Improving detection of patient deterioration in the general hospital ward environment

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Patient monitoring on low acuity general hospital wards is currently based largely on intermittent observations and measurements of simple variables, such as blood pressure and temperature, by nursing staff. Often several hours can pass between such measurements and patient deterioration can go unnoticed. Moreover, the integration and interpretation of the information gleaned through these measurements remains highly dependent on clinical judgement. More intensive monitoring, which is commonly used in peri-operative and intensive care settings, is more likely to lead to the early identification of patients who are developing complications than is intermittent monitoring. Early identification can trigger appropriate management, thereby reducing the need for higher acuity care, reducing hospital lengths of stay and admission costs and even, at times, improving survival. However, this degree of monitoring has thus far been considered largely inappropriate for general hospital ward settings due to device costs and the need for staff expertise in data interpretation. In this review, we discuss some developing options to improve patient monitoring and thus detection of deterioration in low acuity general hospital wards.

Introduction

Patients admitted to ICUs, intermediate or high dependency units are usually connected to systems that provide almost continuous monitoring of multiple variables. By contrast, in patients admitted to the general hospital ward (i.e. low acuity settings, such as those defined in the United Kingdom as 'level 0 or 1 care' or in the United States as 'floors'), monitoring is generally limited to intermittent observations and measurements of simple physiological parameters, for example heart rate (HR), respiratory rate and temperature. Yet such patients can be at risk of sudden, unexpected deterioration.

The chain of prevention concept[1] has been used to describe the steps required to decrease the likelihood of patient deterioration. The classic model includes staff education, monitoring, recognition of deterioration, how to 'call for help' and an effective response. Importantly, each of these components is intimately linked with the others and none on their own will be effective. In this expert opinion review, derived by repeated textual revision among co-authors until consensus was achieved, we will concentrate on how improved monitoring, particularly of respiratory parameters, can help in the recognition of deterioration and why this is important in general ward patients. Aspects of staff education will not be discussed.

Identification of deterioration should be improved

Failure-to-rescue, defined as death of a patient following a complication, is a metric that has been widely used to identify differences in the quality of care between hospitals within healthcare systems.[2–4] In a recent prospective international 7-day cohort study of outcomes following elective adult in-patient surgery [International Surgical Outcomes Study (ISOS)],[5] 44 814 patients were

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enrolled in 474 hospitals in 19 high, seven middle and one low-income countries; 5270 patients admitted to the hospital ward after surgery (13.2%) developed at least one postoperative complication; 99 of these patients died (1.9%). The ISOS project highlighted not only the impact of patient complications on mortality outcomes but also marked variations among hospitals in failure-to-rescue rates. Importantly, hospitals with the highest complication rates did not have the highest failure-to-rescue rates, suggesting differences in the capability of individual hospitals to identify and escalate the care of patients who develop complications after surgery.[6] Variations in failure-to-rescue rates may be related to multiple factors, including patient casemix (differences in demographics, comorbidities, severity of acute illness) but also hospital activity volume, nurse : patient ratios, training of nursing and medical staff, and ability to identify and respond early to patient deterioration.[4,7–9]

Early identification of deterioration on general hospital wards, enabling rapid targeted management, can help reduce need for transfer to higher acuity units, reduce hospital lengths of stay and costs, and improve survival rates.[10,11] Cardoso *et al.*[12] reported that each hour of delay in admission of a patient to the ICU was associated with a 1.5% increase in the risk of death in the ICU and a 1% increase in hospital mortality. Likewise, Sakr *et al.*[13] reported that mortality among critically ill patients was clearly related to the initial evolution of organ failure and the sequential organ failure (SOFA) score at the time of ICU admission. Indeed, more than 50% of all hospitalised patients in that study did not receive optimal treatment before admission to the ICU, and many admissions could have been avoided.[14]

To detect deterioration sooner, patient monitoring needs to be improved. Indeed, almost 10 years ago, participants at a consensus conference on patient monitoring noted that 'if practical and affordable, all patents should be monitored continuously' and identified, in particular, the need to monitor HR, respiratory rate, temperature, pulse oximetry and level of consciousness.[15]

