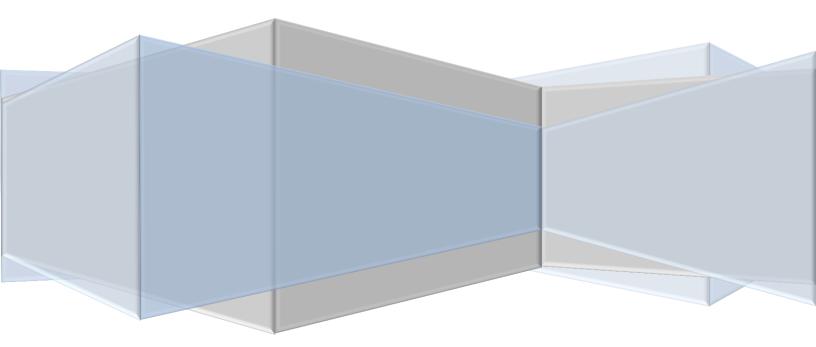# Pediatric Early Warning System (PEWS)

Summary of literature review

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Purpose of this document

Child Health BC (CHBC) is an initiative of the BC Children's Hospital (BCCH), which consists of a network of health authorities and health care providers dedicated to ensure children receive the right service at the right time, in the right place, by the right provider. Through many cooperative partnerships; Child Health BC is creating an integrated, standardized and accessible system of care available to all children in British Columbia.

Hospital care, including emergency department visits, is delivered in 109 sites in BC, and only 11 of those have designated paediatric staff. The majority of BC hospital sites rely on general providers who see predominately adults, to also care for children. Only 2 BC emergency departments are dedicated to children. A survey on nurses across these care settings was done in the summer of 2014 and revealed that 40% of nurses responding to the survey reported caring for children once a week or less, and 21% of nurses reported caring for children occasionally. 35% of the nurse respondents reported themselves as competent in distinguishing normal and abnormal vital signs in infants and children, and 37% reported themselves as able to anticipate and respond to paediatric clinical deterioration or acute urgent situations.

In June 2013, the Child Health BC Steering Committee recommended provincial adoption of the BCCH tools and system for pediatric early warning system (PEWS) of physical deterioration in a hospital setting. At that time, Vancouver Coastal health identified 3 sites for piloting, which was, conducted in the summer and fall of 2014. Following the pilot, other health authorities expressed readiness to work to implement a standard BC paediatric escalation of care system.

This literature review provides a summary of the evidence available for the paediatric early warning system (PEWS) to assess children at risk of clinical deterioration using vital sign parameters and risk indicators. The system is made up of a risk score based on physiological findings, evidence based risk factors, escalation responses, and a communication framework. Together these system parts are designed to provide a standardized framework and language to identify potential deterioration in a child; mitigate that risk; and escalate care as needed – all as early as possible. In addition, this literature review will help inform some the implementation decisions, evaluation strategies and provide evidence base decision making in the process of adopting PEWS in BC

Background & Objectives

The incidence of cardiopulmonary arrest (CPA) in hospitalized children is relatively low (0.7-3%) (Berg et al. 2008, North America, Tucker et al. 2009) however mortality (11-37%)(Tucker et al, 2009, Mclellan et al. 2013) and morbidity remains high despite advances in resuscitation training, technology and treatment (Tibballs et al. 2005). The devastating consequences of CPA on both child and family are well documented (Meert et al., 2009, Balluffi et al., 2004). There are also substantive financial costs to the healthcare system for 'failing to rescue' deteriorating children in hospital (Duncan & Frew, 2009). There is evidence indicating that mortality prevention is possible. A detailed confidential panel review of 126 child deaths in the UK concluded 63 of the 89 deaths occurring in hospital, (71%) were avoidable or potentially avoidable (Pearson GA, 2008 CEMACH). This suggests an urgent need to improve early identification and mitigation of deterioration in hospitalized children.

Research in adults has demonstrated CPA and other serious adverse events (SAE) are often preceded by a period of physiological instability that, when recognized earlier, offer a window of opportunity for the health-care team to intervene to improve outcome (Kause et al. 2004, Hodgetts et al., 2002, Buist et al. 1999 & Franklin C et al. 1994). Pediatric patients also demonstrate physiologic and behavioral symptoms of deterioration 24 hours prior to CPA (Robson et al, 2013; McLellan et al. 2013). Thus, a similar window of opportunity may exist within which to identify children at risk of SAE (Haines C 2005, Tusker RC 2005, Tume L & Bullock I 2004). Internationally, Pediatric Early Warning Systems (PEWS) have been implemented to improve the safety for hospitalized children (CEMACH, 2008; Lambert et al, 2014). However, there are a number of key differences that make this more complex than with the adult population. These differences include: variation in physiologic norms for pediatric patients, developmental limitations to communication; compensatory mechanisms, and limitations in health provider knowledge, skill or focus (Haines et al, 2006 in Lambert et al, 2014).

