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The Future ICU

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THE FUTURE ICU

Critical Care Medicine has existed for many years, but was only recognised as a specialty in the last 40 years or so. However, during this time, there has been a tremendous amount of change. Over the years, our understanding of different critical illnesses has improved, and our treatment strategies have become more effective. Technology has also played a key role in improving patient care, and adopting a human approach in the ICU. This pace of change is likely to continue in the years to come, and we will eventually see critical care medicine becoming less invasive, and more personalised.

Our cover story, **The Future ICU**, envisions what the future ICU will look like and how smart technology, Big Data, and Artificial Intelligence will shape the future of our ICUs. It presents the many possibilities that could further improve the treatment and management of the critically ill patient and highlights some of the challenges that need to be addressed to make the future better for both clinicians and patients.

Frederic Michard, Magna Fortunato, Ana Pratas and Sergius Arias Rodrigues de Oliveira talk about the future of haemodynamic monitoring and the need to consider the accessibility to scientific and technological progress, particularly in resource-limited countries while Antonio Naharro-Abellán, Beatriz Lobo-Valbuena, and Federico Gordo discuss the Clinical Decision Support Systems and how they will further develop in the near future, and become an essential part of ICU monitoring.

Anda Butnar, Adrian Wong, Serene Ho, and Manu Malbrain explore the future of Critical Care Ultrasound and how it will continue to push boundaries in the years to come. D. Kirk Hamilton, Sandra Swoboda, and Charles Cadenhead highlight the importance of staff-patient and staff-staff visibility and how this factor will be considered in future designs for critical care units.

Vitaly Herasavich, Mark Keegan, Matthew Johnston, and Brian Pickering talk about an AI-enabled ICU while Greg Martin explores the intersection of Big Data, AI, Precision and Predictive Medicine and how critical care will evolve from a system that reacts to patient deterioration into a system that predicts and prevents these events.

Seasonal Influenza remains a significant health burden. Laurence Busse and Craig Coopersmith present a framework for the comprehensive management of influenza while Bruno Pastene and Marc Leone talk about future strategies in sedation and analgesia.

Katerina Iliopoulou and Andreas Xyrichis talk about Critical Care Telemedicine, and how it is likely to be a key feature of the future ICU, and Eline Cox and Iwan van der Horst discuss the integration of care, research and education in the intelligent ICU.

In our Matrix section, Andy Higgs, Sam Goodhand, and Aidan Joyce introduce the intubation credit card, a go-anywhere checklist format to improve tracheal intubation. Mary Catherine Harris, Aaron Masino and Robert Grundmeier discuss early recognition of sepsis in the neonatal intensive care unit using machine learning models while Robert Arntfield talks about lifesaving applications of Transoesophageal Echocardiography in critical and emergency care.

In our Management section, Massimo Micocci, Arkeliana Tase, Melody Ni, Peter Buckle, and Francesca Rubulotta present an overview of Human Factors Engineering and how it can help reduce errors and preventable harm.

Our interview section features Rui Moreno, Neurocritical and Trauma Intensive Care Unit, São José Hospital, Centro Hospitalar Universitário de Lisboa Central E.P.E, Lisbon, Portugal.

There is no perfect way to predict the future, as there are many complex factors at play. However, our contributors have presented the many possibilities that exist, and the areas which could further improve the way we treat the critically ill patient. There are many exciting things to look forward to, and many challenges to handle. The goal, as always, is to improve patient care and patient outcomes. The future that we present in this issue is full of potential and hope, and many of these possibilities will make the Future ICU better for our patients.

As always, if you would like to get in touch, please email JLVincent@icu-management.org.

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COVER STORY

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The Future of Haemodynamic Monitoring:

From Planet Mars to Resource-Limited Countries

When envisioning the future of haemodynamic monitoring, we cannot limit the discussion to new sensors and computer innovations. We also need to consider the accessibility to scientific and technological progress, particularly in resource-limited countries where a large number of patients deserve more rational haemodynamic management.

