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Identifying the patient-at-risk: Technology and ICU Outreach Services

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The provision of intensive care to critically-ill patients is a costly endeavour. Intensive care units (ICUs) account for approximately 10% of inpatient acute-care beds in the United States,[1,2] and this proportion is expected to increase as our population ages.[3] Intensive care medicine has traditionally been described as "advanced and highly specialized care provided to patients whose conditions are life-threatening" and that is administered within "specially equipped care units."[4] However, there has been a recent movement to expand the conventional model of "intensive care" to encompass the provision of expertise in critical care medicine to patients who are not yet (or are no longer) admitted to the ICU.[5]

The movement to expand intensive care has been driven in part by the publication in 2000 of the United Kingdom Department of Health report, "Comprehensive Critical Care. A review of Adult Critical Care Services."[6] This document attempted to develop a framework for the future organization and delivery of healthcare for the U.K. One of the principle tenets of this report was that healthcare providers should strive to provide "comprehensive critical care," defined as the "complete process of care for the critically-ill, which focuses on the level of care that individual patients need, rather than on beds and buildings."

The impact of this initiative has been far-reaching. Most National Health Services hospitals in the United Kingdom have introduced, or are in the process of implementing, the comprehensive critical care approach to healthcare delivery. Special outreach teams have been developed to provide specialized care outside the ICU and to attempt to identify patients at risk.[7] With earlier intervention, it is hoped that these outreach teams will help avert admissions to ICUs, facilitate discharges from ICUs, and share critical care skills across acute care areas.[8]

In the United States, the "Leapfrog" initiative has also caused institutions and providers to examine how critical care services are provided. The Leapfrog Group represents more than 90 public and private organizations that purchase healthcare on behalf of their employees. The group has recommended that all hospitals should strive to ensure that the ICU is staffed by a full-time, specially-trained, critical care physician for at least 8 hours daily.[9] The impetus for this recommendation stems from mounting evidence that patient outcomes are better if dedicated intensivists are involved in the care of critically-ill patients.[10-12] Faced with a nationwide shortage of intensive care specialists,[3] many hospitals will experience difficulty meeting the objectives outlined by the Leapfrog Group. Some of the strategies that have been proposed to deal with this deficit of intensivists include the implementation of telemedicine solutions and "virtual" ICUs to attempt to increase the number of patients cared for by specialists.

Patients at risk

There is a growing body of evidence to suggest that many seriously ill patients may receive suboptimal care in hospital wards prior to their admission to the ICU. This is often the result of a lack of awareness of, misinterpretation of, or mismanagement of clinical signs for life-threatening dysfunction of the airway, breathing, or circulation.[13]

Most survivors of in-hospital cardiopulmonary resuscitation (CPR) will be admitted to the ICU. In one observational study, as many as 5.8% of patients admitted to the ICU from the hospital ward received CPR prior to ICU admission, but this group accounted for 30% of all

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deaths.[14] It has been well-demonstrated that patients admitted to the ICU following cardio-respiratory arrest have often displayed premonitory signs prior to their acute deterioration.[15-20] Up to 80% of these patients suffer severe (and perhaps unrecognized) physiological deterioration in the hours before their arrest.

In a study by McGloin and colleagues,[21] blinded assessors judged that suboptimal care had been provided prior to admission to the ICU in 32 of 87 (37%) patients. The mortality amongst this cohort was shown to be significantly higher than in a group of "well-managed" patients.

In 1998, McQuillan and colleagues conducted a prospective, confidential inquiry into the quality of care of 100 consecutive patients prior to their admission to the ICU.[13] Using structured interviews and questionnaires that were subsequently reviewed by two blinded external intensivists, these researchers demonstrated that 54% of the patients were perceived to have received suboptimal care between the time of hospital admission and their admission to the ICU. The in-hospital mortality of this group was greater than that of the cohort of patients judged to have received adequate care, although the difference did not reach statistical significance (48% vs 25%, P=0.07). Interestingly, the assessors felt that 69% of the patients who had received suboptimal care had been admitted to the ICU late. The authors concluded that major causes of suboptimal care included:

- failure of organization
- lack of knowledge
- failure to appreciate clinical urgency
- lack of supervision
- failure to seek advice.

They went on to suggest the implementation of a medical emergency team that could respond preemptively to clinical signs of life-threatening dysfunction of the airway, breathing, and circulation.

