2022-09-07

Escalation of care in children at high risk of clinical deterioration in a tertiary care children's hospital using the Bedside Pediatric Early Warning System

Gawronski, O

10.1186/s12887-022-03555-0
BMC Pediatrics
BioMed Central

Escalation of care in children at high risk of clinical deterioration in a tertiary care children's hospital using the Bedside Pediatric Early Warning System

Orsola Gawronski, Jos M Latour, Corrado Cecchetti, Angela Lula, Lucilla Ravà, Marta Luisa Ciofi degli Atti, Immacolata Dall'Oglio, Emanuela Tiozzo, Massimiliano Raponi, Christopher S. Parshuram

Journal Title: BMC Pediatrics

Acceptance date: 16 August 2022

Orsola Gawronski, RN MSN Ph.D. Professional Development, Continuing Education and Research Unit, Medical Directorate, Bambino Gesù Children's Hospital IRCCS, P.zza S. Onofrio 4, Rome, Italy (corresponding author)

Jos Maria Latour, RN Ph.D. Faculty of Health, School of Nursing and Midwifery, University of Plymouth, United Kingdom. School of Nursing, Midwifery and Paramedicine, Faculty of Health Sciences, Curtin University, Perth, Australia

Corrado Cecchetti, MD. Pediatric Intensive Care Unit, Department of Emergency, Acceptance and General Pediatrics, Bambino Gesù Children's Hospital IRCCS, P.zza S. Onofrio 4, Rome, Italy

Angela Iula, RN MSN. Professional Development, Continuing Education and Research Unit, Medical Directorate, Bambino Gesù Children's Hospital IRCCS, P.zza S. Onofrio 4, Rome, Italy

Lucilla Ravà, MSc. Clinical Epidemiology Unit, Bambino Gesù Children's Hospital IRCCS, P.zza S. Onofrio 4, Rome Italy

Marta Luisa Ciofi degli Atti, MD. Clinical Epidemiology Unit, Bambino Gesù Children's Hospital IRCCS, P.zza S. Onofrio 4, Rome Italy

Immacolata Dall'Oglio, PedRN MSN Ph.D. Professional Development, Continuing Education and Research Unit, Medical Directorate, Bambino Gesù Children's Hospital IRCCS, P.zza S. Onofrio 4, Rome, Italy

Emanuela Tiozzo, PedRN MSN. Professional Development, Continuing Education and Research Unit, Medical Directorate, Bambino Gesù Children's Hospital IRCCS, P.zza S. Onofrio 4, Rome, Italy

Massimiliano Raponi, MD. Medical Directorate, Bambino Gesù Children's Hospital IRCCS, P.zza S. Onofrio 4, Rome, Italy

Christopher S. Parshuram, MBChB, DPhil, Paediatric Intensive Care Unit, Critical Care Program, Hospital for Sick Children, 555 University Ave, Toronto, ON M5G1X8, Canada

Corresponding author: Orsola Gawronski: orsola.gawronski@opbg.net +39 0668592595

Abstract

Background: Escalation and de-escalation are a routine part of high quality care that should be matched to clinical need. The aim of this study was to describe escalation of care in relation to the occurrence and timing of Pediatric Intensive Care Unit (PICU) admission in a cohort of pediatric inpatients with acute worsening of their clinical condition.

Methods: A single center, observational cohort study was performed from January to December 2018. Eligible patients were children: 1) admitted in one of the inpatient wards other than ICU; 2) less than 18 years of age at the time of admission; 3) with two or more Bedside Paediatric Early Warning System (BedsidePEWS) scores ≥7 documented at least one hour apart and within a 4 hour period during the ward admission. The main outcome - the 24-hour disposition – was defined as admission to PICU within 24-hours of enrolment or remaining on the inpatient ward. Escalation of care was described using an eight-point scale - the Escalation Index (EI), created by the authors. The EI was calculated every 6 hours beginning at the time a patient became eligible. Analyses used multivariate quantile and logistic regression models.

Results: The 228 episodes evaluated had 574 EI scores calculated and 24-hour disposition of inpatient ward in 129 (57%) and PICU in 99 (43%). Patients who were admitted to PICU within 24-hours had higher maximum EI score [median (IQR) 6 (5-7) vs 4 (3-5), p<0.001]; higher initial BedsidePEWS scores [median (IQR) 10(8-13) vs. 9 (8-11), p=0.02], had chronic disease less frequently [n=62 (63%) vs. n=127 (98%), p<0.0001], and were rated by physicians as more likely to have a cardiac arrest (p=0.01) than patients remaining on the ward. The EI increased over 24 hours before PICU urgent admission or cardiac arrest by 0.53 every 6 hour time interval (CI 0.37-0.70, p<0.001) while it decreased by 0.25 every 6 hour time interval (CI -0.36-0.15, p<0.001) in patients who stayed on the wards.

Conclusion: Escalation of care was related to temporal changes in severity of illness, background patient and environmental factors. The EI can help characterize responses to evolving critical illness.

Keywords: escalation of care, pediatric, track and trigger tool, BedsidePEWS, PEWS, intensive care, urgent admission.

BACKGROUND

Late Pediatric Intensive Care Unit (PICU) admission and failure-to-rescue in children admitted to hospital wards is often a consequence of missed signs of increasing clinical deterioration, ineffective observations, low situational awareness and/or failure in the response system (1,2). Escalation of care has been defined as an organizational response to different levels of abnormal or physiological measurements or other observed deterioration (3). This process requires the timely identification of deterioration, the communication among team members and appropriate interventions.

Pediatric track and trigger tools provide recommendations for graduated escalation to be matched to the patient's severity of illness, according to the early warning score or other triggers. The Bedside Paediatric Early Warning System (BedsidePEWS) is a validated pediatric score and system which has undergone rigorous validation (4–6) and resulted among the best performing screening tools for hospital wards (7). Figure 1 shows the BedsidePEWS score clinical indicators and subscores.

Figure 1. The Bedside Pediatric Early Warning System clinical indicators and subscores.

*vital signs ranges are defined by five age groups (0-3 months, 3-12 months, 1-4 years, 4-12 years, >12 years)

Note: adapted from Parshuram C. S. et al, 2011.