The growing number of publications regarding new biomaterials, non-invasive sensors and artificial intelligence hold promises for the future of haemodynamic monitoring. In the first part of this article, we will briefly describe innovations that may become available soon in high-income countries and flagship hospitals. It is worth noting that recent surveys and audits have shown that the adoption of existing haemodynamic monitoring techniques is far from optimal, and that one of the key reasons is economic. Therefore, when discussing the future of haemodynamic monitoring we also have to consider that more patients from more countries need to have access to scientific and technological progress. In the second part of the manuscript, we will discuss alternatives to premium haemodynamic solutions, and how they could help rationalise haemodynamic management in resource-limited hospitals and countries.

The Future of Haemodynamic Monitoring in a Perfect World With Unlimited Resources

Let us imagine that we are in 2040 visiting a brand-new hospital built for the first human colony on planet Mars. This hospital would have been developed by an international consortium with virtually unlimited resources and would integrate the most recent medical innovations available on Mother Earth. The ICU would be a very quiet place where alarms would have been excluded from patient rooms (why bother patients with alarms?). Alarms would be seen or heard or felt (haptic signal) exclusively by caregivers at central monitoring stations, or on mobile or wrist devices. Patients would be continuously monitored with wearable sensors (aka electronic tattoos: youtube.com/watch?v=4oeFBGFzcrg). Some of these tiny, flexible and non-invasive sensors would be able to *feel* our carotid or femoral pulse and record high quality central blood pressure waveforms, from which blood flow information (e.g. stroke volume and cardiac output) would be derived by smart pulse contour algorithms (Michard 2016). Specific sensors would continuously monitor tissue perfusion and oxygenation, when not directly mitochondrial oxygen consumption (Vincent et al. 2017). Other adhesive skin sensors or biostamps would enable measurement of lactates, electrolytes and metabolites in sweat or interstitial fluid (of course, by 2040, clinical studies would have clarified the meaning and kinetics of these measurements).

Many of the above-mentioned sensors would be part of ergonomic monitoring tools such as helmets, shirts, belts, bracelets, gloves or rings worn by patients

(Michard et al. 2017a). Data would be transmitted wirelessly to computers and artificial intelligence systems able to filter artefacts, fuse parameters together and predict most adverse events before they actually occur (Pinsky 2016; Michard and Teboul 2019). Decision support systems would constantly help clinicians to think proactively, to make the right therapeutic decisions and to minimise drug side effects (Michard 2013). The use of central venous catheters would belong to the past, as well as their associated thrombotic, haemorrhagic and infectious complications (Vincent et al. 2018). Blood samples would be very small (the size of a blood drop) to prevent iatrogenic anaemia. When needed, larger blood samples would be obtained by robots using infra-red transcutaneous illumination and colour Doppler guidance (veebot.com/solutions.html) to improve safety, efficiency and decrease nurse workload. Electrical impedance tomography (EIT), routinely used for visual and functional lung monitoring, could also be useful to monitor stroke volume, cardiac output and pulmonary artery pressures (Braun et al. 2018). All doctors would have an echo probe in their pocket to *augment* clinical examination **(Figure 1)**. High-end echo machines would only be used from time to time for detailed examination and when precise measurements would be necessary. These measurements would be greatly facilitated by smart systems recognising heart structures and movements and helping clinicians to properly position the probe.

Figure 1. Examples of pocket echo devices.Given their relatively low cost, these devices have potential to be used not only in high-income but also in resource-limited countries. In a perfect world, most clinicians should have one in their pocket and be trained for basic qualitative ultrasound evaluations. From left to right: Lumify from Philips, IQ from Butterfly, VScan from GE Healthcare.

The Future of Haemodynamic Monitoring in Resource-Limited Countries

In many hospitals and in many countries, what we envisioned for the flagship hospital on Mars will never be implemented for several reasons that include lack of awareness, lack of training and of course lack of resources. However, hypovolaemic, septic and cardiogenic shocks will likely remain a reality for millions of patients and thousands of caregivers working in resource-limited settings. In the following paragraphs, we describe existing and future solutions to improve the quality of care of patients with haemodynamic instability without necessarily increasing costs.