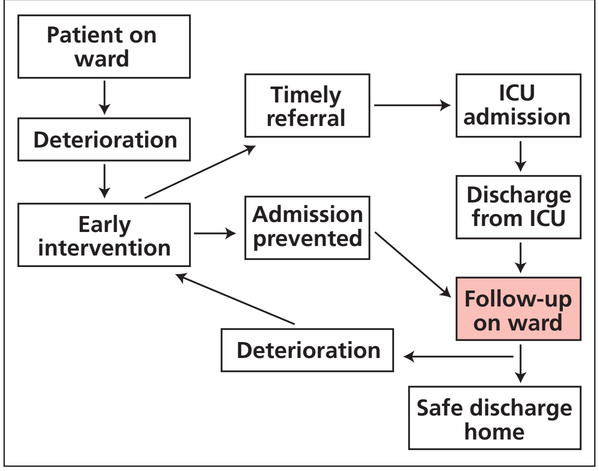
Clearly, a strong argument can be made for developing strategies to identify patients at risk of deterioration. In doing so, preemptive interventions aimed at averting admission to the ICU may be implemented or, alternatively, appropriate and timely admission to the ICU can be arranged.[22] Although several methods of achieving these goals have been described, it is the implementation of medical emergency teams or ICU outreach teams that has recently gained the most popularity.

The medical emergency team

Several units in different countries have now implemented services that strive to identify patients at risk of deterioration. Although the function of these services is similar, the names given to these teams have varied. They have been called "medical emergency teams,"[23] "patient-at-risk teams,"[24] and "ICU outreach services."[25,26] An illustration of the manner in which such a service might improve patient care is shown in Figure 1.

The results of observational studies examining the effectiveness of these services in improving patient care have been encouraging. Buist et al demonstrated a reduction in the rate of unexpected cardiac arrest following the implementation of a medical emergency team (3.77 arrests per 1000 deaths in 1996 versus 2.05 per 1000 deaths in 1999, $P<0.001$). The mortality rate following unexpected cardiac arrest also decreased after the service was introduced and this reduction persisted even after adjustment for case-mix (adjusted odds ratio 0.52, 95% CI, 0.36-0.74).[23]

Figure 1: The ICU outreach team



When Goldhill and colleagues retrospectively examined the impact of their own patient-at-risk team, they found that patients were less likely to have required CPR before ICU admission if they had been seen by the service (3.6% of patients seen by the team received CPR versus 30.4% of those not seen, $P<0.005$).[24] A reduction in post-ICU in-hospital mortality was observed by Young et al following the implementation of an ICU outreach service, though this trend did not reach statistical significance (7.8% mortality in the 6 months following implementation of the service versus 12.8% in the preceding 6 months, $P=0.068$).[26]

The need for improved monitoring and detection strategies

If early intervention by a medical emergency team is to be successful, a sensitive method for identifying patients at risk of deterioration must first be implemented. This represents several challenges. Primary-care nurses or physicians working on the ward must be relied upon to detect changes in a patient's status that might foreshadow deterioration. However, often these physicians and nurses may not have received suitable training in the care of seriously ill patients and consequently, may be poorly prepared to identify critical changes in a patient's status. Most hospitals that have implemented medical emergency teams have used a set of pre-defined physiological parameters to identify patients at risk of deterioration (Table 1). However, the sensitivity, specificity, and accuracy of these parameters have not been proven.[27]

Goldhilll and colleagues, in discussing their own patient-at-risk team, acknowledged that the physiological criteria used to notify the team might have been unsatisfactory.[24] Some patients admitted to ICU fulfilled none of

Table 1: Example of parameters used to identify patients at risk of deterioration prior to activation of a Medical Emergency Team*

Criteria for calling the medical emergency team	
Airway Respiratory distress Threatened airway	**Neurology** Any unexplained decrease in consciousness Agitation or delirium Repeated or prolonged seizures
Breathing Respiratory rate >30/min Respiratory rate <6/min SaO_2 <90% on oxygen Difficulty speaking	**Other** Concern about patient Uncontrolled pain Failure to respond to treatment Unable to obtain prompt assistance
Circulation Blood pressure <90 mmHg Heart rate >130 min	

* Adapted from Buist et al,[23]

the prespecified criteria intended to indicate the need for a response.

It may be that a reliance on predefined physiological criteria to identify patients at risk of deterioration is an approach that is too rigid and that inclusion of more subjective or qualitative parameters may improve sensitivity. Daffurn et al examined nurse response to the implementation of a medical emergency team in Australia.[28] Using a questionnaire administered to nurses, they were able to demonstrate that the majority of calls placed to the team were triggered by obvious patient distress, whereas a change in observations prompted the call for help in only 2.8% of cases. In a related study, Cioffi and colleagues further explored the shortcomings of reliance on changes in physiological parameters in patients at risk.[29] According to this group, nurses often identified the need to call for help based on "feelings they had about patients – a gut feeling, a sixth sense." It may be that individual physiological variables do not adequately predict the potential for further deterioration, whereas a healthcare worker's ability to form a global, subjective assessment based on past experiences may be far more powerful and accurate.