This review was conducted to provide a summary of the important literature findings in regards to PEWS to inform the provincial implementation and evaluation initiative. The review was generated to address the following objectives:

1. Where does the need for PEWS come from and what is the level of evidence to support its implementation?
2. What PEW Systems are out there and what are the overarching results? Any comparisons made with or without other systems/interventions?
3. Are there any comprehensive evaluations of PEWS as a system in the literature that indicates the effectiveness of PEWS across different settings?
4. What are the strengths and limitations associated with the adoption of PEWS?

To guide the systematic review a Population, intervention, comparison and outcome (PICO) table was generated to capture the important scopes and objectives of the project.

Table 1. Population, Intervention, comparison/control and Outcome (PICO) for the literature review

Population/participants
Studies including children from birth up to 18 years of age who are in-patients in a hospital. Studies, which combine children and adult populations and do not give details of the child sub-group, were not included.
Intervention
Pediatric Early Warning Systems (PEWS) are organizational systems put in place with the intention of identifying deterioration in hospitalized children in order to intervene in a timely manner to reduce morbidity and risk of death (clinical deterioration). Many of these systems include a track and trigger score, which consists of a number of items covering physiological parameters and sometimes incorporating levels of concern from both parent and health professional. These items are monitored regularly (tracked) with set thresholds at which escalation is initiated (triggered).
Comparison
Comparison between the different PEW score (and systems) Comparison between PEWS and non-PEWS
Outcomes
Primary outcomes Mortality and clinical deterioration events including: unplanned admission to Pediatric Intensive Care (PICU) or Pediatric High Dependency Unit (PHDU), cardiopulmonary arrest, respiratory arrest, medical emergencies requiring immediate assistance (arrest calls who were not respiratory or cardiac arrests) (resuscitation events), Referrals for PICU review (in tertiary centres) or PICU retrieval Clinical Deterioration (CD) as defined in literature/study All/any of these outcomes reported for hospitalized children only

Literature Review

Search strategy

Phase 1: Used key words (PEWS, pediatric early warning system and score, track and trigger scores, clinical deterioration) in major databases *(Database: UBC Books@Ovid, EBM Reviews - ACP Journal Club <1991 to January 2015>, EBM Reviews - Cochrane Central Register of Controlled Trials <January 2015>, EBM Reviews - Cochrane Database of Systematic Reviews <2005 to January 2015>, EBM Reviews - Cochrane Methodology Register <3rd Quarter 2012>, EBM Reviews - Database of Abstracts of Reviews of Effects <1st Quarter 2015>, EBM Reviews - Health Technology Assessment <1st Quarter 2015>, EBM Reviews - NHS Economic Evaluation Database <1st Quarter 2015>, Embase <1980 to 2015 February 19>, Health and Psychosocial Instruments <1985 to January 2015>, Ovid MEDLINE(R) In-Process & Other Non-Indexed Citations, Ovid MEDLINE(R) Daily, Ovid MEDLINE(R) and Ovid OLDMEDLINE(R) <1946 to Present>- All accessed through Medline OvidSp , PubMed and CINAHL database)* to find all relevant evidence (all study designs that met the PICO restrictions that mentioned PEWS or related topics). This review helped expand the search by retrieving more key words used in the literature.
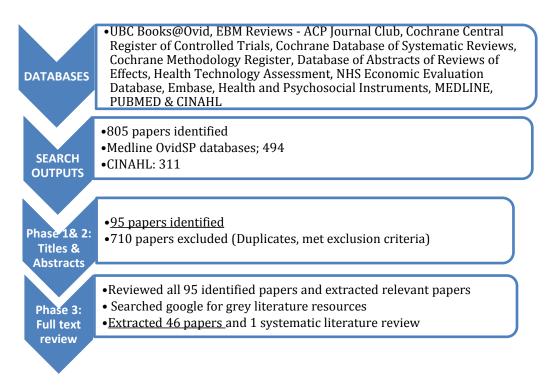
Phase 2: Expanded the search using new key words (severity of disease scoring systems, critical care organization, pediatrics physiological monitoring, early warning system, medical emergency team/activation, Pediatric rapid response teams, situational awareness tools, pediatric alert criteria and MeSH terms retrieved in stage 1) and conducted a thorough search in all the relevant databases using Medline OvidSP, PubMed and CINAHL database. An examination of the titles and abstract helped narrow the scope of the search and identify the key articles/evidence in the databases. A grey literature research was also conducted using Google.