We hypothesized that amongst sick children, those with initially elevated BedsidePEWS scores could: [i] get better over a 24-hour period: their BedsidePEWS scores should fall, their doctors and nurses should think they are at lower risk of an arrest, and their care should be de-escalated, and they should not be admitted to the PICU within 24 hours or in the time afterwards; or [ii] not improve (stay the same or get worse) over a 24-hours period: their BedsidePEWS scores may stay the same or increase, their doctors and nurses should think that are at increased risk of arrest and their care should be escalated and they should be admitted to PICU within 24 hours.

Escalation practices, timing and trends to our knowledge, have not been described for patients at high risk of clinical deterioration with elevated BedsidePEWS scores (BedsidePEWS ≥7), nor a comparison between escalation practices on high scoring children urgently admitted to PICU compared to children staying on hospital wards. Thus, the primary aim of this study was to describe escalation of care including the

occurrence and timing of PICU admission in a cohort of pediatric in-patients with acute worsening of their clinical condition. Secondary aims were [i] to identify patient characteristics associated with the escalation of care and [ii] to compare healthcare professionals' perceptions of risk of clinical deterioration in children admitted to PICU vs those remaining on a hospital ward.

METHODS

A single center, observational cohort study was performed. The hospital Ethics Committee reviewed and approved the study protocol (EC n 915_OPBG_2015).

Eligible inpatient units were ten hospital inpatient wards, including the Cardiology Unit, the General Pediatrics, 2 Stem Cell Transplant and Hematology- Oncology Units, 4 Pediatric specialty wards, the sub-intensive care Pediatric Unit and the Pediatric Emergency Care Unit. Ineligible areas were the three PICUs, the Neonatal Department and the Outpatient Services. Eligible patients were admitted in one of the participating units, were less than 18 years of age at the time of hospital admission, and had two or more documented BedsidePEWS scores ≥7 separated by at least one hour in a 4 hour period. Repeat enrolment was permitted in patients who were enrolled and were subsequently discharged from an ICU. Children with BedsidePEWS≥7 were enrolled for this study as this score cut-off indicates a high risk of critical deterioration and a PICU consult is locally and elsewhere recommended (5).

The main outcome was 24-hour disposition. Patients were either in PICU or in an inpatient ward. The main predictor of interest was escalation of care, which was measured using the Escalation Index (EI). The EI is a composite measure created by the authors derived using the domains: monitoring technology, vital sign frequency; and secondary consultation. These domains are aligned with the BedsidePEWS Score Matched Care Recommendations (SMCR). The EI ranges from 0 (least escalation) to a maximum of 7 (Figure 2).

Figure 2: Escalation index for patients with BedsidePEWS score ≥7: score items and points

Secondary outcomes were the healthcare professionals' retrospective rating of the patients' clinical deterioration and the intensity of care provided by HCPs as determined by the Children's Resuscitation Intensity Scale (CRIS) reported on supplementary file 1.

Study context

The BedsidePEWS has been used at the hospital since 2014. The seven-item BedsidePEWS score ranges between 0 and 26. The score was reported to identify children at risk for cardiopulmonary arrest with a very good performance, reported by an AUROC curve of 0.87 (95% CI=0.85 to 0.89). Increasing scores were reported as significantly associated to clinical deterioration events (6). A randomized controlled cluster trial showed a significant reduction of significant clinical deterioration events in hospitals using the BedsidePEWS (5).

The BedsidePEWS score matched care recommendations (SMCR) for escalation of care are matched to the BedsidePEWS score ranges. They have been defined according to the consensus of more than 280 healthcare professionals on reasonable care in the domains of vital signs assessment, continuous, intermittent or type of monitoring, nursing, medical and ICU review, and the number of patients per nurse according to patients' risk by score (8). Escalation of care of patients at high risk of clinical deterioration, set by a response system policy which includes the BedsidePEWS, involves increasing frequency of monitoring and nursing or medical reviews including PICU consultation, in relation to patient risk. The BedsidePEWS SMCR are not intended to substitute but to support HCPs' clinical judgement and situational awareness of deteriorating children, which are the main drivers of escalation of care. The SMCR for BedsidePEWS≥7 are reported on table 1.

Patients of higher acuity are cared for on step down/sub-intensive care units, where advanced treatments such as inotropes or non-invasive ventilation can be provided. The ward team is responsible for patients and consultations. PICU physicians can be consulted to see a patient in a hospital ward by a ward physician or by a ward nurse. The BedsidePEWS recommends a PICU consult when the BedsidePEWS score is ≥7.

Study Measures and procedures

Two researchers (OG, AI) performed daily patient screening by consulting the electronic patient register, examining the clinical information and the BedsidePEWS scores written on the medical handover records. Patients meeting the inclusion criteria had clinical data abstracted from their medical records by trained research nurses. Patient characteristics and clinical data on risk factors for cardiac arrest, BedsidePEWS scores, medical reviews, monitoring, ICU consultation and other clinical interventions were collected by direct abstraction from clinical records. Data began when the BedsidePEWS reached the first score $\geq$7 and continued, for the following 24 hours. Data on the BedsidePEWS and escalation index was grouped into 6-hour blocks for the 24 hours after enrolment. An EI was calculated within each 6 hour block according to the interventions provided in response to the first BedsidePEWS score≥7 documented within that time interval. Clinical data were abstracted and entered into a database. Data were checked for consistency and accuracy by a second independent study nurse. Inconsistencies were resolved by checking the medical records and discussion among the research group.

Nurses and physicians who cared for the enrolled patients during the observation period were interviewed within 72 hours of patient enrollment to provide additional data on their perception of the patient's clinical condition and escalation of care. They completed a survey to describe their retrospective global rating of the risk of clinical deterioration and actions envisioned for that patient. They were asked 'How much would you have been surprised if this patient arrested?'; 'Would you have called for an urgent PICU consult for this patient?' Responses were recorded on a 10-point Likert scale.

Analysis

Data were described through mean and standard deviation or median and interquartile range, as appropriate, according to the distribution, tested with D'Agostino Pearson test. Inferences were calculated with chi-square, by Student's T-test and Mann-Whitney U Test according to the distribution. A $p<0.05$ was considered as significant.

