireland only. The intellectual property rights of any National Clinical Guideline information, that is used for parameter or threshold development or any other inclusions, should be respected.

Aspects such as the system's functionality, usability and safety need to be considered. The system should be developed by a multidisciplinary team who have given due consideration to clinical, engineering and ICT elements and have a proven track record of excellence in provision of electronic early warning/clinical handover systems. Rather than being considered simply as ICT hardware/software, these systems are considered to be medical devices and will therefore require approval according to appropriate medical device standards prior to being considered for deployment.

To realise the full potential of the system, it would also be important to take advantage of additional large amounts of clinical data that will be accessible and to use this to assist in audit and governance functions. These electronic systems are tools that if utilised to full capacity would strongly support the ongoing in-hospital audit and governance functions. The collected data can be used to identify areas of greatest clinical need and monitor the response that was taken in terms of the deteriorating patient. However, as with all audit functions, the system itself is a means to collect and collate data in an accessible way, however the analysis and subsequent actions in response to the findings are reliant on robust and regular intelligent analysis and dissemination of the data that should be facilitated through pre-exisiting in-hospital audit and governance structures.

Finally, once a system is in place, it is important that those responsible for the manufacture of the system have strong mechanisms in place to ensure that the system can be easily updated to accommodate advances in either clinical or ICT domains. Long term maintenance and future 'add-ons' may lead to considerable future investment requirements. When assessing potential options for electronic early warning systems, it is important to give due consideration to the long term requirements of maintenance and to be clear from the outset, what these may entail. Development of a bespoke Irish system to meet all healthcare needs of the Irish healthcare setting and training of in-house ICT staff to manage maintenance issues may mitigate some unforeseen ongoing system costs.

5.3.2 External factors' impact on implementation

A robust system may fail to achieve effectiveness if there are neither resources, nor leadership for implementation of electronic early warning /clinical handover systems into a healthcare system. Of key importance is that staff are adequately trained to respond to the identified deteriorating patient. Without appropriate resources to manage the identified deteriorating patient, which includes an adequate number of trained staff, the benefits of early identification of the deteriorating patient are negated by the lack of resources available to mount the appropriate response. To maximise the return-on-investment of any such ICT tool, links to a training programme for assessing and treating the acutely deteriorating patient should be considered. To maximise the effectiveness of implementation the employment of human factors analysis would help to create work environments that boost productivity while minimizing safety issues.

Other areas of possible resource restriction should be identified and resolved prior to implementation of any new ICT system. For example, limited internet access in the acute setting would hamper use of wireless devices which are an integral part of electronic early warning systems. Efficient and standardised roll-out is important to

mitigate the risk of dual recording and risk to patient safety. As for the system design, a multidisciplinary approach is required for implementation. This will require strong governance and project management. Some initial deployments of electronic early warning systems would assist in the refinement of specifications and cost-effectiveness for the Irish context. A single supplier framework may protect against the complexities and costs that arise from multiple supplier implementation and maintenance strategies. A mixed deployment strategy of electronic early warning systems and continuous monitoring may need to be considered, for example, the use of continuous monitoring for certain cohorts such as the high dependency patients may be considered worthwhile, while continuous monitoring for all patients may be an excessive measure.

The implementation of any ICT system should be considered in the context of the wider health ICT agenda. The timing of implementation of an electronic early warning system may be part of a larger move towards electronic health records. However, even with a move towards roll out of electronic patient records systems, the generic set of core functions for a robust electronic early warning system, as outlined in Tables 5.1, 5.2 and 5.3, still apply, whether these functions are provided by a stand-alone electronic early warning system or from a wider electronic patient record system.