Phase 3: Compared the reference list to systematic review articles and key articles to see if any important articles were missed.

Search outputs

The number of search outputs from each of the phases of the search strategy that met the inclusion criteria are highlighted in the flowchart below in figure 1.

Figure 1 Flowchart of search outputs for the PEWS studies

DATABASES
- UBC Books@Ovid, EBM Reviews - ACP Journal Club, Cochrane Central Register of Controlled Trials, Cochrane Database of Systematic Reviews, Cochrane Methodology Register, Database of Abstracts of Reviews of Effects, Health Technology Assessment, NHS Economic Evaluation Database, Embase, Health and Psychosocial Instruments, MEDLINE, PUBMED & CINAHL

SEARCH OUTPUTS
- 805 papers identified
- Medline OvidSP databases; 494
- CINAHL: 311

Phase 1& 2: Titles & Abstracts
- 95 papers identified
- 710 papers excluded (Duplicates, met exclusion criteria)

Phase 3: Full text review
- Reviewed all 95 identified papers and extracted relevant papers
- Searched google for grey literature resources
- Extracted 46 papers and 1 systematic literature review

Nature of PEWS tools

> **KEY MESSAGES**
> - Pediatric Early warning Score tools are internationally used across the globe with the majority of the work coming from UK, USA, Canada and Australia
> - There are a number of PEWS tools available with no agreed consensus on which one is the optimal tool to use as different tools measure clinical deterioration using different markers/outcomes
> - There is lack of level-one evidence in the literature to support the use of one specific PEWS tool. Most tools are adapted to fit the setting and context in which it is used in with some validation to support the modifications. No tool has both high sensitivity and specificity.

- There is high heterogeneity of PEW scoring systems; **numerous systems have been developed and are used extensively internationally, particularly in the USA, England, Australia, Canada and Wales** (Chapman et al. 2010; Lambert et al, 2014). The majority were developed by expert opinion and working groups in varied contexts.
- Organizations across these countries have indicated the need for a standardized, validated tool and efforts are underway to develop clinical guidelines, recommendations and resources.
- There are 7 original PEWS (4 validated) and 8 adaptations of these PEWS (5 validated)

Table 2. Original PEWS tools and their characteristics

PEWS tools (original tools)	#Of parameters and score range	Escalation Protocol
Brighton Score - UK (Monaghan 2005)	5 Parameters Aggregate score Score range 0-13	4 actions prescribed according to score Call MET if scored 3 in one parameter or total score greater/equal to 4
Birmingham/Toronto PEWS UK/Canada (Duncan et al 2006)	16 parameters Aggregate score Score range 0-26	Not reported
Bristol PEWS tool UK (Haines et al. 2006)	Single parameter Trigger score	Call MET if any criteria met
C-CHEWS USA (McLellan et al. 2013)	5 parameters Aggregate score Score range 0-11	Escalation protocol provided > 5 MET activation
Cardiff &Vale PEWS Wales (Edwards et al. 2009)	8 parameters Single/multiple parameter Score range 0-8	Not reported
Melbourne Activation Criteria (MAC) – Australia (Tibballs et al. 2005, 2009)	9 Parameters Single parameter Trigger score	If child meets any criteria, MET activated
Bedside PEWS Canada (Parshuram et al 2009,2011)	7 parameters Aggregate score Score range 0-26	Not reported but cut-off score set at 8

- Eight Studies reported modifications based on one of these PEWS. Five studies validated a modified version of the Brighton PEWS, one study modified Bedside PEWS, one study modified the Bristol PEWS and one study modified MAC for MET activation. Brighton score was the most frequently adopted tool for its ease of use (15-30 seconds) and simplicity (5 parameters in total)

- Modifications in each of these tools ranged from minor wording changes to inclusion/exclusion or reordering of parameters. For a detailed summary of the modifications made to each adoption *Appendix A* is attached from the systematic review currently completed (Lambert et al. 2013). The performance of the PEW scoring tools were measured using their sensitivity and specificity for a certain outcome studied/measured.