From this data we calculated the maximum EI within the 24 hours of a PICU admission or progression of ward admission. A linear mixed effect regression model was performed to evaluate the temporal evolution of the EI preceding urgent PICU admissions. The dependent variable was the first EI calculated during the 6

hours interval before the unplanned admission. The independent variable was the time interval before an unplanned PICU admission.

A quantile regression and a multivariate model was used to describe patient characteristics, the healthcare professionals' retrospective rating of the clinical deterioration and other factors associated to escalation of care. A Proportional Hazard Cox Regression model was performed to describe the association of the EI and other factors to PICU admission by time interval. Adjustment was performed by chronic disease, patient complexity (>10 medications), recent transfer, isolation, CRIS, highest BedsidePEWS score, total length of stay, EI by time interval, highest EI, nurses and doctors rating of clinical deterioration and need for a PICU transfer, and the nurse patient ratio. Chronic disease was defined as an illnesses that last for 3 months or more or require long term care.

Survey data from frontline nurses and physicians were paired with corresponding data from patients while on the wards in the 24-hour study period and were used to calculate the maximum EI score. When more than one physician or nurse was surveyed, the one that cared for that patient closer to the event was selected. The responses of the frontline physicians and nurses were represented on a numerical scale from 1 to 10. Adjustment was made for predictors of escalation of care: the highest BedsidePEWS score in 24 hours, chronic disease, isolation, complexity (>10 medications), recent transfer from other units or service, diagnosis and age.

Subgroup analyses of the EI was performed for the following domains: age, chronic disease, diagnosis, reason for admission, isolation, complexity (>10 medications), devices, recent transfer from other ward or service, BedsidePEWS score.

RESULTS

The study was conducted between January and December 2018 in 10 eligible inpatient units of a 607 bed tertiary care pediatric hospital. The 225 included children had 228 episodes, and 574 6-hour blocks were evaluated. The mean age was 3.53 (SD±5.24) years. Of the included children, 189 (83%) had chronic disease and the most common reason for admission was respiratory illness (n=95, 42%). The median (IQR) BedsidePEWS score at enrolment was 8 (7-9). In each patient the BedsidePEWS scores were ≥7 a median

(IQR) of 5 (3-8) times in 24 hours after enrolment. The 24-hour disposition was the ward in 129 patient-episodes and the PICU in 99 patient-episodes. PICU admission occurred within 6 hours of meeting eligibility in 37 (37%) children, in 6-12 hours in 13 (13%) and in 12-18 hours in 17 (17%).

Escalation of care

EI scores for the initial 6-hour period reflected children having continuous saturation and ECG monitoring (86%), vital sign assessments at 1-4 hour frequency (73%) and physician review within 4 hours (62%) (Supplementary Electronic Table 1.) EI scores increased from initial levels in children who were urgently admitted to the PICU; and were significantly higher than children who were not admitted to the PICU within 24 hours (median (IQR) of 6 (5-7) vs 4 (3-5), p<0.001). Escalation of care at enrolment was significantly different in children urgently transferred to PICU compared to ward patients in the domains of vital signs monitoring frequency and PICU consult (P<0.001). When stratifying for age, respiratory, cardiovascular and oncological disease, any reason for admission, chronicity, recent transition, complexity of care (>10 medications) and isolation, the maximum EI was significantly higher in patients with PICU urgent admission compared to patients remaining on the ward (Table 2).

A significant correlation between the BedsidePEWS and the EI was found (Spearman r=0.31, P<0.0001). Univariate quantile regression analyses showed an association between the independent variable, the higher maximum EI scores and the highest BedsidePEWS score, the absence of chronic disease, not having cardiovascular and neurological diagnosis, isolation, complexity (>10 medications), <24 hour transition from Emergency Room or primary care service. The multivariate quantile regression showed an association of the highest EI and the maximum BedsidePEWS and isolation. An inverse association was found for chronic disease and complexity (>10 medications) in the 24 hour observation period (Table 3).

The EI was 1.63 times higher in children urgently admitted to PICU than in children who stayed on the wards (CI 1.29-1.97, p<0.0001). A mixed effect regression model showed that on a total of 223 children episodes, the EI increased over 24 hours before PICU urgent admission or cardiac arrest by 0.53 every 6 hour time interval (CI 0.37-0.70, p<0.001). In children who stayed on the wards, over a total of 351 patient episodes, the EI decreased over the 24 hours after the first BedsidePEWS $\geq$7 by 0.25 every 6-hour time

interval (CI -0.36-0.15, p<0.001), The median values of the EI and the highest BedsidePEWS by time interval among ward and PICU patients is presented in Figure 3.

Figure 3_ Progression of escalation of care and the BedsidePEWS of high risk patients (BedsidePEWS $\geq$7)

[a] Data are from 228 patients. The graph represents the trend of the median value of the Escalation Index and the highest BedsidePEWS during the 24 hours observation period in the 99 patients urgently admitted to PICU and the 129 patients who stayed on a hospital ward. T1-T4 define the 6 hour intervals of data collection. EI= Escalation Index; T=Time; BPEWS=BedsidePEWS; PICU=Pediatric Intensive Care Unit.

The Proportional Hazard Cox Regression model found the Hazard Ratio of unplanned PICU admission increased by 42% at 12-6 hours and by 39 % <6 hours from PICU admission for every unit increase of the escalation index. No other variables included in the model were found significant.

Healthcare Professional Ratings.

There were 102 physicians (45%) and 120 nurses (52%) which retrospectively rated the potential for clinical deterioration of the patient they provided care for and the 'need' for a PICU consult. A quantile regression adjusting for predictors of escalation of care found that healthcare professionals' (HCPs) clinical deterioration rating, (physicians β coeff=0.28, p=0.003; nursing rating, β coeff=0.16, p=0.025) and HCPs' perception of the importance of obtaining a PICU consult (physician's rating, β coeff=0.23, p<0.001; nursing rating, β coeff=0.11, p=0.03) were significantly associated with the highest EI during the 24 hour period.