> **upfront investment in monitoring techniques is often a barrier to hospital purchase and clinical adoption**

Predicting Fluid Responsiveness

Predicting fluid responsiveness is useful to rationalise fluid therapy. It helps to identify patients who may benefit from fluid administration and, perhaps more importantly, to prevent unjustified fluid administration in fluid non-responders. In emergency departments and intensive care units, the applicability of dynamic predictors of fluid responsiveness such as pulse pressure variation (PPV) is limited (Michard et al. 2015). Therefore, recommended methods to predict fluid responsiveness include the assessment of changes in stroke volume during a passive leg raising manoeuvre, an end-expiratory occlusion test, a lung recruitment manoeuvre or simply during a fluid challenge (Michard and Biais 2019). The main limiting factor to the clinical adoption of these methods is the availability of a cardiac output monitor to quantify stroke volume changes. In this regard, several alternative methods have been proposed to predict fluid responsiveness **(Figure 2)**. For instance, the decrease in PPV during a fluid challenge has proved to be proportional to the increase in cardiac output (Michard et al. 2000; Mallat et al. 2015). In other words, changes in PPV can be used as a surrogate for assessing changes in stroke volume or cardiac output during fluid administration. Similarly, the rise in PPV during a transient increase in tidal volume (e.g. from 6 to 8 ml/kg) has been shown to be useful to predict fluid responsiveness with high sensitivity and specificity (Myatra et al. 2017; Messina et al. 2019). Additionally, in patients who do not have an arterial catheter in place, pulse oximeters have recently been proposed to track changes in peripheral perfusion index (PI). Beurton et al. showed that changes in PI are proportional to changes in cardiac output during passive leg raising manoeuvres and able to predict fluid responsiveness with acceptable sensitivity and specificity (Beurton et al. 2019). De Courson et al. recently made the same observation during lung recruitment manoeuvres: most patients who experienced a dramatic decrease in PI during a recruitment manoeuvre were

fluid responders, whereas patients who did not, were fluid non-responders (De Courson et al. 2019).

Goal-Directed Fluid Therapy in High-Risk Surgical Patients

Most patients undergoing major surgery have an arterial line in place for continuous monitoring of blood pressure and blood samples. General anaesthesia with mechanical ventilation is also the rule in this context. In addition, atrial fibrillation, right ventricular failure, and decreased lung compliance are far less common in patients undergoing elective surgery than in critically ill patients. Protective mechanical ventilation is often described as a potential obstacle to the use of PPV. But it is only the case when very low tidal volumes are used (e.g. 6 ml/kg). If outcome clinical studies have shown that using a tidal volume of 6-8 ml/kg is better than of 10-12 ml/kg, until today there is no evidence than 6 is better than 8 ml/kg (Futier et al. 2013). Actually, a large observational study done in >29,000 patients from the UK suggested that the ideal tidal volume for surgical patients is around 8-9 ml/kg (Levin et al. 2014) and such a tidal volume is ideal to use PPV as a marker of fluid responsiveness. In summary, PPV can be used to rationalise fluid therapy in a large number of patients undergoing major surgery. Lopes et al. were the first to show a dramatic decrease in postoperative complications and hospital length of stay when using PPV to guide fluid therapy in a resource-limited setting (Lopes et al. 2007). Their pilot findings have been confirmed by several more recent clinical studies (Benes et al. 2014).

