International Journal of Computational and Experimental Science and ENgineering (IJCESEN)

Vol. 10-No.4 (2024) pp. 3763-3770
http://www.ijcesen.com

ISSN: 2149-9144

Research Article

Early Nursing Recognition of Subtle Physiological Changes Before Clinical Deterioration

Manal Mubarak Q Alruwili[1]*, Latifah Bauad Alhazmi[2], Muteb Hammad H Shlamari[3], Bashayr Zahid N Alanazi[4], Alsubaie, Bandar Abdullah[5], Reem Mulfi J Alanazi[6], Alanazi, Fatimah Mohammed S[7], Najah Subhi Turki Alshammari[8], Saeed Salem Saeed Alsehly[9], Reem Murdhi Sudi Alanazi[10], Badriah Redha Alenezi[11]

[1]Nursing Technician – Al-Tuwayr Primary Health Care Center, Al Jouf Health Cluster, Ministry of Health, Sakaka, Al Jouf Region, Saudi Arabia
* **Corresponding Author Email:** mamualrwily@moh.gov.sa - **ORCID:** 0000-0002-5007-7000

[2]Nursing Technician – Maternity and Children's Hospital, Northern Borders Health Cluster, Ministry of Health, Arar, Northern Borders Region, Saudi Arabia
Email: Olbalhazmi@moh.gov.sa - **RCID:** 0000-0002-5007-7001

[3]Health Assistant (Nursing) – Branch of the Ministry of Health, Ministry of Health, Hail, Hail Region, Saudi Arabia
Email: ahaa6@hotmail.com- **ORCID:** 0000-0002-5007-7002

[4]Nursing Technician – Al-Mohammydia Primary Health Care Center, Northern Borders Health Cluster, Ministry of Health, Arar, Northern Borders Region, Saudi Arabia
Email: bzalenazi@moh.gov.sa- **ORCID:** 0000-0002-5007-7003

[5]Nursing Technician – Al Muzahimiyah General Hospital, First Riyadh Health Cluster, Ministry of Health, Al Muzahimiyah, Riyadh Region, Saudi Arabia
Email: baalsubaie@moh.gov.sa - **ORCID:** 0000-0002-5007-7004

[6]Nursing – Prince Abdulaziz bin Musaed Hospital, Northern Borders Health Cluster, Ministry of Health, Arar, Northern Borders Region, Saudi Arabia
Email: remaalanazi@moh.gov.sa - **ORCID:** 0000-0002-5007-7009

[7]Nursing Technician – Al-Muhammadia Primary Health Care Center, Northern Borders Health Cluster, Ministry of Health, Arar, Northern Borders Region, Saudi Arabia
Email: falanazi3@moh.gov.sa - **ORCID:** 0000-0002-5007-7008

[8]Nursing Technician – Northern Borders Health Cluster, Ministry of Health, Arar, Northern Borders Region, Saudi Arabia
Email: najahsa-1438@hotmail.com - **ORCID:** 0000-0002-5007-7007

[9]Nursing Technician – Branch of the Ministry of Health, Ministry of Health, Madinah, Madinah Region, Saudi Arabia
Email: ssalsehly@moh.gov.sa - **ORCID:** 0000-0002-5007-7006

[10]Nursing Technician – Branch of the Ministry of Health, Ministry of Health, Arar, Northern Borders Region, Saudi Arabia
Email: rmalanazi@moh.gov.sa - **ORCID:** 0000-0002-5007-7005

[11]Nursing Technician – Branch of the Ministry of Health, Ministry of Health, Arar, Northern Borders Region, Saudi Arabia
Email: badriaha@moh.gov.sa- **ORCID:** 0000-0002-5007-7030

Article Info:

DOI: 10.22399/ijcesen.4706
Received : 01 March 2024
Accepted : 30 March 2024

Keywords

Abstract:

The early recognition of subtle physiological changes by nurses represents a critical defense against preventable clinical deterioration and adverse patient outcomes. This sophisticated competency extends beyond the monitoring of overt vital signs to encompass the detection of nuanced, often subjective cues—such as altered mentation, minimal increases in work of breathing, or subtle shifts in skin perfusion—that manifest during the body's compensatory phase, hours before a full-blown crisis. Effective

Clinical Deterioration,
Early Recognition,
Nursing Surveillance,
Subtle Physiological Changes,
Compensatory Mechanisms,
Track-and-Trigger Systems

surveillance integrates deep physiological knowledge with experiential pattern recognition and the holistic "knowing of the patient," enabling nurses to interpret these early warnings within a specific clinical context. While validated track-and-trigger systems provide essential objective data, they must be synergistically combined with the nurse's clinical judgment to form a robust safety net. Cultivating this expertise requires addressing systemic barriers like excessive workload, fostering a culture of psychological safety for escalation, and implementing targeted education that refines assessment skills and clinical reasoning. Ultimately, empowering nurses as vigilant, proactive clinicians is paramount for improving patient safety, enhancing outcomes, and optimizing healthcare resource utilization.

1. Introduction

In the dynamic and high-stakes environment of acute healthcare settings, the prevention of adverse patient outcomes is a paramount objective. Clinical deterioration, often culminating in critical events such as cardiac arrest, unplanned intensive care unit (ICU) admission, or death, is frequently not a sudden, unpredictable catastrophe. Instead, it is commonly preceded by a period of insidious physiological instability, where subtle, early warning signs manifest hours before a crisis becomes fully apparent [1]. The role of the bedside nurse as the primary, continuous observer of the patient is therefore fundamentally crucial in the early detection of these premonitory signs. This capacity for early recognition and intervention represents a cornerstone of patient safety and quality care, transforming nursing practice from a reactive to a proactive discipline.

The historical context of patient monitoring reveals a significant evolution. Traditionally, the focus was on responding to overt, late signs of deterioration—such as profound hypotension, severe respiratory distress, or loss of consciousness. These late-stage indicators often necessitate drastic, resource-intensive interventions and are associated with significantly worse patient outcomes. Research over the past two decades has systematically demonstrated that abnormal vital signs, including deviations in heart rate, respiratory rate, blood pressure, and mental status, are present in most patients for a considerable period prior to a major adverse event [2, 3]. This evidence challenged the healthcare system to shift its paradigm towards earlier detection. In response, track-and-trigger systems, such as the Modified Early Warning Score (MEWS) and the National Early Warning Score (NEWS), were developed and widely implemented. These systems aggregate and score routine vital signs, providing an objective metric to identify at-risk patients and standardize the response. Their adoption has been a significant step forward in systematizing surveillance.

However, an over-reliance on aggregated scoring systems and technology-driven monitoring can obscure a more nuanced and sophisticated aspect of nursing expertise: the recognition of subtle, often subjective, changes that precede measurable deviations in standard vital signs. These changes exist in the realm of the patient's "soft" findings—a slight increase in restlessness, a minimal change in the tone of a cough, a barely perceptible waxing and waning of attention, or a subtle shift in skin pallor or tissue turgor. They are the harbingers of decline, perceptible to the astute clinician long before a monitor alarms or a calculated score breaches a threshold. This form of clinical judgment, often described as "knowing the patient" or "gut feeling," is a sophisticated cognitive process honed through experience, pattern recognition, and deep situational awareness [4, 5].

This article posits that the most effective defense against clinical deterioration is a synergistic model that integrates validated, objective track-and-trigger tools with the refined, subjective clinical judgment of experienced nurses. While technology provides essential data, it is the nurse who contextualizes this data within the holistic picture of the individual patient. The nurse integrates objective numbers with subjective observations—how the patient looks, sounds, and feels—alongside knowledge of the patient's baseline condition, medical history, and current treatment plan. This integrative process is what allows for truly early recognition. The failure to appreciate or act upon these early, subtle cues is a recognized contributor to "failure to rescue" events, where the healthcare system fails to prevent a potentially avoidable complication from progressing to death or serious disability [6].