Improving identification of respiratory deterioration

Respiratory compromise is one of the most common reasons for ICU admission from general hospital wards. Identifying deteriorating respiratory function early could reduce ICU admissions, the need for mechanical ventilation and its associated complications. Several specific groups of patients are at greater risk of respiratory compromise than others. Most obvious are those with chronic respiratory disease. Then there are patients who receive sedation outside the operating room for relatively minor diagnostic or surgical procedures (e.g. dental treatment or endoscopy). Sedation may be accompanied by respiratory depression even some time after the procedure has taken place. In addition, there are patients who receive opioid analgesia, which can be associated with respiratory depression. Lee *et al.* identified 92 claims for postoperative opioid-induced respiratory depression: 77% of the patients involved had severe brain damage or died. The vast majority of these injuries occurred within 24 h of surgery and 97% were judged to have been preventable with better monitoring and response.[16] Clinically significant drug-induced respiratory depression has also been reported with patient-controlled analgesia (PCA).[17,18] The Emergency Care Research Institute has recently declared that inadequate monitoring for respiratory depression in patients receiving opioids is one of the top 10 patient safety concerns for healthcare organisations.[19]

Pulse oximetry

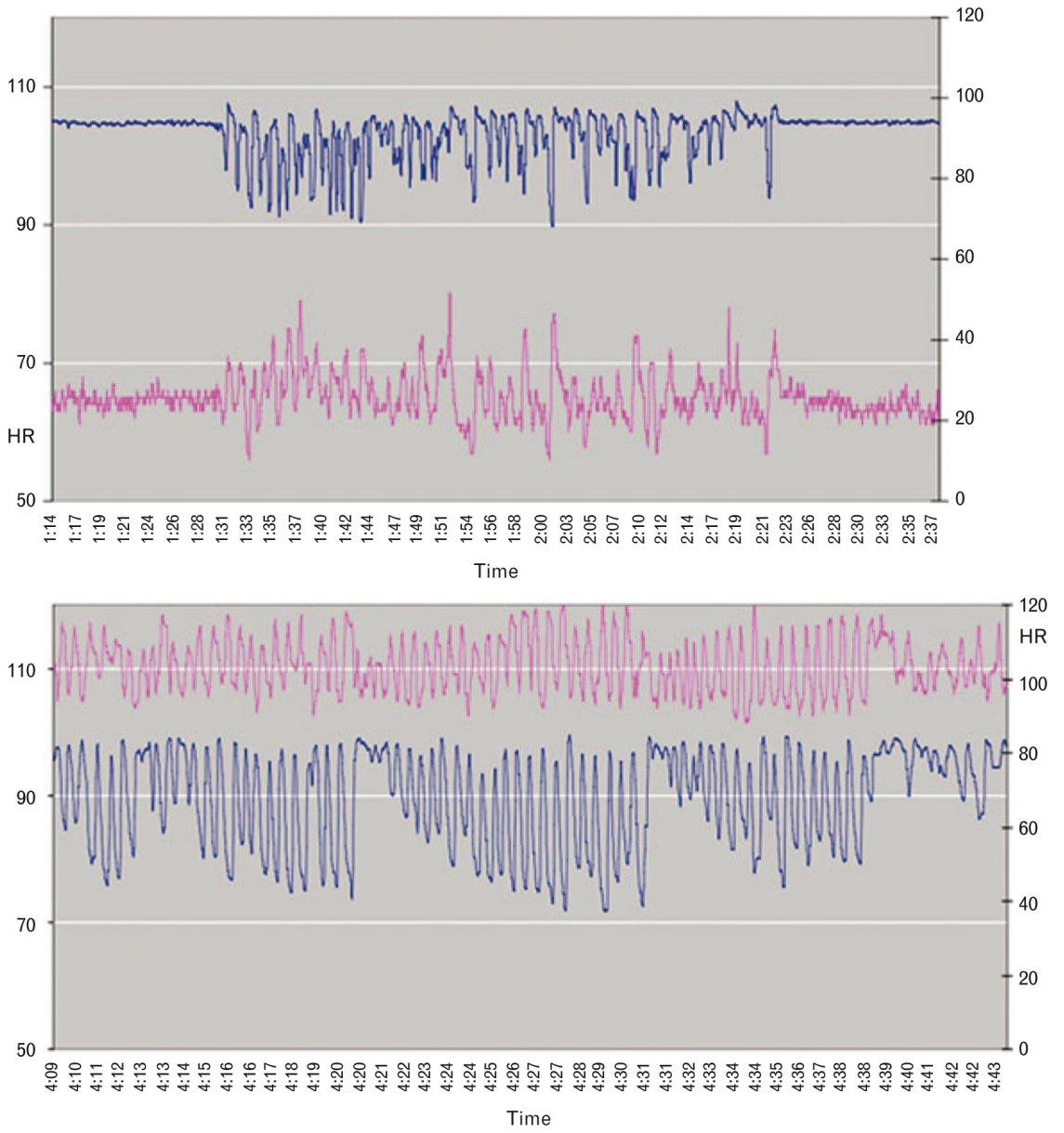
Pulse oximetry is often used to monitor patients in the general hospital ward, because it is noninvasive and provides a rapid indication of oxygenation levels. In a recent study using continuous pulse oximetry in postoperative patients,[20] 21% of patients were hypoxaemic ($SpO_2 < 90\%$) for more than 10 min h^{-1}, 8% averaged more than 20 min hypoxaemia h^{-1}, 37% were hypoxaemic for more than 1 h, 11% for more than 6 h and 3% desaturated below 80% for more than 30 min. Of note, these findings were not captured by nursing staff, whose observations recorded hypoxaemia in only 5% of patients and missed 90% of hypoxaemic events that lasted more than 1 h. The study has limitations as monitoring equipment tended only to be tolerated by those patients who were unable to mobilise (leading to attrition bias), and the generalisability of the findings may be questioned as the average BMI of patients was close to 30 kg m^{-2} and 16% had obstructive sleep apnoea. In the context of anaesthesia and critical care, it has been acknowledged that pulse oximetry may be misleading or even detrimental as a means of monitoring respiration.[21]