Among PICU patients the retrospective HCPs' ratings of the patients' clinical deterioration (52 patients, 53%) and the nursing rating of their need for a PICU consult (58 patients, 59%) was also significantly associated with the EI (Clinical deterioration rating, β coeff=0.44, CI=0.11-0.76, p=0.01; Need for PICU consult, β coeff=0.32, CI=0.11-0.54, p=0.004). No significant association was found with the highest BedsidePEWS score.

ICU admission

Compared with patients who remained on the ward, patients who were urgently admitted to PICU within 24 hours of enrolment were less likely to have chronic health conditions of any sort or to have cardiovascular reasons for admission, were more likely to have respiratory or haematologic / oncologic conditions, a recent

transfer from other wards or services (all p<0.0001), had a higher maximum BedsidePEWS score [median (IQR) 10 (8-13) vs 9 (8-11), p=0.02], higher EI values [6 (5-7) vs 4 (3-5), p<0.0001] and related proportions of continuous monitoring, vital signs documentation, physician review and PICU consultation (Table 4).

Patients admitted to PICU had BedsidePEWS scores that were either high at enrolment or rose after the initial 6-hour block (Figure 3), 83 (84%) had PICU consults made to facilitate care, and had a median (IQR) CRIS score of 1 (1-3). There were 13 (13 %) late PICU admissions that included 5 resuscitation team calls, of which 4 (4 %) patients were intubated prior to PICU admission. There were no deaths. Children who remained in inpatient wards at 24 hours had more escalation of care if their initial BedsidePEWS scores were higher; overall BedsidePEWS scores that became lower over time, had lower levels of escalation – suggesting de-escalation - over the 24 hours (Figure 3) and had physicians rating their concern higher in patients for whom there was greater escalation (Table 5).

DISCUSSION

The aim of this study was to describe escalation of care and the occurrence and timing of PICU admission in a cohort of pediatric in-patients with acute worsening of their clinical condition. Prospective evaluation of 228 patient-episodes of increased severity of illness for at least four hours found that escalation of care over 24-hours varied with patient characteristics and ongoing severity of illness. This is the first study showing differences in escalation trends among children admitted to hospital wards, showing that children with acute conditions without baseline chronic conditions or children in need of isolation due to immune deficiencies or infections are more likely to be receiving earlier increased attention from the ward team when their BedsidePEWS score is $\geq$7. Greater escalation occurred also in children rated by healthcare professionals with a higher risk of deterioration and higher need for a PICU consult. This study also reported on the timeliness and magnitude of escalation in a children's hospital, which are essential determinants of earlier PICU admissions and prevention of critical illness.

The four main findings relate to the relationship between severity of illness and escalation, and the timeliness of transfer from the ward environment. First, the observed correlation between the BedsidePEWS

score and the EI may reflect application of the BedsidePEWS score matched care recommendations. Considerable variability in extent of escalation across the domains of vital signs monitoring, documentation, secondary review by ward based clinicians and PICU consultation demonstrates application of clinical judgment by involved clinicians, potentially reflecting the consideration of the score in the broader contexts of patient, ward environment and temporal trends (9,10). The patients who remained on the ward for 24 hours after enrolment had decreasing BedsidePEWS scores and relative de-escalation.

Second, healthcare professionals' perceptions of patient's risk was linked to escalation decision making about monitoring, secondary nursing and medical review, consultation to the PICU for management recommendations and consideration of PICU admission. This finding shows the responsiveness of the EI to HCPs' clinical judgement of critical deterioration in children. A lower association might have been found if nurses had been blinded to patient disposition, considering a potential risk of recall bias.

Third, among patient and organizational factors, isolation was associated to escalation of care while having a chronic disease was inversely related. We noted that of the 127 of 129 episodes where patients remained on the wards were patients with chronic diseases and that patients receiving care in isolation rooms were also more likely to receive more attention. Chronic disease was an important modifier of extent of escalation - patients with chronic diseases were less likely to have care escalated. This may reflect greater understanding of the basis of physiologic states of patients, of anticipated trajectories, of higher 'baseline' scores, preferences to keep patients within specialized wards or other unmeasured factors. On the other hand, almost all patients with isolated acute severe illness were admitted to PICU. Other factors including age, diagnosis, and recent transitions from ICU and Emergency department were not significantly associated to escalation of care in multi-variable analysis.

Fourth, timing of escalation is essential in preventing or determining earlier PICU admissions to reduce severity of illness. This study showed an increasing escalation trend starting 12 hours after enrollment and 12 hours before PICU admission, from a partial escalation at enrollment, showed by an intermediate EI value. Moreover most children requiring advanced airway management in this study had a prolonged observation on the ward up to 24 hours, suggesting a late PICU admission. The role of the PICU team in

facilitating PICU admission warrants further consideration. Increased risk of PICU admissions and mortality has been reported for patients who have manifested prolonged clinical deterioration on the wards, suggesting the relevance of timely involvement of PICU teams in their management.

In addition, the cohort of children at high risk who stayed on the wards was almost completely with chronic conditions. That one third had a PICU urgent admission a median (IQR) of 17.5 (6.5-32) days after enrolment suggests ongoing elevated risk and leads to questions about the ideal threshold for ICU admission (11,12). Normalizing the score of patients with complex and chronic illness can cause the underestimation of these children's risk potentially leading to unexpected critical events (13). A 'score to PICU door' time to prevent delays in recognition and treatments of deteriorating children might be taken into consideration for defining safe care to those children (14).

Limitations

This study has some limitations. First, as a single center study generalizability of the findings to hospitals with different escalation practices and response systems to critically ill children may be limited. Second, other factors may explain decisions to admit to PICU – for example monitoring for arrhythmia, for hemorrhage, for trending the lactate, or closer observation of electrolytes, or clinical preference. Other measures such as laboratory, radiologic, diagnostic tests or other interventions almost certainly influenced clinical decision-making, and should be reflected in the clinicians' assessment of risk of cardiac arrest and their perception of benefit of a PICU consultation. Future work may consider calibrating the elements of the EI, to confirm the weight of each element within the score (15). Third, in this study we are unable to assess the effect of the BedsidePEWS escalation algorithm on important patient outcomes, such as mortality, mechanical ventilation days or PICU length of stay. Greater adherence to the SMCR may have prevented late PICU urgent admissions but whether this is associated to a reduction of PICU urgent admissions overall needs to be further explored. Fourth, we examined patients with BedsidePEWS$\geq$7, excluding children with lower scores. Thus we do not know the pattern of escalation of care and the characteristics of patients urgently transferred to PICU with BedsidePEWS scores<7. Lastly, the retrospective nature of HCPs' questionnaires possibly increased the risk of recall bias. However questionnaires were anonymous, thus limiting the risk of any social desirability bias.