- The sensitivity of the PEW scoring tool is the ability of the tool to correctly identify children who are clinically deteriorating (however this is defined differently across the studies ranging from unplanned ICU admission, CPA etc.) (i.e. the probability of testing positive (scoring high) on the PEWS tool when the outcome is truly present)

- The specificity of the PEW scoring tool is the ability to score low on the PEWS tool when the children are not clinically deteriorating (i.e. the probability of testing negative of the PEWS tool (scoring low) when the outcome is truly absent)

- The performance of these PEWS tools varied as the outcome measured differed across the validation studies. No tool achieves both high sensitivity and specificity. *Appendix B* from the systematic literature review recently completed (Lambert et al. 2014) shows the sensitivity and the specificity of the different PEWS tools

PEWS Implementation Strategies

> **KEY MESSAGES**
> - Scarce literature available on the 'optimal' implementation strategy for PEWS system to influence clinical/process outcomes (even these outcomes are rarely explicitly mentioned)
> - The available literature is highly variable and dependent on the context of the settings in which PEWS was implemented. A commonality in most implementation studies is using the piloting strategy to roll-out PEWS.
> - Some lessons on the 'real-life' barriers and facilitators in the different settings presents valuable insight to consider when mapping out an implementation strategy for PEWS
> - Most educational strategies to implement PEWS include online e-learning modules and scenario based faced to face workshops. Two educational packages currently available are COMPASS and RESPOND

- The **majority of implementation occurs in inpatient pediatric units but modifications of the PEWS have been developed for use in emergency departments (ED), cardiac units, and for pediatric transfer** (Lambert et al. 2014).

- Clinical utility and simplicity has been prioritized over validity by some sites when choosing a particular scoring tool.

- The stated purpose for using or implementing PEWS differs across settings e.g. Quality improvement initiatives, activation of Rapid Response Teams (RRT), screening of acutely ill children, identification of children at risk of deterioration etc.

- There is also high diversity in how PEWS response systems are operationalized and what escalation protocols should entail i.e. who responds (team composition), when to activate (cut-off PEW scores), and what to measure in terms of outcomes.

- There are limited studies describing the implementation process (and education) involved with PEWS and once again, high diversity according to context. However, most implementations studies in the literature used a piloting strategy to roll-out PEWS.

- ➢ Most notable perceived <u>barriers</u> in implementation included hierarchical doctor-nurse relationships, communication concerns such as between physician-led MET and primary medical team and hierarchies within the current hospital system. A highlighted perceived barrier was that a 1/3rd of staff felt they lacked support from superiors to activate MET and in addition poor communication between physician-led MET and primary care team.
- System factors that contributed to Implementation process included:
  - o Culture and professional norms (hierarchies and doctor-nurse disengagement, inter-professional resistance)
  - o Resource constraints (nurse multi-tasking, workload pressure, data collection and maintenance)
  - o Training/educational concerns (loss of learning due to MET 'take-over')
- Other challenges with a scale-up implementation (a provincial implementation) was due to centers being at different places on the continuum of existing systems which leads to implementing a different component of the system at different times.
- Educational packages and strategies to implement PEWS mostly consist of self-directed e-learning online modules and face to face scenario based workshops that highlight the use and importance of using PEWS
- Two educational packages are available in the literature. COMPASS is an Australian educational package available for free and RESPOND is a UK based educational package meant to train healthcare workers (Bedside nurses) to use PEWS

Overarching PEWS results

➢ **KEY MESSAGES**
➢ There are positive directional trends in using PEWS including improvement in clinical and non-clinical outcomes (earlier interventions, enhanced staff communication, reduced in hospital mortality and morbidity, improved PICU service delivery etc.)
➢ No harm in using PEWS has ever been reported in the literature
➢ There is a lack of consensus on a standardized outcome or marker for clinical deterioration to measure, hence the results from PEWS studies cannot be comparatively evaluated limiting the quality of the evidence.
➢ Due to lack of level one evidence, the effectiveness of PEWS cannot be definitively determined

- To date, the majority of published studies evaluating PEWS have focused on individual tools in single-center studies in children's hospital settings. The exception is a study of BPEWS (Parsharum, 2011). Most commonly, the studies examine the impact of PEWS on incidence of CPA or respiratory arrest, code blue and RRT activation or PICU transfer/admission (unplanned) of sick children.

- Majority of studies are observational in design ranging from cohort, case-control (retrospective and prospective), descriptive audits, program evaluations and chart reviews. Some are experimental including pre-post cohort designs. There is a lack of level 1 evidence results (i.e. RCT studies)_-however current clinical trials by Parsharum(Completion October 2015 – Clinical trials registry) are underway to randomize the allocation of BPEWS in particular sites around the globe, to determine the effect on morbidity and mortality of hospitalized children compared to the hospital standard of care.

- More recent emerging studies have explored the clinical utility of PEWS when implemented as a situational awareness system rather than an individual scoring chart (Brady et al. 2010) but most available studies focus on particular aspects of the system (e.g. the PEWS score), leading to limited understanding of the critical components of PEWS as a complex system (Lambert et al 2014).

- A recent UK project is examining PEWS implementation and evaluation as a 'complex intervention' across multiple sites (National Institute for Health Research (NIHR) – Started January 2015). Locally, the situational awareness tool (Patient At Immediate Risk -P.A.I.R) developed by Brady et al. was incorporated in the BCCH PEWS tool in 2011 to highlight the importance and need for clinician's judgment and team collaboration to enhance the detection of clinical deterioration in children.