Unlike the traditional single-alarm threshold value for the SpO_2, which is typically chosen arbitrarily and has not been shown to correlate with outcomes, patterns of oxygen saturation can give important clues to a patient's ventilation status. Rapid desaturation and resaturation with corresponding spikes in HR are typical in patients with obstructive sleep apnoea (Fig. 1a). When treated with opioids and sedatives, these patients are at risk of respiratory failure (Fig. 1b). However, supplemental oxygen given routinely and without indication not only hinders the ability of pulse oximetry to detect hypoventilation in a timely manner but may also 'wash out' these patterns, so that they are no longer apparent.

Capnography

An abnormal respiratory rate can be an important indicator of impending complications or deterioration,[22,23] but

Fig. 1



Oxygen saturation (blue) and heart rate (pink) traces in a patient with obstructive sleep apnoea. (a) Preoperatively. (b) Postoperatively during patient-controlled morphine analgesia.

is often not monitored on the general hospital ward, even in patients with known respiratory disease and, when monitored, the methods used are often unreliable. Moreover, it is normally recommended that respiratory rate be counted over a whole minute or two 30-s intervals, and this procedure can represent a significant investment in nursing time in the ward setting, such that accurate rates may only be recorded as little as 37% of the time.[24]

Capnography, the measurement of CO_2 concentrations in respiratory gases, can be performed noninvasively through nasal prongs and offers an accurate and reliable means of measuring respiratory rate, with the availability of instant readings and, when monitored continuously, trends. The respiratory rate is calculated from the frequency of the waveform and changes in the capnography waveform can help identify patient deterioration and the likely cause. For patients already being given additional oxygen, capnography monitoring does not constitute an additional monitoring burden.

There are now clear recommendations for use of continuous capnography in the ICU, cardiac resuscitation and surgical settings,[25,26] and studies have demonstrated its

Table 1 Benefits and disadvantages of waveform capnography

Benefits
Detects airflow; it is not a surrogate measure of air flow, such as impedance-based methods that may interpret obstructed chest excursion as 'breathing'
Can assess adequacy of ventilation
Ventilation status remains reliable in patients receiving supplemental oxygen, in whom pulse oximetry detects hypoventilation late
Early detection of abnormal respiratory rates or patterns, and of apnoea during acute cardiac or respiratory decompensation
Drawbacks
Patient compliance is moderate in low acuity settings in which patients are awake and mobile, and especially with 'scoop' cannulas, which are required when patients become mouth breathers at deeper levels of sedation
Interpretation of $ETCO_2$ waveform requires bedside provider training (although indexes combining parameters simplifies monitoring)
False positive low RR, apnoea, and low $ETCO_2$ alarms can be frequent when the cannula is malpositioned
Cost of disposables
Prone to false alarms for patients on CPAP or BiPAP