CONCLUSION

Evaluation of a cohort of children with acutely increased severity of illness showed variability in escalation responses that was related to temporal changes in severity of illness, background patient and environmental factors. EI scores were higher in children urgently admitted to PICU than in children who stayed on the wards, for whom EI scores gradually decreased. Bedside PEWS and isolation were associated to escalation of care while chronic illness was inversely related. Use of measures such as the escalation index can help characterize responses to evolving critical illness as part of assessment of the effectiveness of rapid response systems.

List of abbreviations

BedsidePEWS: Bedside Pediatric Early Warning System

CRIS: Children Resuscitation Intensity Score

EI: Escalation Index

HCP: Health Care Provider

ICU: Intensive Care Unit

PICU: Pediatric Intensive Care Unit

SMCR: Score Matched Care Recommendations

Declarations

Ethics approval and consent to participate: The study has been performed in accordance with the Declaration of Helsinki and was approved by Bambino Gesù Children's Hospital ethics committee. Patients' informed consent was waived by Bambino Gesù Children's Hospital ethics committee as only aggregated clinical data was used for this study. Healthcare providers' informed consent was provided on the electronic survey before data collection.

Availability of data and materials: The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

Consent for publication: Not applicable

Competing interests: Christopher Parshuram is a named inventor of the patent for the Bedside Paediatric Early Warning System, and has shares in a decision support company established by SickKids to commercialize this product. All the other authors declare that they have no competing interests.

Funding: This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Authors' contributions: OG and CP designed the study. OG and AI coordinated the study and collected data. LR and OG analyzed the data. OG, CP, MCA and JML interpreted the results. OG and CP wrote the manuscript. All authors contributed to the drafting of the manuscript and critical revision of it for important intellectual content. All authors read and approved the final manuscript.

Acknowledgements: We thank all the department nurse coordinators and nurse managers of Bambino Gesù Children's Hospital who facilitated patient enrollment and data collection.

References

1. Tume L. The deterioration of children in ward areas in a specialist children's hospital. Nurs Crit Care. feb 2007;12(1):12–9.
2. Pearson G. Why Children Die: the report of a pilot confidential enquiry into child death by CEMACH (Confidential Enquiry into Maternal and Child Health). Clinical Risk. 1 sept 2008;14(5):166–8.
3. Australian Commission on Safety and Quality in Health Care. National safety and quality health service standards. Sydney: Australian Commission on Safety and Quality in Health Care; 2012.
4. Parshuram CS, Hutchison J, Middaugh K. Development and initial validation of the Bedside Paediatric Early Warning System score. Crit Care. 2009;13(4):R135.
5. Parshuram CS, Dryden-Palmer K, Farrell C, Gottesman R, Gray M, Hutchison JS, et al. Effect of a Pediatric Early Warning System on All-Cause Mortality in Hospitalized Pediatric Patients: The EPOCH Randomized Clinical Trial. JAMA. 13 mar 2018;319(10):1002–12.
6. Parshuram CS, Duncan HP, Joffe AR, Farrell CA, Lacroix JR, Middaugh KL, et al. Multicentre validation of the bedside paediatric early warning system score: a severity of illness score to detect evolving critical illness in hospitalised children. Crit Care. 3 aug 2011;15(4):R184.
7. Chapman SM, Wray J, Oulton K, Pagel C, Ray S, Peters MJ. «The Score Matters»: wide variations in predictive performance of 18 paediatric track and trigger systems. Arch Dis Child. jun 2017;102(6):487–95.
8. Parshuram CS, Dryden-Palmer K, Farrell C, Gottesman R, Gray M, Hutchison JS, et al. Evaluating processes of care and outcomes of children in hospital (EPOCH): study protocol for a randomized controlled trial. Trials. 2 jun 2015;16:245.
9. Ede J, Jeffs E, Vollam S, Watkinson P. A qualitative exploration of escalation of care in the acute ward setting. Nurs Crit Care. may 2020;25(3):171–8.
10. Ede J, Petrinic T, Westgate V, Darbyshire J, Endacott R, Watkinson PJ. Human factors in escalating acute ward care: a qualitative evidence synthesis. BMJ Open Qual. feb 2021;10(1):e001145.
11. Cunningham S. Critical Care Thresholds in Children with Bronchiolitis. Am J Perinatol. sept 2020;37(S 02):S42–5.
12. Liu YC, Cheng HY, Chang TH, Ho TW, Liu TC, Yen TY, et al. Evaluation of the Need for Intensive Care in Children With Pneumonia: Machine Learning Approach. JMIR Med Inform. 27 jan 2022;10(1):e28934.
13. Simon TD, Berry J, Feudtner C, Stone BL, Sheng X, Bratton SL, et al. Children With Complex Chronic Conditions in Inpatient Hospital Settings in the United States. Pediatrics. 1 oct 2010;126(4):647–55.
14. Whebell SF, Prower EJ, Zhang J, Pontin M, Grant D, Jones AT, et al. Increased time from physiological derangement to critical care admission associates with mortality. Crit Care. dec 2021;25(1):226.
15. Chapman SM, Wray J, Oulton K, Peters MJ. Systematic review of paediatric track and trigger systems for hospitalised children. Resuscitation. dec 2016;109:87–109.

Table 1: Score matched care recommendations for BedsidePEWS ≥7

BedsidePEWS score range	BedsidePEWS=7-8	BedsidePEWS>8
Vital signs documentation	15-60 minutes	15 minutes (15-60 minutes if stable*)
Nursing re-evaluation	2 hours (4 hours if stable*)	15 minutes
Medical evaluation	2 hours (4 hours if stable*)	15 minutes
Type of monitoring	ECG, SpO2	ECG, SpO2
PICU consult	Evaluate	Evaluate
Additional patients of same risk score/nurse	0-1 patients	0

Note* this recommendation is applied to children who remain in this risk range after the first assessment.