- **The overarching conclusion is that an elevated score is associated with sicker patients at risk of needing ICU/higher level of care** (Monaghan A et al. 2005, Duncan H et al. 2006, Haines C et al. 2006, Tucker KM et al. 2009, Akre M et al. 2010, Parshuram et al. 2011, Skaletzy et al. 2012). These positive findings are logically expected as PEWS is composed of physiologic data and it is known that abnormalities in vital signs often accompany critical illness. However evidence for a cut-off/threshold point for identifying deterioration is limited in the literature.

- **The effectiveness of PEWS cannot be concluded definitively** due to a lack of level-one evidence and diverse results from other levels of evidence such as quasi-experimental and observational studies.

Strengths and Advantages of PEWS systems

- ✓ **The evidence suggests there are positive directional trends with the use of PEWS improving clinical outcomes (e.g. earlier intervention, reduced CPA, mortality rates, transfer to PICU)**

- ✓ There are positive outcomes in relation to "enhanced multi-disciplinary team work, communication and confidence in recognizing, reporting and making decisions about a child at risk of clinical deterioration" (p.10, Lambert et al 2014, Bonafide et al. 2013, Brady et al. 2010)- *This finding was supported by two Vancouver Coastal Health (VCH) PEWS pilot sites*

- ✓ There are also no negative outcomes reported in the literature related to the use of PEWS

Limitations and shortcomings of PEWS

❖ **There is limited evidence to support any particular system** (Lambert et al, 2014). Studies have shown different levels of sensitivity (the ability of the score to correctly identify patients who are deteriorating) and specificity (the ability of the score to correctly identify patients who are not deteriorating) with different PEW detection systems.

❖ There is limited uniformity in the age-delineated norm ranges for physiological measurements. This makes it challenging to conclude optimal parameters for identification of deterioration and accounts for some of the difference in the performance of the PEWS tools studied. In fact recent studies have highlighted a need to update the reference ranges for hospitalized (Bonafide et al. 2013) and non-hospitalized children (Fleming et al. 2011).

❖ There is a shortage of evidence to highlight the cost-benefit analysis and economic evaluation of PEWS implementation and clinical outcomes in hospitals with the current evidence being poor and slightly contradictory.

Subsection on ED & Post Anesthetic Care Unit (PACU)

Emergency Department

- There is some emerging evidence in the literature in regards to the use of PEWS in ED with most studies reporting prediction of ICU admission and/or hospital admission as the outcome measured.

- The results highlight that PEWS can be a good predictor for ICU admission but not necessarily hospital admission. However, PEWS cannot replace the triage tool in the ED, and cannot be used independently in the ED environment.

- One of the major limitations of PEWS in the ED is the experience of vital signs alterations in the ED due to the acuity of illness, medication, fear, anxiety in the dynamic emergency setting that could lead to higher PEWS score but not necessarily reflect critical illness ; thus sensitivity in the ED may be limited. However, clinician report value in the tool regardless of limitations in sensitivity

- Some of the positive associations with the use of PEWS in ED include: helping nurses who primarily work with adult populations to accurately assess children's needs and interventions (*also supported by the VCH pilot sites*), reduced PICU admission that require advanced interventions (invasive ventilation) and shorter length of stay in the PICU (which all contributed to better PICU service delivery) (Sefton et al. 2014) and providing a baseline for monitoring deterioration of children who are admitted to hospital.

Post Anesthetic Care Unit (PACU)

- There is dearth published literature on the use of PEWS in PACU.

- The American society of Perianesthesia Nurses recommends the use of scoring systems to help assess the patients' readiness for discharge into ward. However, these scoring systems are quite specific to the perianesthesia specialty and don't cross over to the nurses at the ward (Inpatient or ICU) and therefore aren't easily interpreted.
- Implementing PEWS in the PACU shouldn't replace any existing specific scoring systems in the unit but it will help create a standardized language for the care of inpatients.
- A PEW score has been recommended in grey literature sources (RCN transfer to and from theatres guideline) just before the transfer of patients from PACU to inpatient to help with the handoff of patients and also the consistent objective assessment of patients at each level of care.