When cardiac output monitoring is a requirement to predict fluid responsiveness (e.g. when PPV cannot be used), recent studies have shown that pulse contour methods are the preferred choice of anaesthesiologists (Ahmad et al. 2015). However, despite the large number of studies demonstrating the clinical value of pulse contour methods in surgical patients (Michard et al. 2017b), surveys and audits have shown that their adoption remains poor (Molliex et al. 2019). Most of these methods require the use of a disposable sensor, which is likely to double or triple the average cost of anaesthesia (around 100 euros in Europe). The onus of monitoring equipment has to be balanced with the potential savings related to the expected reduction in postoperative morbidity and length of stay. However, upfront investment in monitoring techniques is often a barrier to hospital purchase and clinical adoption. In addition, only a few hospitals have perioperative medicine departments and associated budgets. In most hospitals, anaesthesia departments have to pay for monitoring technologies used by anaesthesiologists, whereas the clinical benefits and associated savings are for the surgical departments. A solution may come from innovative business models recently proposed by several companies that, instead of charging for a single-use-sensor-per-patient, developed sensor-free pulse contour methods. The arterial pressure waveform is simply slaved from the bedside monitor towards a dedicated monitor or computer containing the pulse waveform analysis software. These companies usually charge hospitals a flat fee, that depends on the number of monitors they need, but not on the number of patients they treat. As a result, it gives clinicians the freedom to monitor as many patients as they want without increasing hospital costs **(Figure 2)**.

In the future, one may also expect that bedside monitoring companies will develop or simply acquire existing pulse contour algorithms (Michard et al. 2019a). By doing so they will be able to offer cardiac output as a novel vital sign for all patients in whom a continuous BP waveform is recorded, either invasively from a radial catheter, or non-invasively from a volume clamp or tonometric sensor. Another option would be the improvement of methods based on the analysis of expired carbon dioxide (Peyton et al. 2019). These methods would have strong

PREMIUM SOLUTIONS	ALTERNATIVES
To assess cardiac function	**To assess cardiac function**
High-end echo evaluation (quantitative)	Pocket echo device (qualitative evaluation)
Continuous $ScvO_2$ from fibre-optic CVC	On-demand $ScvO_2$ from CVC blood sample
Advanced Swan + dedicated monitor	Basic Swan + regular bedside monitor
To track cardiac output changes	**To track cardiac output changes**
Pay-per-use pulse contour method	Pulse contour with unlimited usage plan
Pulse contour with disposable sensor	Disposable-free pulse contour system
To predict fluid responsiveness	**To predict fluid responsiveness**
SV changes during fluid challenge	PPV changes during fluid challenge
SV changes during EEOT	PPV changes during VT challenge
SV changes during PLR manoeuvre	PI changes during PLR maneuver
SV changes during lung recruit manoeuvre	PI changes during lung recruit manoeuvre

Figure 2. Haemodynamic monitoring solutions for resource-limited countries. Several monitoring solutions do exist to ensure that patients living in resource-limited countries may benefit from rational haemodynamic management. ScvO2, central venous oxygen saturation; CVC, central venous catheter; EEOT, end-expiratory occlusion test; PLR, passive leg raising; PPV, pulse pressure variation; PI, peripheral perfusion index.

potential for wide clinical adoption if they were integrated into anaesthesia machines.

Assessment of Cardiac Function

Echocardiography is gold standard for the bedside assessment of cardiac function in critically ill patients. Pocket echo probes are now available and have the potential to replace the stethoscope in the pocket of many clinicians, in the ICU and beyond **(Figure 1)**. Although miniaturised, these tools have proven to be useful for a qualitative (e.g. pericardial effusion, right ventricular dilation, left ventricular dysfunction) or even quantitative assessment of cardiac function (e.g. estimation of left ventricular ejection fraction or inferior vena cava variations) (Biais et al. 2012, Liebo et al. 2011). Given their relatively low cost (as compared to high-end ultrasound machines), these pocket echo devices have the potential to be accessible to resource-limited countries and should help to increase the number of patients with shock who may benefit from quick ultrasound evaluations and rational haemodynamic management (Michard et al. 2019b).

Conclusion

Given the number of hardware and software innovations coming to market, the future of haemodynamic monitoring should be nothing but bright. However, the clinical adoption of existing solutions is somewhat concerning, with a minority of patients benefiting today from haemodynamic monitoring tools. In a medical world with increasing economic constraints, in parallel to the exciting development of technical and digital innovations, we must find ways to improve the accessibility of monitoring solutions to more patients and in more countries.