ECG= electrocardiogram monitoring; SpO2=peripheral oxygen saturation; PICU= Pediatric Intensive Care Unit

Table 2: Escalation index in 228 patient episodes [a]

24-hour disposition	PICU admission		Ward		
Patient characteristics	**N (%)**	**Median (IQR) EI**	**N (%)**	**Median (IQR) EI**	***p* value**
All	99	6 (5-7)	129	4 (3-5)	<0.001
Age					
<1 year	43 (43)	6 (5-7)	58 (45)	4 (4-4)	<0.001
1-<5 years	29 (29)	5 (4-7)	40 (31)	4 (3-5)	0.001
5-<12 years	11 (11)	7 (5-7)	10 (8)	4 (3-5)	0.004
≥12 years	16 (16)	6 (5-7)	32 (16)	4 (3-5)	<0.001
Chronic disease	62 (63)	6 (4-7)	127 (98)	4 (3-5)	<0.001
Diagnosis					
Respiratory	45 (45)	6 (5-7)	50 (39)	4 (4-5)	<0.001
Cardiovascular	12 (12)	5.5 (4-6)	53 (41)	4 (3-4)	<0.001
Neurological	12 (12)	5 (4-7)	12 (9)	3 (2.5-4.5)	0.062
Onco-haematological	24 (24)	6 (4-7)	13 (10)	4 (3-5)	0.002
Reason for admission					
Respiratory	51 (52)	6 (5-7)	60 (47)	4 (4-5)	<0.001
Cardiovascular	11 (11)	5 (4-6)	42 (33)	4 (3-4)	<0.001
Abdominal	7 (7)	5 (5-7)	3 (4)	4 (3-4)	0.007
Infection	6 (6)	7 (6-7)	7 (5)	4 (2-5)	0.001
Onco-haematological	14 (14)	6 (5-7)	13 (10)	5 (4-5)	0.049
Isolation	39 (39)	6 (5-7)	39 (31)	4 (4-5)	<0.001
Medications (≥10)	52 (53)	6 (5-7)	78 (60)	4 (3-4)	<0.001
Recent transition	37 (37)	6 (5-7)	31 (24)	4 (4-5)	<0.001
Type of transition					
< 24 hours from ER	20 (20)	7 (6-7)	18 (14)	4 (4-6)	0.002
< 48 hours from PICU	6 (6)	5.5 (4-6)	12 (9)	4 (3.5-4)	0.075

[a] EI = Escalation index. Data are from 228 patients with two consequent BedsidePEWS ≥7 within 4 hours of admission on a paediatric ward. The maximum Escalation Index over 6-hourly evaluations was calculated for 24 hours ending on the last 6 hour interval before an urgent PICU admission or progression of ward admission. The Escalation Index was higher in patients admitted to PICU compared with all patients who stayed on the ward in each category. ER=Emergency Room; PICU=Pediatric Intensive Care Unit.

Table 3: Patient characteristics associated with escalation of care [a]

	Univariate			Multivariate		
Characteristic	Coeff	*p* value	95% CI	Coeff	*p* value	95% CI
Age						
<1 year	-	-	-	-	-	-
1-<5 years	0	1	-0.74-0.74	-0.30	0.3	-0.88-0.27
5-<12 years	1	0.085	-0.14-2.14	-0.75	0.5	-1.27-0.57
≥12 years	1	0.032	0.09-1.91	-0.77	0.06	-1.56-0.02
Chronic disease	-2	<0.001	-2.5 - -1.45	-0.90	0.01	-1.61- - 1.20
Diagnosis						
Respiratory	-	-	-	-	-	-
Cardiovascular	-1	0.005	-1.7—0.3	-0.63	0.09	-1.44- 0.09
Neurological	-1	0.05	-2--0.01	-0.07	0.89	-1.05-0.91
Onco-haematological	0	1	-0.84-0.84	0.72	0.15	-0.27-1.71
Other	0	1	-1.7-1.7	0.16	0.88	-1.05-1.91
Isolation	1	0.001	0.42-1.58	0.67	0.009	0.17-1.17
Medical devices	0	1	-0.64-0.64	0.32	0.27	-0.27-0.97
Medications (≥10)	-1	0.001	-1.59-0.4	-0.60	0.04	-1.19- -0.02
Transitions						
No transitions	-	-	-	-	-	-
<24 hours from ER or primary service	2	<0.001	1.40-2.60	0.47	0.18	-0.21-1.15
<48 hours from PICU	0	1	-0.84-0.84	- 0.67	0.13	-1.53-0.21
< 48 hours from other wards	1	0.07	-0.1-2.1	-0.23	0.68	-1.35-0.89
Maximum BPEWS	0.13	0.02	0.02-0.2	0.21	<0.001	0.12-0.30

[a] Data are from 228 patients. Factors associated to the Highest median Escalation Index are described through a multivariable quantile regression. Significant associations found patients with higher escalation index values had greater BedsidePEWS scores and were more often in isolation. Less escalation of care occurred in patients with chronic Disease and those receiving more than 10 medications. Diagnosis, presence of medical devices, transitions of care and age were not associated with the extent of escalation in multi-variable models. BPEWS= BedsidePEWS; ER=Emergency Room; PICU=Pediatric Intensive Care Unit.