Table 5.1 summarises the generic core elements that are important considerations for the introduction of electronic early warning/clinical handover systems into a healthcare system. This information was derived from the systematic literature review, but also from discussion with groups who have been involved with implementation of electronic early warning/clinical handover systems internationally. Tables 5.2 and 5.3 summarise the mandatory and desirable elements of electronic early warning/clinical handover systems pertinent to the Irish system as indicated by expert members of early warning score/sepsis Guideline Development Groups. Ideally the generic elements for implementation of electronic early warning/clinical handover systems as outlined in Table 5.1 should encompass the particular areas that were identified as important for the Irish context, as outlined in Tables 5.2 and

5.4 Summary

- All electronic early warning and clinical handover systems should be developed in line with NCEC quality assured National Clinical Guidelines and computer learning algorithms and software driving the system should be developed with due consideration to the clinical parameters that have proven effectiveness.

- Strong leadership and adequate resources, such as the appropriate level of trained staff to manage the identified deteriorating are critical to successful implementation and improvements in patient outcomes.

- The full potential of the system should be realised by taking advantage of the large amounts of collected clinical data and using this to assist in audit and governance functions.

- The implementation of any ICT system should be considered in the context of the wider health ICT agenda for example timing of implementation may be part of a larger move towards electronic health record systems.

Table 5.1. Generic Core Elements for introduction of electronic early warning/clinical handover systems

Generic Core Elements for introduction of EEWS/ECHOS		
The System	**The Implementation**	**The Suppliers**
▪ Usability for clinicians, intuitive data entry. ▪ NCEC National Clinical Guidelines as the standard for threshold parameters and other inclusions ▪ Ability to incorporate National Clinical Guideline updates when necessary. ▪ In line with National Information Standards Architecture. ▪ Appropriate approval as a medical device. ▪ Real time data input. ▪ Lines up with clinical processes. ▪ Linkage with Patient Administration System, pathology and radiology systems. ▪ Has the facility for continuous monitoring if necessary. ▪ Resilient to Wi-fi outages/blackspots. ▪ Has clinical handover facility (ECHOS). ▪ Optimises identification of the patients who need escalation while minimises alarm fatigue and false call rate. ▪ Takes account of social aspect of vital monitoring: the clinician is the primary decision maker, and the technology is the aid. ▪ Appropriate system data security measures. ▪ Governance.	▪ Strong leadership to initiate and progress implementation. ▪ Multidisciplinary input required. ▪ Barriers to implementation identified prior to commencement. ▪ Clinically led implementation to support the appropriate site specific objectives for care. ▪ Appropriate ICT support. ▪ Standardisation of implementation process. ▪ Risks of prolonged roll-out and dual recording processes to be minimised with a standardised, efficient, effective implementation. ▪ Ongoing training, risk management, identification of known and possible current and future risks and proposed solution for mitigation.	▪ Multidisciplinary input from relevant sectors: clinical, information technology, engineering, implementation expertise. ▪ Ongoing peer reviewed research of the system to ensure linkage with clinical, patient safety, clinical governance and systems process innovations. ▪ Proven ability to integrate the new system into existing IT infrastructure and to incorporate local clinical pathways and escalation processes.

Table 5.2.Stakeholder recommended mandatory elements to be incorporated into electronic early warning/clinical handover systems for Irish Healthcare

Mandatory Core Elements for Electronic Solutions to EWS and Clinical Handover	
Core elements	**Clarification**
Information recorded	
All 7 vital sign observations should be included. (Option for continuous monitoring for high risk patients may be something to consider)	Respiratory Rate (RR),SaO_2,FiO_2,Blood Pressure (BP),Heart Rate (HR),AVPU, Temperature
System must be capable of supporting secure access for the user. Ensure correct patient, clinical team and institution identification.	Individual log–in. In the event of theft or loss of the personal handheld device or tablet information cannot be accessed.
Hand held light weight system that staff can move around with easy. System should facilitate rapid entry of data, i.e., drop down menu Easy to clean, compliance with infection control guidelines	
Clear patient identification Memory for observations	Trend of observations can be very important in detecting change in status
Options for including additional recordings (which can be tailored to individual sites) would be preferable e.g. blood chemistry/glucose, fluid balance, weight, skin, bowels, diet etc.	This would help to cover gaps in handover i.e. improve continuity of care.