Bridging the gap: innovation and technology

Although there have been remarkable advances in computer technology, monitoring techniques, and decision-making support software over the last several decades, the penetration of these advances into the field of healthcare has been relatively limited and slow. Monitoring techniques in use today in most hospitals and institutions have changed very little in the past 3 decades. Indeed, outside the ICU, available monitoring devices are usually limited to remote telemetry that provides surveillance for arrhythmias, automated blood pressure monitoring, and pulse oximetry for determining oxygen saturation of hemoglobin. Through the use of these simple monitoring techniques, along with more advanced monitoring aids such as "smart-alarms" and neural network technology, it should now be possible to substantially improve patient care. In particular, with rapidly improving decision-support programs, integrative software tools, and neural networks, computers may soon help practitioners identify patients at risk of deterioration and may even replicate a global assessment or that elusive "sixth sense."

The technology is now available to enable monitoring of a patient's vital signs and physiological parameters from remote locations. Closed-circuit television can similarly be utilized to enable healthcare workers to visually monitor a patient from other locations in the hospital (eg, the physician's office) or even a different institution. As discussed below, the availability of these techniques for remote monitoring has prompted some physicians to advocate the development of "virtual" ICUs enabling the use of continuous monitoring techniques (that are typically only available in the ICU) in patients still in a general ward.

However, several barriers exist to more widespread implementation of currently available monitoring techniques to patients outside of the ICU, including:

- the high costs involved
- the need to train personnel in the use of these monitoring techniques (particularly for telemetry)
- the perception of healthcare professionals that these monitoring aids may not necessarily translate into improved patient outcomes.

The latter barrier may be particularly relevant given the observed shortcomings of a reliance on changes in individual physiological parameters to detect a change in a patient's status.

The virtual ICU

A model of care utilizing remote monitoring and provision of care has been described by Celi et al.[30] This group and their commercial enterprise, VISICU, have developed a system for the remote monitoring of patients admitted to an ICU. Their approach has been marketed as a method of providing care to patients 24 hours/day, 7 days/week using a remote, intensivist-led, multidisciplinary team (eICU team). Telemedicine, video conferencing, and integrated clinical information technologies allow the remote eICU to be in direct voice and video communication at any time with the staff of participating hospitals. The system could potentially increase the number of patients admitted to ICUs that can be cared for by a limited number of intensivists. In the context of the aforementioned Leapfrog initiative, this is of particular relevance. Only an estimated 23.1% of patients admitted to ICUs in the United States are cared for by a full-time intensivist.[3] The first operational eICU was installed at Sentara Healthcare in Norfolk, Virginia and, according to numerous press releases, it appears to have been greeted with considerable enthusiasm. Sentara has reported that mortality rates at Norfolk General decreased by 25% during the first half of 2001 following the institution of the eICU.[31]

The VISICU group has published an observational study examining the impact of telemedicine and remote intensivist input on the outcomes of patients admitted to a surgical ICU in a 450-bed hospital that did *not* have on-site intensivist support.[32] The participating intensivists provided patient care exclusively from their homes using cameras and data transmission equipment. Following a 16-week trial program, they observed that severity-adjusted ICU mortality decreased during the intervention by a range of 46%-68% compared to 2 baseline time periods ($P<0.05$ for both comparisons). They attributed the decreased mortality to a reduction in the incidence of ICU complications. Total ICU costs were also reduced by between 25% and 31% when compared to the 2 baseline periods ($P=0.03$). The authors concluded that technology-enabled remote care could provide continuous ICU patient management and achieve improved clinical and economic outcomes when on-site intensivist coverage is not available. These conclusions need to be confirmed by other centres employing this approach to healthcare delivery. As with all interventions of this type, applying the methodology of a randomized, controlled, clinical trial may not be feasible.

Similar remote monitoring technology may one day be used to improve the quality of care provided on general hospital wards. The incorporation of integrative software employing smart alarms, and possibly the use of neural network technology, could substantially improve the ability to identify patients at risk of deterioration. A "virtual ICU" could be established within the hospital to provide a central hub for monitoring patients admitted to hospital wards, but outside the actual ICU.