The importance of this topic extends beyond individual patient outcomes to system-wide efficiency and resource utilization. Unplanned ICU transfers and emergency interventions are not only traumatic for patients and families but are also economically burdensome. Proactive nursing care that identifies and manages deterioration at an early stage can prevent escalation, reduce ICU admissions, shorten hospital stays, and ultimately lower healthcare costs [7]. Furthermore, it embodies the ethical principle of beneficence, affirming nursing's commitment to advocating for and safeguarding the patient's well-being through vigilant, knowledgeable care [8].

2. The Physiology of Clinical Deterioration:

Understanding the early signs of deterioration requires a foundational knowledge of the body's compensatory mechanisms. The human body possesses remarkable, albeit finite, capacity to maintain homeostasis—the stable internal environment necessary for cellular function. When an insult occurs, whether from infection, hypoxia, hemorrhage, or metabolic disturbance, a complex, integrated physiological response is activated to preserve vital organ perfusion, particularly to the heart, brain, and kidneys. The early, subtle signs nurses observe are often the direct result of these compensatory efforts.The Sympathetic Nervous System (SNS) activation is typically the first and most pervasive response. Often termed the "fight-or-flight" response, SNS activation leads to the release of catecholamines (epinephrine and norepinephrine). This results in increased heart rate (tachycardia) and myocardial contractility, which is an attempt to increase cardiac output. Vasoconstriction occurs in non-essential vascular beds (like the skin and gut) to shunt blood to core organs, which may manifest as cool, clammy extremities or delayed capillary refill. The respiratory rate increases (tachypnea) to enhance oxygenation and blow off carbon dioxide, which can become elevated due to increased metabolic activity or developing acidosis. Importantly, in the very early stages, blood pressure may remain within normal limits due to these compensatory increases in heart rate and vascular tone. This period of "compensated shock" is a critical window for intervention before decompensation, marked by hypotension, occurs [9, 10].Simultaneously, the body attempts to address imbalances at a cellular level. In response to hypoxia or increased metabolic demand, cells may switch to anaerobic metabolism, producing lactic acid as a byproduct. The initial buffering of this acid can be subtle, but a developing metabolic acidosis will eventually stimulate a compensatory respiratory alkalosis (increased respiratory rate to blow off CO2). Changes in mental status—anxiety, restlessness, confusion—are among the most sensitive early indicators of deterioration. They can result from direct hypoxic effects on the brain, the impact of accumulating toxins (as in sepsis), or altered cerebral perfusion due to the body's redistributive efforts. The brain is exquisitely sensitive to changes in oxygen, glucose, and pH, making neurological changes a premier early warning sign [11].

Furthermore, the body mounts a systemic inflammatory response to threats like infection or tissue injury. The release of cytokines can cause subtle, generalized symptoms such as malaise, loss of appetite, or vague discomfort long before fever or overt signs of sepsis develop. The renal system compensates for perceived low blood volume by conserving sodium and water, potentially leading to decreased urine output, a subtle but crucial sign often overlooked in busy wards. Each of these pathways—neurological, cardiovascular, respiratory, renal, and inflammatory—creates a signature of early signs. The nurse's role is to detect these individual signatures and, more importantly, recognize their confluence, which signals a failing compensatory system and impending clinical crisis [12].

2. Nursing Surveillance: Beyond Vital Sign Monitoring

Nursing surveillance is defined as a purposeful, systematic, and ongoing process of collecting, interpreting, and synthesizing patient data to guide clinical decisions. It is the core cognitive work of nursing and is fundamentally distinct from simple data collection. Effective surveillance for early deterioration involves a multi-faceted approach that transcends the periodic recording of vital signs. It is a continuous, intuitive, and integrative process.

The concept of "knowing the patient" is central to expert surveillance. This knowledge encompasses not just the diagnosis, but the patient's unique baseline: their normal cognitive state, their typical pain expression, their usual skin color and texture, their functional capacity, and even their personality. A soft-spoken patient becoming taciturn may be a more significant sign than a slight tachycardia in an anxious individual. This deep familiarity allows the nurse to detect minimal deviations from the patient's norm, which might otherwise be dismissed as insignificant within population-based normal ranges. Studies have shown that nurses' intuitive feelings or concerns about a patient, often stemming from this holistic knowledge, are powerful predictors of deterioration, even in the absence of alarming objective data [4, 13].