EWS calculation	
The NEWS Key should be visible for clarification when entering vital sign scores	
All 7 observations must be scored individually first	This should be automatic
A total NEWS must be calculated	This should be automatic
Escalation	
Escalation of care options included for all possible total NEWS options, i.e., a total NEWS of 1;2;3;4;5;6;or>7	This must be tailored to individual sites as it will depend on available resources.
When a patient displays signs of bradycardia (i.e. HR ≤ 40bpm), a prompt to highlight this trigger must be incorporated indicating the agreed escalation of care for this patient.	
A single score of 3 must also automatically prompt escalation of care to be agreed through the local NEWS implementation governance structure.	
If NEWS is ≥ 4 (5 on supplementary O_2), the escalation protocol must include the trigger/prompt / alert to screen for sepsis, (using the Sepsis Screening Form)	
Systolic BP ≥ 200 must automatically prompt review by a Doctor.	
Electronic sepsis screening and treatment tool with time countdown should be included in escalation module	Screen could prompt treatment steps, be linked with antibiotic guideline and give print out.
Communication	
If the response is not included as agreed in the escalation protocol then a prompt should occur for the Clinical Nurse Manager/Nurse in charge to contact the registrar or Consultant. The NEWS does not replace clinical judgment and if concerned about a patient's condition the healthcare worker must escalate care regardless of the score.	

Link with laboratory so that if inflammatory markers or blood cultures become positive an automatic alert can be signaled As outlined in the National Clinical Guideline No.5 Communication (Clinical Handover) Maternity Services, face-to-face handover is to be considered a critical part of communication and can be assisted by an electronic system, but not replaced by them.	Reduce delay to evaluating abnormal lab results
Ability to print a record of the patient observations in colour as per national adult observation chart, replacing existing documentation. Ability to complete, print and file the ISBAR* communication tool.	This will eliminate duplication. This will provide structure and evidence of communication.
The system should have the ability to search and find by patient name, patient number, and date of birth. Ability to search for registration details for previous episodes of ED attendance or admission. The system should be linked with PAS.	This will assist rapid information retrieval and avoid unnecessary treatment delays. The previous record should be available within an agreed a timeframe.
Governance	
Ability to perform audit of observation trends, accuracy of recordings, adherence to escalation plan.	
Ability to determine who recorded the data on each patient and under whose clinical care the patient was assigned in real time.	

*ISBAR: Identify, Situation, Background, Assessment and Response

Table 5.3. Stakeholder recommended desirable elements to be incorporated into electronic early warning/clinical handover systems for Irish Healthcare

Desirable Elements for Electronic Solutions to Early Warning Scores and Clinical Handover	
Desirable elements	**Clarification**
Information Recorded	
The system could be supported using a barcode reader	This is the ability to access patients data by swiping identification band
EWS calculation	
If there is a score of 3 for any vital sign it should link to the ABCDE Assessment prompt available on the NEWS Adult Patient Observation Chart Template	
To have the NEWS Key available in a split screen	
A facility for altering or suspending a parameter should be made available.	For patient safety reasons the 'total NEWS' section must remain with an additional section for altered NEWS.
The ability to add other modules to the core module as required.	Examples include fluid balance records, infection control modules, frailty assessments.
Patient portal	This would enable data capture on patient experience and self-rated health. This would contribute to the focus on patient centred care.
Escalation	
An automatic NEWS call	The system would issue an alert based on NEWS escalation criteria. The alert would trigger a message on the medical team bleep or mobile phone. However, this would most likely only work if there is a dedicated response team i.e. a rapid response team or a nurse-based response team.

Communication	
There should be a facility to record and generate reports for the escalation of care pathway and actions taken.	This is to encourage documentation of care and support audit and evaluation in the future
The Sepsis Screening Form can be generated, completed, printed and filed from the APP/IT solution	
A screen at a central place to identify the scores of all patients in the ward with the facility to update this information in real-time.	This would assist allocation of staff, patient prioritisation and safe care
A sign-off section for registered nurses could be included where healthcare assistants carry out patient observations.	