Disclosure

Frederic Michard (FM) is the founder and managing director of MiCo Sàrl, a Swiss consulting firm. MiCo does not sell any medical device and FM does not own any shares from any medtech company. ■

Key Points

- Haemodynamic monitoring systems enable the rationalisation of haemodynamic therapy. Multiple studies have reported clinical benefits, particularly in patients undergoing high risk surgery.
- The clinical adoption of existing monitoring solutions remains low. The main barrier to wider adoption is the cost of single-use sensors.
- In many patients undergoing high-risk surgery under general anaesthesia, the conditions are met in order to use pulse pressure variation (PPV) to predict fluid responsiveness and rationalise fluid administration.
- In most patients, tracking changes in PPV can be used to detect changes in stroke volume and cardiac output during fluid challenges.
- Tracking changes in perfusion index (PI) may also have value to detect changes in stroke volume and cardiac output during passive leg raising and lung recruitment manoeuvres.
- The adoption of modern and affordable solutions for cardiac output monitoring should further help to ensure that more patients from more countries can benefit from rational haemodynamic management.

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Clinical Decision Support Systems: Future or Present in ICU?

Clinical decision support systems (CDSS) are today, a reality. More complex, useful systems will be developed in the near future, forging CDSS an essential part of ICU monitoring. However, we need to understand the algorithms embedded in CDSS and to assess them correctly. They will need to first prove their worthiness before becoming indispensable.

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Healthcare professionals working in the ICU environment are exposed to a large amount of data, both because of the intrinsic complexity of the patients, as well as patients' close monitoring. There is also an exponential increase in medical knowledge, and thus an exponential difficulty in treating patients accordingly. Even interventions clearly established in the medical literature as beneficial are not universally applied. For example, when the LUNG-SAFE study (Bellani et al. 2016) was conducted, three interventions had proven to improve survival in Acute Respiratory Distress Syndrome (ARDS): low tidal volume <6 ml/kg, prolonged sessions of prone positioning and neuromuscular blocking for 48 hours; provided data showed mean tidal volume of 7.6 ml/kg, use of prone position in 16% of the cases and NMBA in 37.8%. One-thousand eight hundred to 250,000 deaths per year have been estimated to be due to medical errors regarding adverse effects (Makary and Daniel 2016; Sunshine et al. 2019). Derived costs from medical errors reached 19.5 billion in 2008 (Andel et al. 2012).

> **"CDSS have to be efficient, able to integrate with the workflow, avoiding overload"**

Use of computer systems during clinical practice started during the 1960s (Ledley & Lusted 1959). Clinical Decision Support Systems (CDSS) are defined as "a process for enhancing health-related decisions and actions with organised clinical knowledge, to improve health care delivery." In other words, CDSS are health information technology that builds upon the foundation of an electronic health record (EHR) to provide professionals with specific, filtered and organised information.

Recently, several elements make possible the deployment of this concept into significant and practical applications:

- Digitalisation and increased connection of medical devices with EHR.
- Possibility of incorporating CDSS both in the EHR and in the medical devices themselves, from monitors to ventilators.
- Improvement in data processing: new analytical techniques, based on the analysis of big data, and different forms of machine learning (Núñez Reiz et al. 2019; Sanchez-Pinto et al. 2018).
- Change from an old working model focused on ICU mortality to a new model focused on the patient's continued care (including ICU and hospital ward) (Vincent

and Creteur 2015).

CDSS Classification

There are different types of CDSS depending on the work-chain link they support. CDSS can be more specific by supporting a single specific task, such as anticoagulant weekly dosing, or more complex by integrating different aids, such as guiding the management of a septic patient along the hospital stay (from initial screening to the ICU admission). CDSS can improve:

- **Data entry:** Automating this step minimises errors and decreases workload. When automation is not possible CDSS may ease data entry using smart forms. CDSS may also detect errors during data entry and present immediate alerts if necessary, and transform unstructured inputs to analytically processable data. For example, there are systems that are capable of data-mining diagnostics (structured data) from free text inputs (unstructured data).
- **Data review:** CDSS may provide summary of relevant data through predictive and retrospective analysis. This process may allow screening of deteriorating patients.
- **Management:** CDSS may present relevant references and resources like guidelines and protocols, and advise during prescription adjustment of medication or techniques. Computerised physician order entry (CPOE) refers to computer-based systems that facilitate the medication ordering process, including clinical assistance systems. It is a field where CDSS have great impact, although once established it can go unnoticed. It eliminates transcription errors in which medication administration errors occurred due to errors in the eligibility of prescriptions, and it facilitates pharmacology departments' follow-up, which entails significant savings (Calloway et al. 2013). Prescription help systems generate automatic alerts of allergies, interactions and dose adjustment depending on creatinine clearance.
- **Alerts:** Alerts and tasks not initiated by the user, by patient data or by time. For example, systems predicting ICU admission of patients staying at the hospital ward, systems detecting worsening in ICU patients and systems predicting need of prolonged mechanical ventilation.

Features and Limitations

We must acknowledge the characteristics CDSS should include and the problems they may face in their application.

CDSS should give advice on relevant issues, including staff and patient needs. This advice must be intuitive and easy to use; required training to obtain results should not be needed. The way in which CDSS advises the user must be respectful, and its implementation explained so that the staff accepts it (Ginestra et al. 2019).

> "other CDSS screening examples are systems that detect specific syndromes, such as sepsis"

Black boxes are not desirable; clinicians should understand the advice before accepting it. The only exception would be that there was no other option, or its usefulness was clearly demonstrated (e.g. in a randomised clinical trial, where the result is relevant without question).

CDSS have to be efficient, able to integrate with the workflow, avoiding overload. They should keep advice only for relevant information, reducing alert fatigue, should avoid the need for manual data collection, and should ease the needed tasks when different computer systems and medical devices that hinder the extraction work together. Anonymised data is mandatory, notably if databases are exported for collaborative research networks.

Assess CDSS

Like any medical intervention, CDSS must have a scientific basis and provide evidence about its usefulness. There is a specific regulation on closed loop systems where a software or a set of software and hardware intervenes directly in a patient, but, to our knowledge, there is no paperwork on systems that guide the healthcare staff interventions.

Sometimes it is difficult to define what a correct decision is. We should focus on obtained CDSS outcomes compared to other clinicians or experts rather than on a specific decision within a specific case. Moreover, CDSS must include systems that correct predictable and unpredictable errors, monitoring their performance.

Examples in Critical Care

It is out of scope to review all existing CDSS. We will however present some current examples with which we are familiar.

Early detection of patients with clinical worsening (Vincent et al. 2018) is a well-studied field. Computer systems have the ability to monitor all generated data within the hospital, providing itself feedback for continuous improvement (Cardoso et al. 2011). Vital signs collection systems at emergency departments and wards are automated to reduce errors, avoiding increase of the burden of nursing. It is crucial for the healthcare staff to be aware of its usefulness (if some of the data collection depends on their participation, this has to be performed correctly).

Processing data has gone a long way. Scoring systems, like Early Warning Scores (EWS), allocate points based on several physiological variables, yielding a total