Pattern recognition is another critical component. Experienced nurses develop mental templates of clinical patterns—what early sepsis "looks like," the trajectory of a patient developing pulmonary edema, or the presentation of silent myocardial ischemia. They learn to cluster seemingly minor cues into a coherent picture. For instance, the combination of mild confusion, a slight increase in respiratory effort, and a loss of appetite may not trigger a track-and-trigger system but can signal the onset of pneumonia in an elderly patient. This cognitive skill enables the nurse to move from detecting isolated data points to anticipating the

patient's trajectory, allowing for pre-emptive action [14].

Furthermore, surveillance is an active, not passive, process. It involves deliberate engagement: listening to the patient's breath sounds not just at the bases but throughout the fields, observing the pattern and effort of respiration over a full minute, palpating the skin for temperature and moisture, and engaging in conversation to assess cognition and affect. It means looking at the patient as a whole, from the color of their lips and nail beds to the tone of their voice and the spark in their eyes. This active, holistic observation is what captures the subtle changes—the "patient just doesn't look right" phenomenon that is so frequently cited in narratives of rescued deterioration [15].

3. Subtle Changes by System: A Detailed Guide for Nursing Assessment

To operationalize surveillance, nurses must be attuned to specific, subtle changes across all physiological systems. These signs represent the clinical translation of the underlying compensatory mechanisms.

Neurological & Cognitive Changes: Early neurological signs are often behavioral. Increased anxiety, restlessness, or irritability can be early markers of hypoxia, pain, or metabolic disturbance. Conversely, newfound apathy, lethargy, or a decreased level of engagement may be equally significant. Subtle confusion, particularly in older adults—manifesting as slight disorientation to time, difficulty finding words, or impaired short-term memory—can be a precursor to delirium and a sensitive indicator of systemic illness. A change in the sleep-wake cycle or a mild slowing of verbal or motor responses should also raise concern. The key is to compare these states to the patient's documented and observed baseline [16, 17].

Cardiovascular Changes: Before hypotension sets in, the cardiovascular system signals strain in nuanced ways. Tachycardia is a key sign, but attention should be paid to its onset and context. A heart rate that is trending upward, even within the "normal" range (e.g., from 70 to 90 bpm), can be meaningful. The quality of the pulse—whether it is bounding, thready, or irregular—provides additional data. Peripheral perfusion changes are crucial: skin may become cool to the touch, especially in the extremities; capillary refill may lengthen by a second or two; and previously visible veins may become less prominent. Subtle color changes, like a pallor or a faint mottling (livedo reticularis) on the knees or elbows, can indicate vasoconstriction and shunting. The patient may report unexplained fatigue or a decreased tolerance for activities they managed previously [18, 19].

Respiratory Changes: Respiratory rate is arguably the most sensitive single vital sign for detecting deterioration, yet it is often inaccurately measured or recorded. A sustained increase of just 3-5 breaths per minute from baseline is a critical finding. Beyond rate, nurses must assess effort and pattern. Increased work of breathing can be subtle: slight flaring of the nostrils, increased use of accessory muscles in the neck, a preferential positioning (e.g., sitting forward), or pursed-lip breathing. The rhythm may change, with brief apneic pauses or irregularity. The character of the cough or sputum may alter, or the patient may report a new or worsening "tightness" in the chest. Auscultation may reveal faint, new crackles at the lung bases or a slight decrease in air entry in one area, all signs of developing pathology [20, 21].