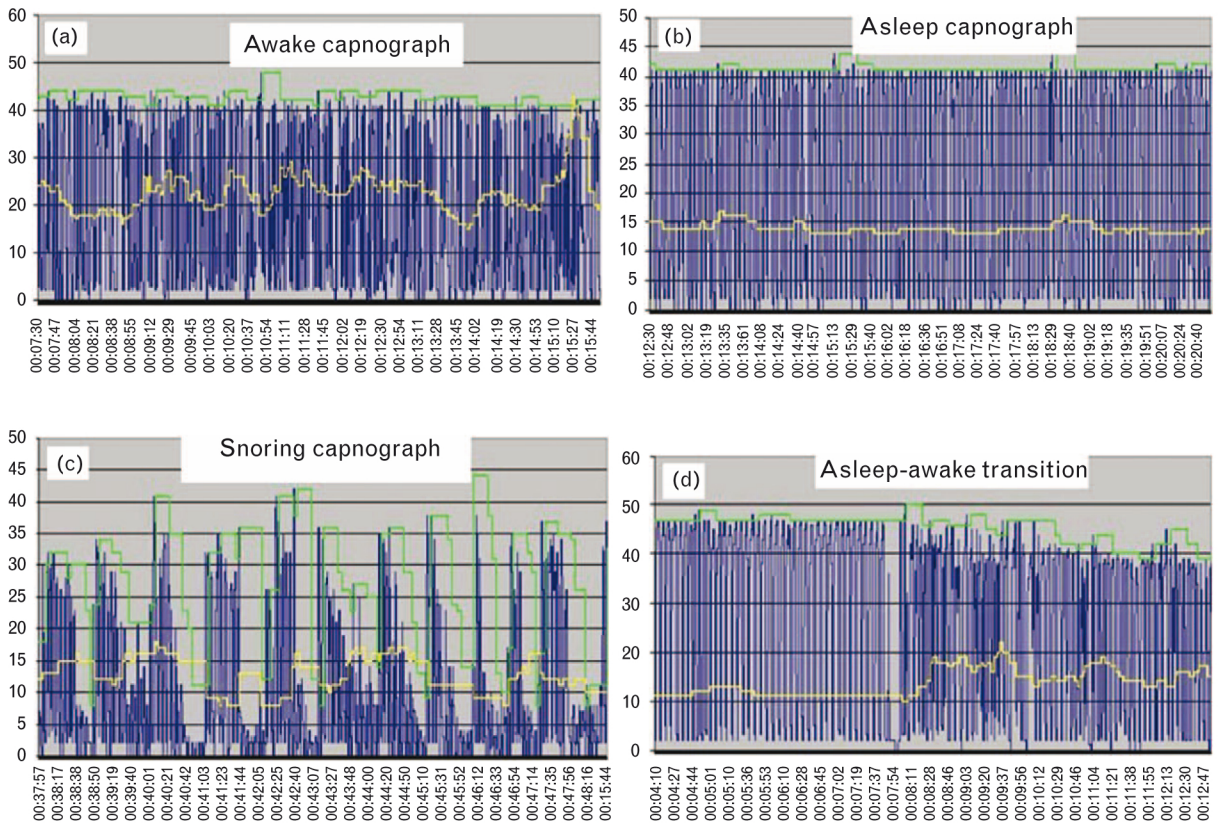
BiPAP, bilevel positive airway pressure; CPAP, continuous positive airway pressure; $ETCO_2$, end-tidal CO_2; RR, respiratory rate.

effectiveness at identifying respiratory deterioration in general ward patients.[27,28] Importantly, capnography provides monitoring of ventilation and, to a certain degree, of pulmonary perfusion and not just monitoring of oxygenation, which is the case with pulse oximetry. Indeed, pulse oximetry may only provide a late alert of respiratory deterioration, particularly if the alarm threshold is set to occur only with sustained desaturation.[29] Once oxygen saturation starts to decrease, it decreases quickly, especially in patients at high risk (elderly patients, obese patients, known obstructive sleep apnoea). In addition, patients receiving supplemental oxygen may develop respiratory depression with long periods of apnoea not detected by pulse oximetry.[30]

Capnography patterns are useful to detect respiratory compromise (Table 1). In Fig. 2, a compressed capnography pattern clearly demonstrates a patient who is experiencing recurrent obstruction of the airway and was observed to be snoring loudly. The pattern when the patient is sleeping soundly but without respiratory compromise is clearly different from that of the patient when they are awake.