Recommendations and Conclusion

- Although evidence is limited, what is available suggests that PEWS has the potential to improve the detection of clinical deterioration and reduce adverse outcomes and thus should be carefully implemented across healthcare settings that serve pediatric patients.
- There is a need for PEW scores to be validated for different patient cohorts and different pediatric inpatient contexts/settings. Consensus on the most appropriate outcomes to measure and report need to be standardized to enable comparison between different PEWS.
- There is a need to monitor and evaluate the provincial implementation of PEWS in order to support the building of evidence. A need for standardization is crucial as highlighted in the lack of consistency in the reported outcomes in most evidence found in the literature
- Contextual and cultural factors are important to consider in hospitals and have unintentionally led to high diversity in PEW systems. This makes comparison and the drawing of conclusions difficult. Consideration should be given both to facilitating individual hospital implementation and the need for uniformity for the purpose of outcome evaluation. Factors essential to effective measurement of PEWS should be standardized and monitored across sites.

Acknowledgements

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Appendices

Appendix A

Table 1 Modifications made to the original PEWS tools

MODIFIED PEW system score	MODIFICATIONS to Measurement/Scoring Parameters
Akre et al. (2010) Modified Brighton PEWS (Monaghan 2005)	*Slight wording modifications as highlighted in bold/italic below:* 1) Behaviour: Playing/Appropriate (score 0); Sleeping (score 1); Irritable (score 2); Lethargic/confused or reduced response to pain (score 3) (2) Cardiovascular: Pink or capillary refill 1-2 seconds (score 0); Pale *or dusky* or capillary refill 3 seconds (score 1); Grey *or cyanotic* or capillary refill 4 seconds *OR* Tachycardia of 20 above normal rate (score 2); Grey *or cyanotic* and mottled or capillary refill 5 seconds or above *OR* Tachycardia of 30 above normal rate or bradycardia (score 3) (3) Respiratory: Within normal parameters, no *retractions* (score 0); >10 above
	normal parameters *OR* using accessory muscles *OR* 30+% FiO2 or **3+** litres/min (score 1); >20 above normal parameters *OR retractions OR* 40+% FiO2 or 6+ litres/min (score 2); >=5 below normal parameters with *retractions* or grunting *OR* 50+% FiO2 or 8+ litres/min (score 3) Score 2 extra for every **15min nebs (includes continuous nebs)** or persistent post-op vomiting
Edwards et al. (2011) adopted MAC from Tibballs	*No modifications were made* MET criteria for activation (any ONE or more of) 1. Nurse or doctor worried about clinical state 2. Airway threat 3. Hypoxaemia; SpO2 <90% in any amount of oxygen; SpO2 <60% in any amount of oxygen (cyanotic heart disease) 4. Severe respiratory distress, apnoea or cyanosis 5. Tachypnoea (age dependent rate) 6. Tachycardia or bradycardia (age dependent rate) 7. Hypotension (age dependent rate) 8. Acute change in neurological status or convulsion 9. Cardiac or respiratory arrest
Brighton PEWS modified from Monaghan (2005) by Skaletzky et al. (2012)	*Slight wording modifications as highlighted in bold/italic below:* 1) Behaviour: Playing/**Smiling** (score 0); ***Irritable, consolable*** (score 1); Irritable, inconsolable (score 2); Lethargic/confused or ***Decreased*** response to pain (score 3) (2) Cardiovascular: Pink or capillary refill 1-2 seconds (score 0); Pale or capillary refill 3 seconds (score 1); Grey or capillary refill 4 seconds *OR* Tachycardia of 20 above normal rate (score 2); Grey and mottled or capillary refill 5 seconds or above *OR* Tachycardia of 30 above normal rate or bradycardia (score 3) (3) Respiratory: Within normal parameters, no *retractions* (score 0); >10 above normal parameters *OR* using accessory muscles *OR* 30+% FiO2 or **3+** litres/min (score 1); >20 above normal parameters *OR retractions OR* 40+% FiO2 or 6+ litres/min (score 2); 5 RR below normal parameters with *retractions and*/or grunting *OR* 50+% FiO2 or 8+ litres/min (score 3) ***Did not include nebulisers and vomiting items thus overall maximum score was 9.***