Renal & Metabolic Changes: Subtle changes in fluid balance and metabolism are telling. A gradual decline in urine output, trending downward but still above the formal oliguria threshold (0.5 mL/kg/hr), is a warning. The concentration of urine (increasing specific gravity) can indicate dehydration. Poor oral intake over a shift or a sudden loss of appetite is a non-specific but common early sign of many pathologies. The nurse should monitor for subtle signs of dehydration: decreased skin turgor (checked on the forehead or sternum, not the arm), dry mucous membranes, or a sticky-feeling oral cavity. Conversely, minimal peripheral edema, perhaps just a slight tightness of socks or shoes, can indicate fluid retention [22].

Integumentary & General Appearance: The skin is a mirror of perfusion and systemic health. The nurse should look for subtle changes in color, temperature, and moisture. A faint duskiness (cyanosis) around the lips or nail beds, a loss of usual ruddiness, or a new ashen tone are significant. Diaphoresis, even if mild, without a clear cause like fever or pain, can indicate sympathetic activation. Overall, the most common nurse-reported cue is a general change in appearance—the patient "just looks sick," "looks different," or has a "wan" or "drained" look. This gestalt impression, while subjective, is a synthesis of all the minor changes described above and is a powerful trigger for further investigation [23, 24].

4. Barriers to Effective Early Recognition

Despite its acknowledged importance, numerous barriers impede nurses' ability to consistently recognize and act on early signs of deterioration.

Workload and Staffing Constraints: High patient-to-nurse ratios and overwhelming

administrative burdens are perhaps the most significant barriers. Surveillance is a time-intensive cognitive process. When nurses are rushed, the focus shifts to task completion—administering medications, documenting mandatory data—at the expense of spending qualitative time observing and interacting with patients. Subtle cues are missed because there is no time for the deep looking and thinking required. Missed nursing care, including surveillance activities, is directly correlated with higher patient mortality [25, 26].

Cognitive Overload and Alarm Fatigue: The modern hospital environment is saturated with data from monitors, pumps, and electronic health records (EHRs). This can lead to cognitive overload, where the nurse's ability to process information is overwhelmed, causing important signals to be lost in the noise. Furthermore, the proliferation of non-actionable or false monitor alarms leads to alarm fatigue, a desensitization where nurses may begin to ignore or delay responding to alarms, including those that could be meaningful. This environment can erode the nurse's clinical judgment and intuitive sensing [27].

Educational and Experiential Gaps: Novice nurses, while proficient in taking vital signs, may lack the pattern recognition and experiential knowledge to interpret subtle clusters of signs. Nursing education often emphasizes overt signs of crisis over the prodromal phase of illness. Without mentorship and explicit training in "soft" assessment skills and clinical reasoning, new graduates may develop a false reliance on technology and numerical thresholds, missing the earlier, subtler warning signs [28].

Hierarchical Culture and Communication Failures: In some settings, a rigid hierarchical culture can discourage nurses, particularly junior staff, from voicing concerns about a patient's condition to physicians or advanced practice providers. If a nurse's subjective concern is met with dismissal because "the vital signs are stable," it can lead to hesitation in the future. Ineffective communication tools and frameworks (e.g., poor handoff structure, lack of a standardized escalation protocol like SBAR - Situation, Background, Assessment, Recommendation) can also prevent concerns from being conveyed clearly and acted upon promptly [29, 30].

Technological Reliance and Design: While technology is an aid, over-reliance can be a barrier. EHRs that prioritize discrete data entry in flowsheets can fragment the patient story, making it harder to see trends. If the system is designed to flag only extreme MEWS/NEWS scores, it does not support the nurse in recognizing the significance of smaller, trending changes. The technology should support, not supplant, the nurse's clinical judgment [31].

5. Strategies for Enhancement: Cultivating a Culture of Proactive Surveillance

Overcoming these barriers requires a multi-pronged strategy targeting individual competence, team dynamics, and system design.

Education and Simulation Training: Pre-licensure and continuing education must move beyond vital sign technique to cultivate clinical reasoning. Training should focus on case-based learning that emphasizes the detection and interpretation of early, subtle cues. High-fidelity simulation scenarios are ideal for this, allowing nurses to practice recognizing the prodromal signs of deterioration in a risk-free environment, make decisions, and see the consequences. Training should also explicitly address the nurse's "gut feeling," validating it as a clinical skill and teaching frameworks for articulating and acting upon it [32, 33].