6. Summary and Conclusion

6.1 Description of the technology

There are a number of different types of Information and Communications Technology (ICT) options to consider for detection of the deteriorating patient. The main areas for consideration are:

1. Electronic early warning systems
2. Electronic clinical handover systems
3. Continuous patient monitoring *without* electronic early warning system integration
4. Continuous monitoring *integrated with* electronic early warning systems.
5. Electronic physiological surveillance systems that incorporate more patient and hospital variables than electronic early warning score calculation alone.

While commercial electronic early warning systems may comprise a wide range of features, there are four core elements that are common to all systems including information capture, automated calculation of the early warning score, escalation triggered by pre-determined thresholds and subsequent communications of actions taken to respond to the deteriorating patient. While electronic systems are tools to facilitate the identification of the deteriorating patient, to be effective, they must impact patient outcomes. External system factors such strong leadership, a supportive infrastructure and the availability of appropriately trained responders are integral to the successful management of the deteriorating patient rather than simply the deployment of an electronic tool.

6.2 Systematic Literature Review Findings

6.2.1 Electronic early warning systems

The quality of studies of effectiveness was variable and the interpretation of the data made more complicated by differences in the comparator used such as paper-based systems compared with electronic systems, stand alone electronic alerts or the assessment of continuous monitoring systems. The move from a paper-based early warning system to an electronic system was most relevant to the Irish setting. Despite the complexities of data synthesis, some evidence emerged that the implementation of electronic early warning systems has contributed to reduced mortality rates. Data on cardiopulmonary arrest rate was equivocal, with studies variably reporting both increases and decreases in the event rate. LOS reports were inconsistent ranging from no change to substantial reductions; of note, interpreting

LOS data was made more difficult due to differences in baseline LOS between studies. However, change in general and ICU LOS varied from a minimal reduction up to reductions of 30% and 40%, respectively. Improved accuracy of recording, compliance with escalation protocols and significant user (clinician) satisfaction were also reported.

6.2.2 Electronic clinical handover systems

The quality of studies on the clinical effectiveness of electronic clinical handover systems were hampered by poor study design, small sample size and unspecified follow-up. The trend of results showed increased accuracy of recording handover, efficiency gains for staff and positive clinician user perception of improved patient safety due to better handover communication processes. However, a face-to-face element to clinical handover was identified as an important part of patient care. There was no clinical outcome data such as mortality or ICU LOS reported in these studies.

Systems that combine processes of electronic early warning systems, electronic clinical handover systems with other clinical data such as fluid balance, cognitive and nutritional status are gaining favour commercially because of the advantages of integration and analysis of complex data in one central repository with the resultant facility to use this information for many other hospital processes such as ward work-flow.

6.3 Benefit and investment requirements

Cost-effectiveness data was minimal however; there was some evidence of a positive return-on-investment with continuous monitoring implementation for one US based study. However because of the significant difference in US and Irish healthcare provision models, the generalisability of this return-on-investment to the Irish context is uncertain.

Using data derived from the systematic review and applying this to Irish healthcare setting, potential benefit and resource requirements from implementing a move from paper-based recording of vital sign parameters to an electronic early warning system could mean a potential resource gain for the Irish healthcare setting being realised as general and ICU ALOS being potentially reduced by 28.9% (95%CI 18.6%-40.3%) and 40.3% (95%CI 4.6% - 76%), respectively. This translates to a national hospital capacity gain of 802,096 bed days per annum and 30,628 ICU bed-days per annum. This substantial resource gain would assist the efficient utilisation of acute hospital beds and mean reduced pressure on Emergency Departments, reduced

waiting times for elective surgeries and ultimately more appropriate and timely access to acute hospital services.

A variety of investment requirements related to two types of licensing systems for electronic early warning systems are presented. To purchase the license outright is substantially more of an investment in the first year (Type 2) however, the advantage is that future changes in licensing pricing are mitigated against. To offset the initial license costs of type 2, maintenance costs appear lower compared with type 1 licensing agreements, however these estimates may be subject to future change and it is important to buffer against excessive variations in maintenance costs by requesting transparency from the suppliers regarding future expected maintenance cost changes.