Table 4: Patient characteristics, by timing of PICU or ward admission

PICU admission	**YES**					**NO**	
Time from enrollment, hours	**≤6***	**7-12***	**13-18***	**19-24***	**<6-24***	**At 24**	***P* value ******
Patients, n (%)	37 (37)	13 (13)	17 (17)	32 (32)	99	129	
Age, median (IQR), years	1 (0-5)	1 (0-5)	1 (0-4)	1 (0-7)	1(0-5)	1 (0-4)	0.59
Max BedsidePEWS score, median (IQR)	10 (8-12)	9 (7-11)	9 (7-10)	7 (7-8)	10(8-13)	9 (8-11)	**0.02**
Chronic Disease, n (%)	23 (62)	8 (62)	9 (53)	22 (69)	62(63)	127 (98)	**<0.0001**
Diagnosis, n (%)							**<0.0001**
Haematology-Oncology,	7 (19)	2 (15)	5 (29)	10 (31)	24(24)	13(10)	
Cardiac	-	1 (7)	2 (12)	9 (28)	12(9)	12 (12)	
Respiratory	18 (49)	7 (54)	9 (53)	11 (34)	45(45)	50 (39)	
Neurological or Endocrine	12 (3)	3 (23)	1(6)	2 (6)	18(18)	12 (9)	
CRIS							**<0.0001**
(1-4) (Early) n (%)	35 (95)	11 (85)	14 (82)	26 (81)	86 (87)	129	
>=5 (Late) n (%)	2 (5)	2 (15)	3 (18)	6 (19)	13 (13)	0	
Median (IQR)	1 (1-2)	1 (1-2)	1 (1-2)	1(1-3.5)	1 (1-3)	1(1-1)	**<0.0001**
Recent transfer	21 (57)	5 (38)	7 (41)	4 (13)	37(54)	31(46)	**0.03**
ER<24 hours	13 (35)	2 (15)	4 (24)	1 (3)			
PICU readmissions<48 hours	4 (11)	-	1 (6)	1 (3)		-	
Other	4 (11)	2 (15)	2 (12)	2 (6)		-	
PICU consult n (%)	30 (81)	13 (100)	13 (76)	27 (84)	83(84)		**<0.0001**
Intubation n (%)	1 (3)	0	0	5 (16)	6 (6)	0	**0.005**
First EI score, median (IQR)	6(4-7)	5(4-6)	4(3-5)	4(2-4)	5(4-6)	2(4-4)	**<0.001**
Ward Physician review <2-4 hrs, n(%)	29 (78)	11(84)	12(71)	19(59)	71(72)	71(55)	**0.01**
PICU consult <6h from first BPEWS≥7, n (%)	30 (81)	8(61)	8(47)	10(31)	56(57)	13(10)	**<0.0001**
BPEWS documentation hourly, n(%)	19(62)	5(38)	3(19)	3(9)	30(32)	17(13)	**0.001**
ECG+SpO2, n(%)	27(73)	12(92)	16(100)	32(100)	87(88)	108()	0.28
Escalation index (median, IQR)	4 (2-4)	3(2-4)	4(3-5)	4(2-6)	6(5-7)	4(3-5)	**<0.0001**
Q: Would you have called for an urgent PICU consult for this patient							

MD median (IQR)	10(10-10)	10(10-10)	10(9-10)	10(8-10)	10(9-10)	5(2-8)	**<0.0001**
RN median (IQR)	9(9-10)	10(10-10)	10(10-10)	9(6-10)	10(9-10)	8.5(4-10)	**0.002**
Q: How much would you have been surprised if this patient arrested during your shift							
MD median (IQR)	6 (3.5-7)	3(2-5)	5(3-9)	6(3-9)	5(2-7)	7(3-9)	**0.01**
RN median (IQR)	4(2-6.5)	4(2-7)	4(2-7)	4(2-7)	4(2-7)	3.5(2-6)	0.59

Legend: CRIS= Childrens Resuscitation Intensity Scale, ER= Emergency Room, PICU= Pediatric Intensive Care Unit. *during period time interval. ** *P* value= PICU admission (YES) vs no PICU admission (NO)

PICU admission more than 24 hours after enrolment occurred in 21 (29%) patients at a median (IQR) of 18 days (7-34) after ward admission. There were no PICU admissions within 48 hours of enrolment, suggesting the use of 24 hour disposition provided good separation of patients into ward and ICU groups. Patients admitted to ICU after 24 hours of enrolment had a cardiac diagnosis (n=18, 86%), there was one resuscitation team call made and were all admitted with CRIS scores of 4 or less.

Table 5: Patient characteristics and staff perception of clinical deterioration, by ICU admission and escalation of care. [a]

	PICU admission ″24 hours				
	NO		YES		*P* value*
Maximum Escalation Index score	<5	≥5	<5	≥5	
Patient characteristics					
Maximum BedsidePEWS in last full 6 hour period, median (IQR)	7 (6-9)	7 (6-8)	9 (7-14)	10 (8-12)	0.37
Maximum BedsidePEWS median (IQR)	9 (7-11)	11 (9-11)	10 (8-14)	10 (8-12)	**0.02**
Max BedsidePEWS ≥10, n (%)	46/113 (41)	11/16 (69)	21/40 (53)	34/59 (58)	0.142
Children's RIS, n (%)					**<0.0001**
1-4	113 (100)	16 (100)	33 (83)	53 (90)	
5-7	0 (0)	0 (0)	7 (17)	6 (10)	
Recent transfer, n (%)					**0.03**
Yes	25	6	12	25	
PICU Team Called, n (%)					**<0.0001**
<=6 hours	4 (4)	9 (56)	17 (42)	39 (66)	
6-12 hours	1 (1)	3 (19)	2 (5)	7 (11)	
> 12 hours	0	3 (19)	5 (12)	13 (22)	
no call	108 (96)	1 (6)	16 (40)	0	
Medication complexity, n (%)	72 (64)	6 (37)	21 (53)	31 (53)	**0.230**
Yes	41 (36)	10 (63)	19 (47)	28 (47)	
No					
Isolation, n (%)					
Yes	34 (31)	5 (33)	12 (30)	27 (46)	**0.21**
No	76 (69)	10 (67)	28 (70)	32 (54)	
Chronic disease, n (%)					
Yes	112 (99)	15 (94)	26 (65)	36 (61)	**<0.0001**
No	1 (1)	1 (6)	14 (35)	23 (39)	
HCP perception of patient deterioration, mean, SD					

Physician Q5**	4.85 ± 3.43	7.86 2.19	±	8.53 3.11	±	9.61	±	0.79	**0.02**
Physician Q6***	4.54 ± 3.40	5.17 2.64	±	8.60 3.11	±	9.46	±	0.88	**<0.0001**
Nurses Q5**	6.88 ± 3.38	8.67 1.86	±	8.22 2.97	±	9.06	±	1.98	0.75
Nurses Q6***	6.40 ± 3.20	6.83 2.56	±	8.57 2.69	±	9.09	±	1.99	**0.002**

[a] This table compares escalation practices (the highest escalation index) in patients admitted to PICU and patients who stayed on the wards during the 24 hours observation period. There was a median (IQR) of 2(1-3) 6-hour periods with one or more BedsidePEWS scores ≥7 in patients admitted to PICU and 3 (2-4) in patients remaining on the ward. These permitted calculation of 574 Escalation Index values. The escalation index ranges from 1-7. Escalation of care was classified into "low escalation" for an escalation index score= 1-4; "high escalation" for an escalation index score= 5-7.