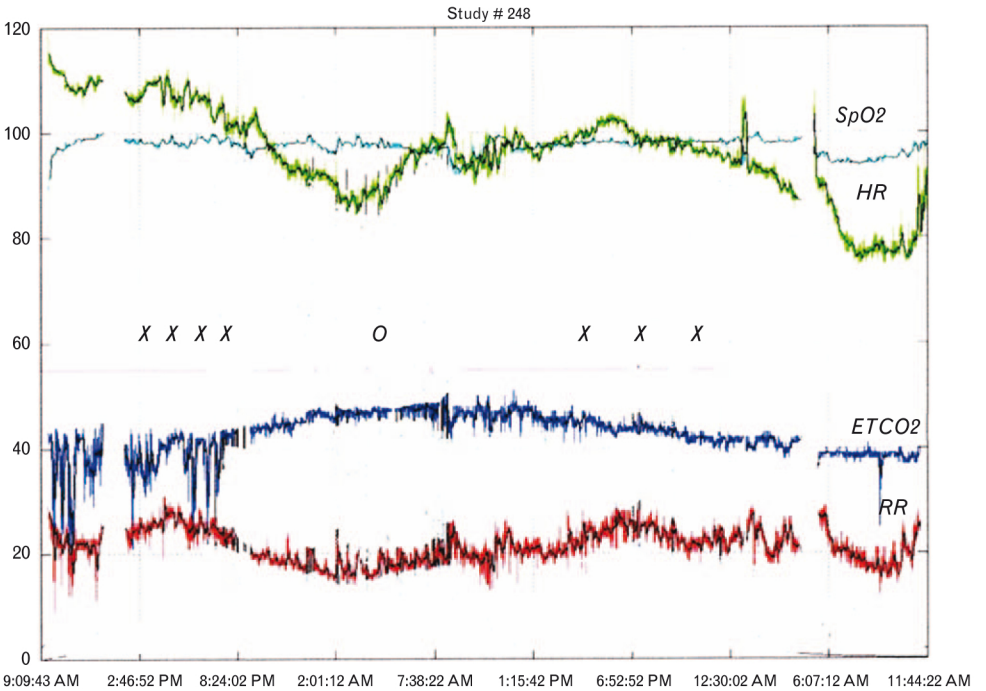
When integrating continuous capnography with oximetry, the expected physiological response to opioid therapy and its potential complications are readily apparent from the tracings. Figure 3 shows a capnography trace from a patient receiving hydromorphone PCA who becomes relatively hypercapnic and bradypnoeic in response to

Fig. 2



Compressed capnography patterns in a postoperative patient corresponding to different levels of consciousness (yellow line = respiratory rate). Panel (c) shows recurrent partial airway obstruction.

Fig. 3



Continuous pulse oximetry and capnography tracings from a postoperative patient receiving hydromorphone patient-controlled analgesia. *x* = patient-controlled analgesia dosing. *o* = patient-controlled analgesia halt enabled due to excessive sedation.

frequent dosing. When the patient is found to be poorly responsive and heavily sedated by the nurse, the pump 'halt' feature is enabled and the patient recovers to their baseline, at which time the lockout interval of the PCA pump is increased. Notable is the absence of desaturation on the oximetry trace in this patient due to the administration of supplemental oxygen, reinforcing the value of a monitor of ventilation and frequent level of consciousness assessments.

Calling for help and response systems

Monitoring systems *per se* cannot improve outcomes and integral to improved detection of deterioration are correct interpretation of monitored variables to know when to call for help and effective systems to respond to that call.

Early warning scores

Various methods have been developed to identify the patient at risk of deterioration on the general ward. Scoring systems allocate points based on the deviation of a physiological variable from 'normal', when measured manually. Some systems trigger a response when individual physiological variables reach a predefined abnormal value. Other more complicated systems allocate points based on the deviation of one or several physiological variables from 'normal', and the sum of these points gives a score. This score is then used to determine what response is needed (who to call for help, what to do in the interim until help arrives, what to prepare and when to reassess), often following a predefined hospital-specific or ward-specific escalation protocol. Such scores include the Modified Early Warning Score,[31] the National Early Warning Score[32] and, more recently, the quick SOFA in patients with suspected sepsis.[33]

Monitors that integrate several physiological parameters into a single variable indicating patient severity (i.e. automated early warning scores) can also be used rather than systems based on manual measurements. The level of response is then determined by the indicated severity. Such systems are increasingly being developed and tested in traditionally low-monitoring environments,[34–36] but further study is needed to assess whether they are associated with improved outcomes.