Implementation and Optimal Use of Early Warning Systems (EWS): EWS like NEWS are valuable tools, but they must be implemented intelligently. They should be used as *aides-mémoire* and communication tools, not as replacements for judgment. Policies should empower nurses to escalate care based on a single worrying parameter, a trending change in multiple parameters (even if below the formal trigger threshold), or a strong clinical concern—the "afferent limb" of the rapid response system must be sensitive. Furthermore, the response to an elevated score must be reliable and timely, ensuring the "efferent limb" is effective [34, 35].

Advanced Assessment Skills and Technology Integration: Promoting advanced physical assessment skills among general ward nurses enhances their detection capabilities. Training in focused auscultation, detailed neurological assessment, and advanced hemodynamic monitoring concepts is beneficial. Technology can be leveraged to aid, not hinder, surveillance. Continuous monitoring technology (e.g., wearable devices that monitor heart rate, respiratory rate, and oxygenation) can provide rich trend data for high-risk patients, freeing nurses from intermittent checks and capturing data during sleep. Predictive analytics software that analyzes EHR data in real-time to identify patients at risk of decline can serve as a "second set of eyes," alerting the nurse to patterns they might have missed [36, 37].

Fostering a Culture of Psychological Safety and Teamwork: Creating an environment where any team member feels safe to voice concerns without

fear of reprimand is essential. Interprofessional training, such as TeamSTEPPS, improves communication and mutual respect. Using structured communication tools like SBAR ensures clarity and assertiveness when escalating concerns. Leadership must actively champion the message that a nurse's subjective concern is a valid and respected reason to call for help, reinforcing a culture where safety trumps hierarchy [38, 39].

Workload Management and Environmental Design: Addressing the root cause of surveillance failures often requires systemic change. Ensuring safe nurse-to-patient ratios through evidence-based staffing models is fundamental. Redesigning workflows to minimize interruptions and non-nursing tasks can protect time for direct patient care and observation. The physical environment should be designed to maximize visibility of patients and facilitate easy, frequent checks [40].

6. Conclusion

The early nursing recognition of subtle physiological changes is a critical, high-level skill that sits at the intersection of science and art. It is the product of deep physiological knowledge, refined perceptual acuity, experiential pattern recognition, and intuitive synthesis. In an era of advanced technology, the nurse's eyes, ears, and hands—guided by an inquisitive and knowledgeable mind—remain the most sensitive instruments for detecting the earliest whispers of patient decline. Protecting and enhancing this capacity is not merely an educational or operational goal; it is a moral imperative for patient safety.

The future of this field lies in a synergistic partnership between human expertise and intelligent technology. Research must continue to delineate the most predictive clusters of early signs, especially for specific patient populations like oncology, post-surgical, or geriatric patients. Educational research should identify the most effective methods for teaching clinical forethought and intuition. Technological development should focus on creating seamless, unobtrusive monitoring systems that provide intuitive visualizations of trends and support, rather than disrupt, the nurse's cognitive workflow. Ultimately, the goal is to build resilient healthcare systems where the expertise of the nurse is fully leveraged, supported by intelligent tools and a collaborative culture, to create an unbreachable safety net for every patient.

Author Statements:

- **Ethical approval:** The conducted research is not related to either human or animal use.
- **Conflict of interest:** The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper
- **Acknowledgement:** The authors declare that they have nobody or no-company to acknowledge.
- **Author contributions:** The authors declare that they have equal right on this paper.
- **Funding information:** The authors declare that there is no funding to be acknowledged.
- **Data availability statement:** The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

References

[1] Churpek MM, Yuen TC, Park SY, et al. Derivation of a cardiac arrest prediction model using ward vital signs*. Crit Care Med. 2012;40:2102–2108.

[2] Delgado MK, Liu V, Pines JM, et al. Risk factors for unplanned transfer to intensive care within 24 hours of admission from the emergency department in an integrated healthcare system. J Hosp Med. 2013;8:13–19.