Brighton PEWS modified from Monaghan (2005) by Tucker et al. (2009)	**Slight wording modifications as highlighted in bold/italic below:** (1) Behaviour: Playing/Appropriate (score 0); Sleeping (score 1); Irritable (score 2); Lethargic/confused or Reduced response to pain (score 3) (2) Cardiovascular: Pink or capillary refill 1-2 seconds (score 0); Pale or capillary refill 3 seconds (score 1); Grey or capillary refill 4 seconds. **OR** Tachycardia of 20 above normal rate (score 2); Grey and mottled or capillary refill 5 seconds or above. **OR** Tachycardia of 30 above normal rate or bradycardia (score 3) (3) Respiratory: Within normal parameters, no recession (score 0); >10 above normal parameters, using accessory muscles, **OR** 30+% FiO2 or **3+** litres/min (score 1); >20 above normal parameters *retractions* 40+% FiO2 or 6+ litres/min (score 2); 5 below normal parameters with *retractions **OR*** 50% FiO2 or 8+ litres/min (score 3) Score 2 extra for (4) 1/4 hourly nebulisers or (5) persistent vomiting following surgery Algorithm incorporated tiered response to scores; increased PEWS or responded to increased allocation of resources to patient. Score 0–2 = no additional intervention; Score 3 = senior RN assess patient; Score 4 = bedside RN notify the paediatric resident of the patient's PEWS; Score 5 = senior RN /paediatric resident assess the patient; Score 6 = senior RN, paediatric resident, and senior resident assess the patient at the bedside; Score 7 or above = bedside RN activate the hospital's MET
Brighton PEWS modified from Monaghan (2005) by Bell et al. (2013); modified tool titled Texas PAWS 3 parameters	Behaviour, cardiovascular, respiratory ***Modification made to respiratory parameter;*** Pulse oximetry added as the monitor for breathing instead of the litres of oxygen per minute. No change was made to the respiratory rate criteria but respiratory parameter changed to include changes in oxygen saturations within baseline limits, 5 points below baseline, or more than 5 points below baseline. ***Changes were made to the scoring criteria descriptors in the behaviour parameter;*** Removed category 1 term "sleeping" as a descriptor of behaviour, felt term did not

Each can score 0-3 points; additional 2 points if respiratory treatments are needed every hour (versus every 15 minutes with PEWS) or if there is persistent vomiting following surgery. Highest possible cumulative score is 13	sufficiently capture early symptoms of deterioration in mental status. It was replaced with "irritable (consolable)" Category 2 changed to "irritable (inconsolable)" as felt that irritable (consolable) behaviour usually precedes irritable (inconsolable) behaviour and are better descriptors of the observed behaviour seen during deterioration. Category 3 descriptors remained "lethargic/ confused" "Reduced response to pain" descriptor in category 3 removed because considered late sign of progression to clinical deterioration. ***Changes to cardiovascular category:*** Diaphoresis added to cardiovascular parameter in category 2 as an early warning symptom for deterioration (heart failure). This addition to the cardiovascular parameter was made to accommodate deterioration in large population of cardiac patients.
Brightom PEWS modified by Solevag et al. (2013)	***Modifications made include:*** The Brighton PEWS was translated to Norwegian The order of the 3 items (behaviour, cardiovascular, and respiratory) was changed to match the ABCD algorithm (airway, breathing, circulation, disability). The AVPU (Alert, Voice, Pain, Unresponsive) scoring system was incorporated for the assessment of disability/behaviour The scoring system was divided into 1) respiratory, 2) circulatory, and 3) behavioural signs of clinical deterioration, which were scored on a scale from 0 to 3 for each parameter. Respiratory rate and heart rate are assessed according to the normal range of values for different age categories, as defined by Akre et al. Two additional 'points' are awarded if either continuous inhalation medications or continuous positive airway pressure (CPAP) are being administered, and 2 additional points for presence of persisting postoperative vomiting. Score ranges from 0 to 13

Bedside PEW systems core modified from Parshuram et al.(2011) by Fuijkschot et al. (2014) 8 parameters Scoring range 0-28	Added **temperature** to scoring system (addition of maximal 2 points to the total score of a patient) expecting to increase PEWS performance, especially in sepsis. Other minor adjustments made to adapt system to setting and improve user-friendliness included a **simplified definition of work of breathing** (normal or mildly, moderately, severely increased) and **supplemental oxygen** (room air, low-flow or high-flow supplemental oxygen). e.g. 3months-1year Heart rate (age dependent) (score range 0,1,2,4) Systolic blood pressure (age dependent) (score range 0,1,2,4) Capillary refill time (<3seconds score 0; >=3 seconds score 4) Respiratory rate (age dependent) (score range 0,1,2,4) Respiratory effort (normal score 0; mild increase score 1; moderate increase score 2; severe increase / any apnoea score 4) Transcutaneous oxygen saturation (>94% score 0; 91-94% score 1; <91% score 2) Oxygen therapy (room air score 0; low flow oxygen score 2; NRB-mask score 4) Temperature 36.5-37.5 score 0; 36-36.4 or 37.6-38.5 score 1; <36 or >38.5 score 2
Bristol PEWS modified by Sefton et al. (2014) The tool is triggered if any one of the parameters are breached.	A-Acute airway obstruction *(seek prompt assistance)* 1. Child receives nebulised adrenaline *OR no improvement after nebulised adrenaline* 2. Clinically tiring or impending complete airway obstruction B-Breathing 1. SaO2<=92% in any amount of oxygen 2. Sa02 <=75% in any amount of oxygen (cyanotic heart disease) 3. Persistent tachypnoea (RR>=70 under 6months; >=60 6-12 months; >=40 1-5 years;>=25 over 5 years) 4. Apnoea +/- bradycardia (HR<=95 in children under 5 years) *5. Marked increased effort of breathing (3+ on table front sheet)* *6. Respiratory depression RR<20 0-3months, <=half lower value for resps for age (table front sheet)* C-Cardiovascular 1. Persistent tachycardia following one bolus of 10mls/kg fluid (HR>=150 under 5 years; HR>=120 5-12 years; HR >=100 over 12 years) 2. Poor perfusion; prolonged capillary refill (>=3secs); +/-low BP, *large central/peripheral temp gradient*