Based on indicative costs from the UK, local site, overall five year investments have been estimated as €1.0 and €1.3 million for Type 1 and Type 2 licenses, respectively. At a national level, the five year investments have been estimated as €40.1m and €51.4m for Type 1 and Type 2 licenses, respectively. These investment requirements will be subject to local tendering and contract arrangements.

6.4 Key determinants for effective implementation

Key determinants that were identified for effective implementation were based on the findings from the systematic review and stakeholder engagement. All electronic early warning and clinical handover systems should be developed in line with NCEC quality assured National Clinical Guidelines and computer learning algorithms and software driving the system should be developed with due consideration to the clinical parameters that have proven effectiveness.

The success of the system will be strongly influenced by the level of supportive infrastructure, a robust implementation plan and the level of development resource that is available to the organisation. Implementation requires a multidisciplinary approach. In addition, once the deteriorating patient is identified, having the resources to respond to the identified patient in a timely, clinically adequate way, such as the appropriately trained number of staff in attendance, rapid response teams, appropriate transfer and availability of higher acuity beds, will impact overall clinical outcomes. Integration of an electronic early warning/clinical handover system would benefit from linkage with a training programme for assessing and treating the acutely deteriorating patient. To maximise the effectiveness of implementation the employment of human factors analysis would help to create work environments that boost productivity while minimizing safety issues.

The system should be developed by a multidisciplinary team who have given due consideration to clinical, engineering and ICT elements and have a proven track record of excellence in provision of electronic early warning/clinical handover systems. The implementation of ICT to support electronic early warning and clinical handover systems should be considered in the context of a standards based approach, the wider ICT agenda and the eHealth Strategy, for example, timing of implementation may be part of a larger move towards electronic health record systems. It is important that any new technology can integrate seamlessly within existing clinical practice and that the system is designed in a way that does not add to workload, interfere with clinical tasks, or compromise patient safety and quality of care.

6.5 Conclusion

International evidence offers some support of the efficacy of electronic early warning and clinical handover systems in improving patient outcomes and the efficiency of healthcare service; however, effectiveness will depend on the its integration into the system and the allocation of resources to ensure that there is timely treatment and escalation of care. There is currently no deployment in Ireland. Implementation will involve a significant initial investment as well as ongoing maintenance costs, but the evidence suggests that in addition to potential gains in patient safety, it can also result in a substantial efficiency gain in terms of the utilisation of acute hospital beds.

Glossary

Continuous Monitoring	This is when a vital sign monitor is attached to a patient to automatically record and relate the parameters to a central data station. It may or may not be linked with EEWS
Case series	Research study design where observations are made on a series of individuals, usually all receiving the same intervention, before-and-after an intervention but with no control group.
ECHOS	Electronic Clinical Handover Systems: These are standard electronic templates developed in-house with locally agreed key domains for effective clinical handover. Traditionally they are developed as standalone web based systems or derived from the electronic patient record.
EEWS	Electronic Early Warning Systems: These systems are where vital sign data are entered manually into an electronic device and using computer learning algorithms, the early warning score is automatically calculated and care escalated according to local protocol parameters.
EPSS	Electronic Physiological Surveillance Systems: These systems incorporate EEWS, ECHOS and additional broader clinical modules such as fluid balance, cognitive assessment tools, nutritional status, infection control surveillance and work flow management.
EWS	Early Warning Score: An early warning score is a composite score that is used to quickly determine the degree of illness of a patient. It is based on data derived from physiological readings (systolic blood pressure, heart rate, respiratory rate, body temperature) and one observation such as level of consciousness. The resulting data are compared to a normal range to generate a single composite score
Human Factors	Human Factors is a discipline of study that examines the human-machine interface. Human Factors deals with the social, physical, biological, psychological, and safety characteristics of the system and a user.
Median	A statistical term to describe central tendency using the value below which 50% of the cases fall.

Appendix A – List of some commercially available electronic early warning/continuous monitoring systems.