Patients who were not admitted to PICU, with higher BedsidePEWS scores and Escalation Index had the greatest improvement (lower BedsidePEWS scores) at the end of the observation period. PICU=Pediatric Intensive Care Unit; Chidren's RIS= Children's Resuscitation Intensity Score; HCP=Health Care Professionals; Q= Question. * P= PICU admission vs no PICU admission; ** How much would you have been surprised if this patient arrested? *** Would you have called for a PICU consult for this patient?

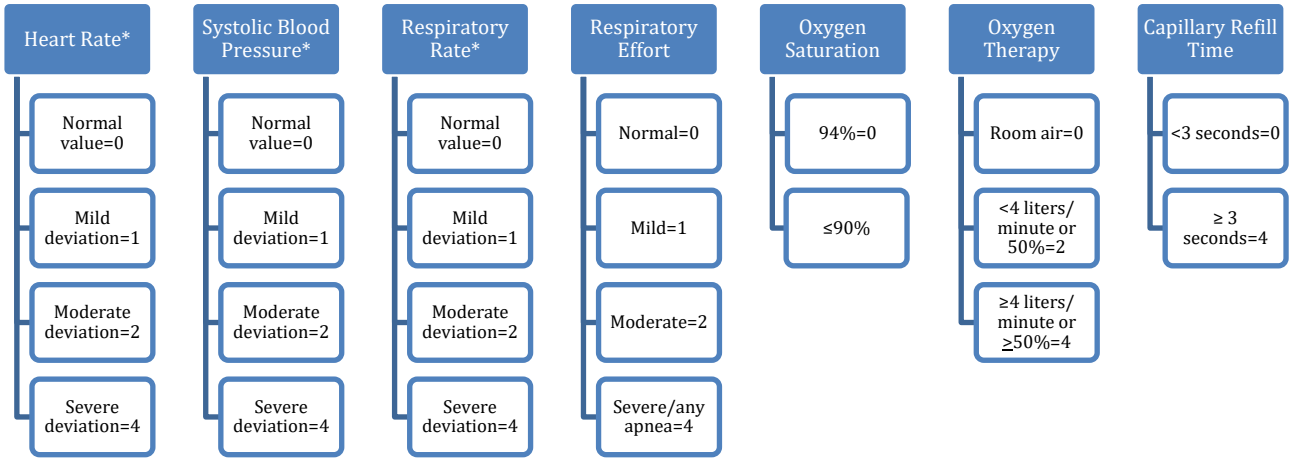

Figure 1. The Bedside Pediatric Early Warning System clinical indicators and subscores.

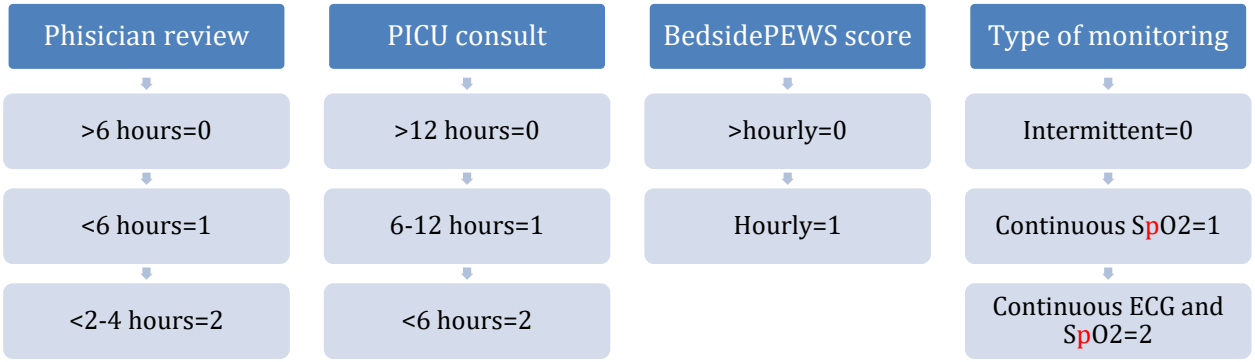

Figure 2: Escalation index for patients with BedsidePEWS score ≥7: score items and points

Supplementary Electronic Table 1: Escalation of care at enrollment

	Total	PICU urgent admissions	Ward patients	P-value
N	228	99	129	
Vital signs and BPEWS scoring*, N (%)				<0.001
<1 hours	47 (21)	30 (30)	17 (13)	
1-4 hours	165 (73)	56 (57)	109 (85)	
>4 hours	69 (4)	6 (6)	3 (2)	
Not applicable	5 (2)	5 (5)	-	
Type of monitoring, N (%)				0.463
Intermittent	17 (7)	5 (5)	12 (9)	
Continuous SpO2	15 (7)	6 (6)	9 (7)	
ECG Monitor + SpO2	195 (86)	87 (89)	108 (84)	
Physician reviews				
Number of Physician review in 24h (n), mean±SD	3.11±2.84	3.86±2.38	2.55±1.75	<0.001
Physician review (timing) N (%)				0.093
≤ 4 hours	142 (62)	71 (72)	71 (55)	
4- 6 hours	11 (5)	3 (3)	8 (6)	
7-12 hours	37 (16)	10 (10)	27 (21)	
> 12 hours	18 (8)	7 (7)	11 (9)	
No call	20 (9)	8 (8)	12 (9)	
MET/RRT review, N (%)				<0.001
≤ 6 hours	69 (30)	56 (57)	13 (10)	
≤ 12 hours	13 (6)	9 (9)	4 (3)	
> 12 hours	21 (9)	18 (18)	3 (2)	
No calls	125 (55)	16 (16)	109 (85)	

Note: *The Escalation Index was calculated at the 1st BPEWS>=7