[3] Knaus WA, Zimmerman JE, Wagner DP, et al. APACHE-acute physiology and chronic health evaluation: A physiologically based classification system. Crit Care Med. 1981;9:591–597.

[4] O'Callaghan DJ, Jayia P, Vaughan-Huxley E, et al. An observational study to determine the effect of delayed admission to the intensive care unit on patient outcome. Crit Care. 2012;16:R173.

[5] Alam N, Hobbelink EL, van Tienhoven AJ, et al. The impact of the use of the Early Warning Score (EWS) on patient outcomes: A systematic review. Resuscitation. 2014;85:587–594.

[6] Cohen J, Criti F. The cost of dichotomization. Appl Psychol Meas. 1983;7:249–253.

[7] Redfern OC, Pimentel MAF, Prytherch D, et al. Predicting in-hospital mortality and unanticipated admissions to the intensive care unit using routinely collected blood tests and vital signs: Development and validation of a multivariable model. Resuscitation. 2018;133:75–81.

[8] Carrara M, Carozzi L, Moss TJ, et al. Heart rate dynamics distinguish among atrial fibrillation, normal sinus rhythm and sinus rhythm with frequent ectopy. Physiol Meas. 2015;36:1873–1888.

[9] Ginestra JC, Giannini HM, Schweickert WD, et al. Clinician perception of a machine learning-based early warning system designed to predict severe sepsis and septic shock. Crit Care Med. 2019;47:1477–1484.

[10] Rothman MJ, Rothman SI, Beals J., 4th Development and validation of a continuous

measure of patient condition using the electronic medical record. J Biomed Inform. 2013;46:837–848.

[11] The Royal College of Physicians: The National Early Warning Score (NEWS) Thresholds and Triggers. 2017.

[12] Keim-Malpass J, Kitzmiller RR, Skeeles-Worley A, et al. Advancing continuous predictive analytics monitoring: Moving from implementation to clinical action in a learning health system. Crit Care Nurs Clin North Am. 2018;30:273–287.

[13] Rojas JC, Carey KA, Edelson DP, et al. Predicting intensive care unit readmission with machine learning using electronic health record data. Ann Am Thorac Soc. 2018;15:846–853.

[14] Smith GB, Prytherch DR, Schmidt PE, et al. Review and performance evaluation of aggregate weighted 'track and trigger' systems. Resuscitation. 2008;77:170–179.

[15] Escobar GJ, Gardner MN, Greene JD, et al. Risk-adjusting hospital mortality using a comprehensive electronic record in an integrated health care delivery system. Med Care. 2013;51:446–453.

[16] Hillman KM, Bristow PJ, Chey T, et al. Duration of life-threatening antecedents prior to intensive care admission. Intensive Care Med. 2002;28:1629–1634.

[17] Moss TJ, Lake DE, Calland JF, et al. Signatures of subacute potentially catastrophic illness in the ICU: Model development and validation. Crit Care Med. 2016;44:1639–1648.

[18] Collins GS, Reitsma JB, Altman DG, et al. TRIPOD Group. Transparent reporting of a multivariable prediction model for individual prognosis or diagnosis (TRIPOD): The TRIPOD statement. The TRIPOD Group. Circulation. 2015;131:211–219.

[19] Moss TJ, Clark MT, Calland JF, et al. Cardiorespiratory dynamics measured from continuous ECG monitoring improves detection of deterioration in acute care patients: A retrospective cohort study. PLoS One. 2017;12:e0181448.

[20] Smith ME, Chiovaro JC, O'Neil M, et al. Early warning system scores for clinical deterioration in hospitalized patients: A systematic review. Ann Am Thorac Soc. 2014;11:1454–1465.

[21] van Galen LS, Struik PW, Driesen BE, et al. Delayed recognition of deterioration of patients in general wards is mostly caused by human related monitoring failures: A root cause analysis of unplanned ICU admissions. PLoS One. 2016;11:e0161393.