	D-Disability
	1. GCS<=11 *or falling. Children score by AVPU*; responding only to pain or unresponsive
	2. Fitting; unexpected OR not responding to prescribed anticonvulsants
	
	E=other
	1. Hyperkalaemia *K>=6.0mmol/Litre*
	2. Any child with pH <7.2 whatever the cause
	3. Any child with unresolved pain on current analgesic therapy
	4. Any child whose condition is worrying – *but not triggering on above parameters*
	
	Action to be taken if PEW tool is triggered
	Tool does not replace clinical judgement. If a child is deteriorating rapidly or periarrest put out an arrest call immediately. Medical review expected within 30 minutes, within 10 minutes if it is an airway trigger; otherwise
	   • Alert nurse in charge on ward
	   • Increase frequency of observations
	   • Notify patients own medical team
	   • Out of hours contact the call team and inform Night Matron
	   • Complete PEW tool assessment on meditech under nursing assessment
	   • Children triggering PEW must be discussed with registrar

Appendix B

Table 3 Performance criteria for PEW scoring tools

Citation	PEWS	Marker of clinical deterioration /endpoint	Threshold /score cut-point	AUROC	Sensitivity	Specificity	Positive predictive value (PPV)	Negative predictive value (NPV)
Akre	Modified Brighton PEWS	RRT call Code blue call	>=4 or domain score of 3	NR	85.5%	NR	NR	NR
Duncan	PEW system score (Birmingham/ Toronto)	Code blue call - require resuscitation to treat actual or	5	90%	78%	95%	4.2%	NR

Citation	PEWS	Marker of clinical deterioration /endpoint	Threshold /score cut-point	AUROC	Sensitivity	Specificity	Positive predictive value (PPV)	Negative predictive value (NPV)
Fuijkschot	Modified Bedside PEWS from Parshurum	Unplanned ICU admission Need for emergency medical interventions Data included up to 2 hour pre endpoint	>=8	NR	67%	88%	NR	NR
Haines	Bristol PEWS	Escalation to higher level of care	>=1	NR	99%	66%	NR	NR
McLellan	C-CHEWS	CPA Unplanned ICU transfer	>=3 >=5	92%	95.3% 67.2%	76.2% 93.6%	50.8% 72.9%	98.4% 91.7%
Parshuram 2009	Bedside PEWS	Urgent ICU admission without a code blue call	>=8	91%	82%	93%	NR	NR
Parshuram 2011	Bedside PEWS	Urgent ICU admission without code blue Code blue calls Data included up to 1 hour pre endpoint	>=7 8	7, 87%	7, 64% 8, 57	7, 91% 8, 94	9%	NR
Robson	PEW System Score (by Duncan)	EMRT call for impending or actual CPA	5	85%	86.6%	72.2%	NR	NR
Skaletzky	Modified Brighton PEWS	Patients transferred to the PICU after a physician's request, rapid response team evaluation (RRTE), or a CBE.	2.5	81%	62%	89%	NR	NR
Tucker	Modified Brighton PEWS	Unplanned transfer to PICU	>=3 >=4	89%	90.2% >=4, 78.4%	74.4% >=4, 82.4%	5.8% 7.2%	99.8% 99.5%

AUROC = area under receiver operating characteristic curve

Citation	PEWS	Marker of clinical deterioration /endpoint	Threshold /score cut-point	AUROC	Sensitivity	Specificity	Positive predictive value (PPV)	Negative predictive value (NPV)
		impending cardiopulmonary arrest						
Edwards 2009	Cardiff and Vale PEWS	Respiratory or cardiac arrest PHDU/PICU admission Death	>=1 (single parameter) >=2 (multiple parameter)	86%	>=1, 89% >=2, 70%	>=1, 64% >=2, 90%	2.2% 5.9%	99.8% 99.7%
Edwards 2011	Melbourne criteria for activation (MAC) (Adopted from Tibballs)	PHDU/PICU admission; death	>=1	79%	68.3%	83.2%	3.6%	99.7%