System Name	Manufacturer	Country of Origin	Type of system
Connex® with Electronic Vitals Documentation	Welchallyn	US	Continuous monitoring with capacity for integrated Electronic Early Warning System
Ground-Vision	Ground-Vision	UK	Manual input Electronic Physiological Surveillance System
Intellivue Guardian	Philips	US	Continuous monitoring with capacity for integrated Electronic Early Warning System
KEWS200,300	SyncroPhi	US	Continuous monitoring with capacity for integrated early warning system
Patientrack™	Patientrack	Australia	Manual input Electronic Early Warning System
NerveCentre	NerveCentre	UK	Manual input Electronic Physiological Surveillance System
Sensium Vitals.	Sensium Healthcare. Toumaz Group	US	Continuous monitoring with capacity for integrated early warning system
Visensia	Obsmedical	US	Continuous monitoring with capacity for integrated early warning system
VitalPAC™	The Learning Clinic	UK	Manual input Electronic Physiological Surveillance System
Wireless Ward	Rotoform	Ireland	Manual input Electronic Early Warning System

Note: this list may not be comprehensive as new innovations are ongoing.

Appendix B – Search details

Pubmed 09/12/2014		Search Strings	Results
Searches	#1	(("electronic health record"[MeSH Terms]) OR "electronic patient record") OR "decision making, computer assisted"[MeSH Terms]) OR "medical informatics applications"[MeSH Terms]) OR "medical records systems, computerized"[All Fields] AND MeSH Terms) OR "automat*") OR "IT") OR "ICT") OR "sensor network") OR "wireless clinical monitor*")) OR "computer"	548,662
	#2	((((Hand-over* OR Handover* OR Hand-off* OR Handoff*)) OR "patient handoff"[MeSH Terms]) OR "communication tool") OR "interdisciplinary communication"	13,535
	#3	(((((("early warning") OR ("track and trigger")) OR "electronic physiological surveillance") OR "outreach") OR "EPSS") OR "escalation protocol") OR "emergency detection")	12,912
	#4	#1 AND #2	601
	#5	#1 AND #3	428
	#6	#4 AND #5	195

EMBASE 09/12/2014		Search Strings	Results
Searches	#1	'electronic medical record'/exp OR 'decision support systems'/exp OR 'medical informatics'/exp	49,580
	#2	'clinical handover'/exp OR 'communication tool' OR interdisciplinary communication'	9,485
	#3	'early warning' OR 'track and trigger' OR 'electronic physiological surveillance' OR 'outreach' OR 'EPSS' OR 'escalation protocol'	16,851
	#4	#1 AND #2	318
	#5	#1 AND #3	271
	#6	#4 AND #5	1

CINAHL 12/12/2014		Search Strings	Results
Searches	#1	"Electronic" OR "computer"	127,643
	#2	'clinical handover' OR 'patient handoff' OR interdisciplinary communication'	209
	#3	'Early Warning' OR 'Track and Trigger' OR 'Escalation Protocol'	884
	#4	#1 AND #2	33
	#5	#1 AND #3	71
	#6	#4 AND #5	0

Cochrane Collaboration 11/12/2014		Search Strings	Results
Searches	#1	(("electronic health record"[MeSH Terms]) OR "electronic patient record") OR "decision making, computer assisted"[MeSH Terms]) OR "medical informatics applications"[MeSH Terms]) OR "medical records systems, computerized"[All Fields] AND MeSH Terms) OR "automat*") OR "IT") OR "ICT") OR "sensor network") OR "wireless clinical monitor*")) OR "computer"	32,851
	#2	((((Hand-over* OR Handover* OR Hand-off* OR Handoff*)) OR "patient handoff"[MeSH Terms]) OR "communication tool") OR "interdisciplinary communication"	195
	#3	(((((("early warning") OR ("track and trigger")) OR "electronic physiological surveillance") OR "outreach") OR "EPSS") OR "escalation protocol") OR "emergency detection")	152
	#4	#1 AND #2	22
	#5	#1 AND #3	32
	#6	#4 AND #5	0

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