Early warning systems eliminate the need to rely entirely on the clinical judgement of the nurse for triggering the response and probably also decrease discussion surrounding nurse expectations versus physician response. However, they should not substitute for clinical judgement altogether, nor should they eliminate respect for 'nurse concern'. Nurses have more direct patient contact than do physicians and should be encouraged to use their intuition when concerned that a patient may be deteriorating. In a systematic review of studies reporting nurse concern, Douw *et al.*[37] noted 170 signs to identify causes of concern and grouped them into 10 categories: change in

respiration, change in circulation, rigors, change in mentation, agitation, pain, unexpected trajectory, patient indicating they are feeling unwell, subjective nurse observation and nurse convinced that something is wrong without a rationale. Early warning systems should always leave some option to trigger a response based on nurse concern alone.

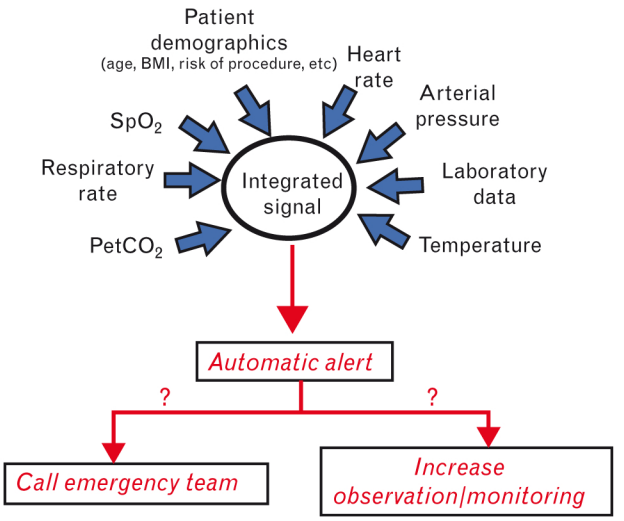
Although there does seem to be some evidence suggesting that early warning scores are good predictors of cardiac arrest and death,[38] they have not been shown to be associated with improved patient outcome.[39] This lack of supportive data is often attributed to the second part of the afferent arm, that is the response to the call for help.

Providing an effective response

An effective response to patient deterioration is best mounted by staff trained and experienced in dealing with acute, critical physiological abnormalities. 'Rapid Response Teams' (RRTs) are comprised of healthcare providers who can take intensive care equipment and expertise to patients on the general hospital ward who have early signs of deterioration to prevent further worsening of the condition. RRTs may also be called high acuity response teams or medical emergency teams (METs). The term MET traditionally refers to a specific RRT developed at the Liverpool Hospital in Sydney.

Hospitals began to recognise the potential for RRTs in the early 1990s[40] and the concept has expanded such that most hospitals now have some form of RRT in place, encouraged by leading national groups, such as the National Institute for Health and Care Excellence in the United Kingdom[41] and the Institute for Healthcare Improvement in the United States.[42] Several studies have demonstrated the effectiveness of such teams in reducing the incidence of cardiopulmonary arrests and ICU admissions, and improving patient outcomes.[43–47] However, research tying deployment of RRTs to patient outcomes has been hampered by difficulties in measuring processes and outcomes. Most available studies are either observational or have retrospective comparison cohorts, limiting the quality of the results provided. Important components of successful RRTs include accurate criteria for RRT activation, the availability of facilities for patient relocation to an environment with a higher level of monitoring if required, and an administrative and quality improvement component to train staff, collect and analyse event data, provide feed-back, co-ordinate resources and ensure improvement or maintenance over time.

Fig. 4



Integrated patient monitoring on the low acuity ward.

Multiparameter integration and intelligent monitors

Importantly, no single parameter will identify early deterioration in all patients, rather combinations of variables

Table 2 Technologies available for continuous monitoring on the general hospital ward