Smart alarms: their time has come

Most monitoring systems currently in use are equipped with alarms that notify the clinician when a particular threshold for the monitored parameter has been reached. However, most of these alarms are quite simple and react only to supra-normal or subnormal values as a parameter. As an example, an automated blood pressure monitor can be set to alarm if the systolic or mean blood pressure is either too low or too high. Similarly, telemetry monitors may identify tachyarrhythmias occurring at a certain rate, or may be set to alarm if ventricular ectopy is detected. It has been observed that as the number of new monitoring devices increases, so does the number of these simple alarms.[33] Concerns have been raised regarding the potential hazard of this growing "orchestra of alarms;" specifically, as the number of alarms increases, so may the risk for errors. A recent study by Chambrin et al estimated that a typical nurse working in an ICU might contend with one alarm every 37 minutes.[34]

These simple alarm systems, while certainly helpful when used in the proper context, are likely still too primitive to detect subtle changes in a patient's overall status. For example, patients presenting with sepsis may initially have preserved blood pressure while still demonstrating evidence of the systemic inflammatory response (SIRS). Although derangement of other physiological parameters (eg, respiratory rate and pulse) might be detected in this situation, these abnormalities may not be sufficient when viewed in isolation to enable the healthcare provider to properly identify the patient as being at risk of deterioration. Only when the blood pressure subsequently falls might the clinician infer that the patient has developed septic shock and attempt to arrange a transfer to a more appropriate setting for treatment and observation. A growing body of literature suggests that early, protocol-driven responses to septic shock may substantially improve patient outcomes[35] and highlights the need for early detection of patients-at-risk.

Many of the devices in use today now incorporate more complex algorithms that are able to detect trends in a patient's physiology that are cause for concern. However, an integrated approach to the many monitoring devices in use is clearly lacking.[33] There is a need for "smart alarms" that incorporate more intelligent data processing algorithms to synthesize the many parameters monitored in a given patient. Systems with such capabilities are widely available in the technology used in other sectors (eg, in the automobile and aeronautics industry). However, the implementation of more integrative software in healthcare has been surprisingly slow.

Neural network technology

Neural networks have been described as "statistical pattern-recognition machines composed of simple nonlinear processors connected into networks."[36] This technology attempts to create a form of artificial intelligence that can provide a better approximation of the human decision-making process than conventional computer analysis aids. A detailed description of neural network theory is beyond the scope of this discussion, but has been well-reviewed elsewhere.[36-38]

In practice, most clinical decisions are based on several pieces of data, each assigned different weights and considered together in the context of the particular clinical situation. Experienced physicians are more likely to make correct diagnoses than novices because they are able to incorporate into their decision-making all of their past experience. Attempts to simulate this process artificially become very difficult using conventional programming techniques, requiring complex algorithms, advanced statistical techniques, and often many assumptions. In contrast, neural networks may be well-suited to medical decision-making, given the ability of this technology to be modified by experience – the neural network is "trained" by the information it receives. The power of these tools to simulate "pattern-recognition" may be particularly important in interpreting changes in physiological parameters. Although experience using neural networks in critical care is still somewhat limited, they have been used with success in other medical domains. To date, most of the applications of neural network technology in healthcare have been to assist in diagnosis, staging (especially of cancer), and prognostication.[37] In the field of intensive care medicine, attempts have been made to apply neural network technology to help estimate risk of adverse outcome.[39]

The application of neural networks to physiological monitoring has been limited. Swiercz and colleagues attempted to use neural networks to improve the monitoring and interpretation of intracranial pressure (ICP) wave forms.[40] It remains to be seen whether or not the application of this technology to ICP monitoring will translate into improved outcomes. Spencer and colleagues attempted to use neural networks to automate the discovery, recognition, and prediction of hemodynamic patterns in real-time.[41] Their preliminary work suggests that their neural network may be able to predict several hemodynamic patterns before they completely unfold in time. Leon and Lorin trained neural networks to analyze flow and pressure wave forms from ventilators and found that their system could correctly recognize ventilation mode (pressure support versus spontaneous breathing) in all of the 433 test wave forms.[42]

It is expected that, as this technology evolves, it will become much more powerful and useful in interpreting physiological trends. We have already alluded to some of the shortcomings of the alarm and monitoring systems that are currently available. If neural networks are able to predict trends with accuracy through pattern recognition, they may become valuable components of future monitoring systems. However, rigorous evaluations of neural networks and "smart alarms" are lacking and must be considered before these new technologies and systems are introduced into widespread use.

Conclusion

There has recently been an important shift from the traditional model of providing critical care as hospitals and healthcare workers strive to provide "comprehensive critical care." This shift involves delivering optimal care to seriously ill patients, regardless of their physical location within the hospital. An important component of this model of care will include advanced monitoring techniques equipped with responsive smart alarms and integrative neural network technology to identify patients at risk of deterioration. A central "virtual ICU" will coordinate the monitoring of such patients and if trends of concern are detected, a medical emergency team will be activated. A physician who is specially trained in critical care medicine will oversee the care of patients admitted to the ICU and provide 24-hour support, 7 days/week via teleconferencing and electronic data transmission. The implementation of these strategies should result in substantial cost-savings as a result of reduced rates of complications and medical error, decreased lengths of hospital stay, and a decreased need to train nurses in the operation of multiple simple alarms. More importantly, these innovations should translate into improved patient outcomes and decreased hospital mortality rates.

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