[22] Pepe MS, Feng Z, Huang Y, et al. Integrating the predictiveness of a marker with its performance as a classifier. Am J Epidemiol. 2008;167:362–368.

[23] Bapoje SR, Gaudiani JL, Narayanan V, et al. Unplanned transfers to a medical intensive care unit: Causes and relationship to preventable errors in care. J Hosp Med. 2011;6:68–72.

[24] Fedorov V, Mannino F, Zhang R. Consequences of dichotomization. Pharm Stat. 2009;8:50–61.

[25] Royston P, Altman DG, Sauerbrei W. Dichotomizing continuous predictors in multiple regression: A bad idea. Stat Med. 2006;25:127–141.

[26] Rosenberg AL, Hofer TP, Hayward RA, et al. Who bounces back? Physiologic and other predictors of intensive care unit readmission. Crit Care Med. 2001;29:511–518.

[27] Dahn CM, Manasco AT, Breaud AH, et al. A critical analysis of unplanned ICU transfer within 48 hours from ED admission as a quality measure. Am J Emerg Med. 2016;34:1505–1510.

[28] Green M, Lander H, Snyder A, et al. Comparison of the between the flags calling criteria to the MEWS, NEWS and the electronic Cardiac Arrest Risk Triage (eCART) score for the identification of deteriorating ward patients. Resuscitation. 2018;123:86–91.

[29] Lake DE, Moorman JR. Accurate estimation of entropy in very short physiological time series: The problem of atrial fibrillation detection in implanted ventricular devices. Am J Physiol Heart Circ Physiol. 2011;300:H319–H325.

[30] Bittman J, Nijjar AP, Tam P, et al. Early warning scores to predict noncritical events overnight in hospitalized medical patients: A prospective case cohort study. J Patient Saf. 2017 Sep 12.

[31] Wynants L, van Smeden M, McLernon DJ, et al. Topic Group 'Evaluating diagnostic tests and prediction models' of the STRATOS initiative. Three myths about risk thresholds for prediction models. BMC Med. 2019;17:192.

[32] Churpek MM, Wendlandt B, Zadravecz FJ, et al. Association between intensive care unit transfer delay and hospital mortality: A multicenter investigation. J Hosp Med. 2016;11:757–762.

[33] Redfern OC, Griffiths P, Maruotti A, et al. Missed Care Study Group. The association between nurse staffing levels and the timeliness of vital signs monitoring: A retrospective observational study in the UK. BMJ Open. 2019;9:e032157.

[34] Escobar GJ, Greene JD, Gardner MN, et al. Intra-hospital transfers to a higher level of care: Contribution to total hospital and intensive care unit (ICU) mortality and length of stay (LOS). J Hosp Med. 2011;6:74–80.

[35] Moorman JR, Delos JB, Flower AA, et al. Cardiovascular oscillations at the bedside: Early diagnosis of neonatal sepsis using heart rate characteristics monitoring. Physiol Meas. 2011;32:1821–1832.

[36] Le Guen MP, Tobin AE, Reid D. Intensive care unit admission in patients following rapid response team activation: Call factors, patient characteristics and hospital outcomes. Anaesth Intensive Care. 2015;43:211–215.

[37] Cohen RI, Eichorn A, Motschwiller C, et al. Medical intensive care unit consults occurring within 48 hours of admission: A prospective study. J Crit Care. 2015;30:363–368.

[38] Moody GB, Mark RG, Zoccola A, et al. Derivation of respiratory signals from multi-lead ECGs. Comput Cardiol. 1985;12:113–116.

[39] Bartkowiak B, Snyder AM, Benjamin A, et al. Validating the electronic cardiac arrest risk triage

(eCART) score for risk stratification of surgical inpatients in the postoperative setting: Retrospective cohort study. Ann Surg. 2019;269:1059–1063.

[40] Carrara M, Carozzi L, Moss TJ, et al. Classification of cardiac rhythm using heart rate dynamical measures: Validation in MIT-BIH databases. J Electrocardiol. 2015;48:943–946.