Device	Vital signs	Technology	Transducer	Sampling location	Connectivity	Ergonomics[a]
Pulse oximeter	SpO_2, HR, RR	Photoplethysmograpy	(1) Transmittance (2) Reflectance	(1) Digit, ear, nasal alae (2) Forehead, chest	(3) Not attached (4) Wireless (Bluetooth, WiFi)	(3) B (4) A–
Capnograph	$ETCO_2$, RR	IR spectography	Nasal cannula	Mouth/nose	Attached	C
Airflow detector	RR	Humidity detector, thermistor	Face mask, nasal transducer	Mouth/nose	Attached	C
Impedance plethysmography	RR, tidal volume	Transthoracic impedance	Electrodes, strain gauges	Chest wall	Attached	B
Bioacoustics	RR	Large airway audio (breath) detection	Microphone	Neck	Attached	B
Piezoelectric	HR, RR	Piezoelectrics	Piezoelectric element	Under mattress	Hardwired to mattress	A
cNIBP	SBP, DBP, MBP	Pulse transit time	Photoplethysmograph, electrodes	Wrist	Wireless	A–
Patch (Wearable)	ECG, RR, HR	Accelerometry, electrical impedance	Accelerometer, electrodes	Chest wall	Wireless (Bluetooth, WiFi)	A

cNIBP, continuous noninvasive blood pressure; $ETCO_2$, end-tidal CO_2; HR, heart rate; RR, respiratory rate. [a](A) High patient acceptance due to small transducer not attached to bedside device. (B) Larger transducer (± adhesive) attached to bedside device. (C) Facial transducer often encumbering for awake patients and attached to bedside device.

need to be monitored and the information integrated to gain a full picture of patient condition. Vigilance (i.e. the quality of staying alert to the possibility of danger) has been studied very little in medical settings. Signals are more likely to be missed when they occur infrequently.[48] More importantly, when the responder is subconsciously aware that they may respond poorly to an alarm or signal, this increases the likelihood that they will miss a rare event.[49] Finally, alarms are most likely to be missed when multiple noisy items are present.[50] The ideal monitoring system would have 100% sensitivity, that is it would always alarm for a clinically important event, and 100% specificity, that is it would never sound for nonimportant events. Current systems tend to focus on the sensitivity factor, but to achieve this lose specificity so that 'false' or 'nonactionable' alerts are frequent.[51] Many alarms do not need clinical intervention, for example those stemming from sensor malposition or incorrect setting of upper/lower alarm limits.[52] False alarms related to sensor displacement due to increased patient mobility are likely to occur more frequently on the general ward than on the much less mobile ICU population. As monitoring increases on the general hospital ward, care needs to be taken to limit the risk of alarm fatigue.[53] Physicians and nursing staff rapidly become desensitised to alarm noise and fail to react, adjust the settings to inappropriate values for that patient or simply turn off the alarm completely. It is widely recognised that alarm fatigue can compromise patient safety. Indeed, the 2017 Joint Commission Hospital National Patient Safety Goals include 'Making improvements to ensure that alarms on medical equipment are heard and responded to on time'.[54]

There are multiple potential solutions to the challenge of alarm noise, which are beyond the scope of this article. One solution, however, lies in 'intelligent monitors' that 'learn' to adjust alarms according to trends in the variable being monitored or by cross-checking with other monitored variables.[55] Indeed, a large variety of continuous monitoring systems that follow trends and integrate multiple variables to detect patterns pathognomonic of deterioration is now available (Table 2). Integrated monitors may also reduce the numbers of wires and probes needed for each patient and wearable systems that enable patients to be monitored whilst maintaining freedom of movement and mobility are being developed,[56,57] particularly important in the general ward patient. Combining monitored values with other patient hospital data (laboratory results, radiology reports, patient comorbid conditions, patient age, risk data) is the next step in developing intelligent monitoring systems; this integration could provide a truly personalised warning system with an alarm activated only when predefined limits enabling identification of deterioration for that specific patient are met (Fig. 4).[58–61]

Conclusion

Improved monitoring of low acuity ward patients is needed to help reduce failure-to-rescue rates. Contrary to previously accepted perceptions that more complex monitoring is not possible on general wards, there is an increasing body of experience demonstrating that the tools required for such monitoring are not only available but may also be easily used. Clearly the aim of improved monitoring in these areas is not to convert them into ICUs, but to enable early identification of patient deterioration such that an appropriate response can be mounted without increasing nurse workload. Increasingly, monitoring will be automated with devices combining variables to trigger a single alert when combined cut-offs are met. More data are needed to define what these cut-offs should be, which patients will benefit most from more intensive monitoring, and which variables should be monitored in which patients. Importantly, more monitoring, use of an early warning score or availability of an RRT cannot alone reduce failure-to-rescue rates and improve patient outcomes; combined, effective application of all three components is needed and must be adapted to local patient casemix, staff skills and training, and institutional capability.

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