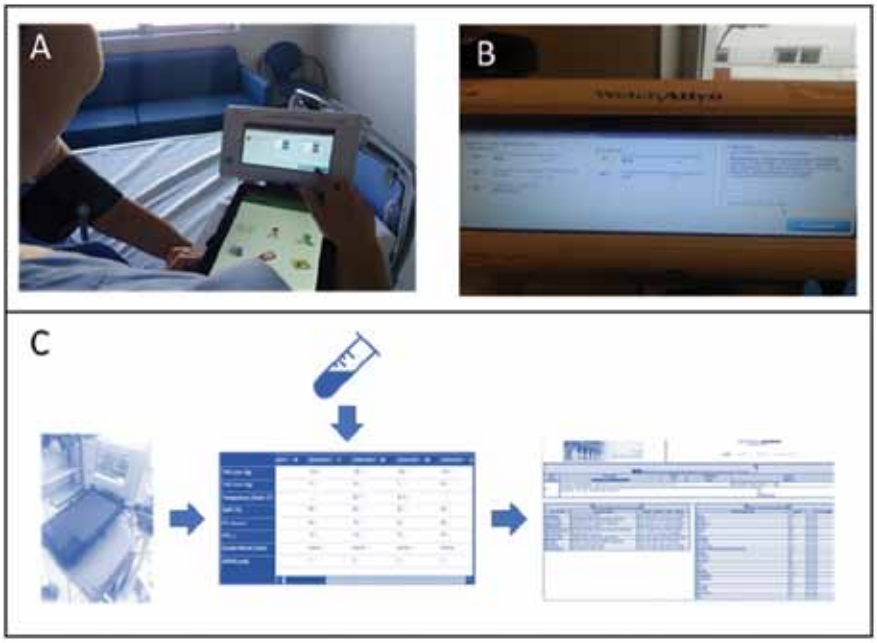

Figure 1. Early Warning Score Application. A) Example of an intelligent vital signs monitoring system with a customised early warning system integrated. B) On the left of the monitor the sum of the score. On the right the given advice to the nurse (e.g. alert the ICU team). C) Data of vital signs are connected automatically with the EHR. These data and lab test results generate warnings of patients at risk to the ICU team.

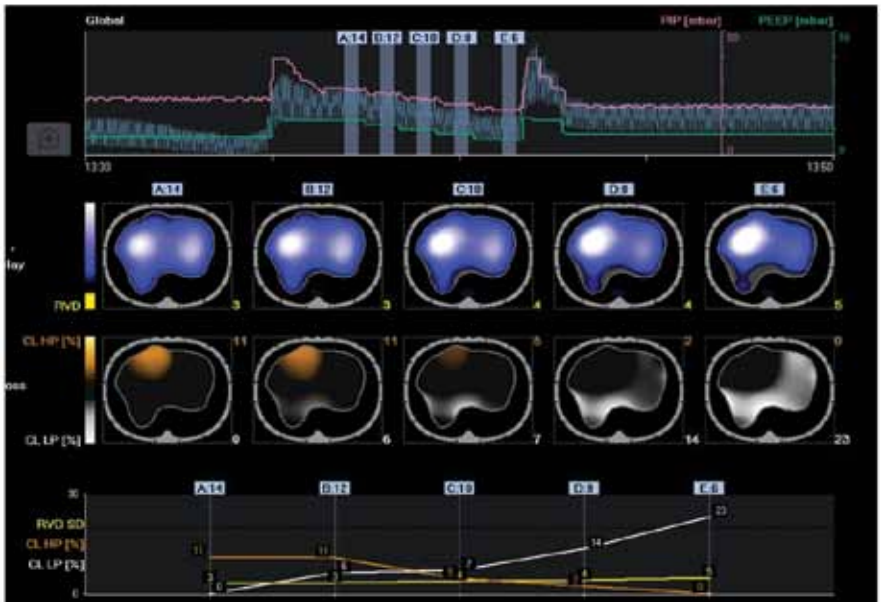

Figure 2. Electrical Impedance Tomography monitoring an optimal PEEP manoeuvre. The software automatically interprets different levels of PEEP during the last minutes of monitoring. The user supervises the choice of the stages before being compared. The software also represents the areas of overdistension and atelectasis so that the user can choose the optimal PEEP.

score after summing up the different points (Royal College of Physicians 2012; Subbe et al. 2001). EWS are used in real workflows; in our particular case, we have been working with an "ICU without walls model" for the past decade, improving patient monitoring admitted in the hospital wards (Abella Álvarez et al. 2013). This system, based on technological support and multi-professional collaboration, uses wirelessly connected with EHR monitors (Welch Allyn®), and customised with our own EWS system (Henares EWS). The CDSS integrates clinical data, vital signs and lab data of patients, improving the alert system and allowing rapid intervention **(Figure 1)**. Other models using deep learning are in development and validation phase on retrospective databases (Desautels et al. 2016).

Other CDSS screening examples are systems that detect specific syndromes, such as sepsis. In this case, machine learning based systems detect patients hours before the onset of sepsis (Desautels et al. 2016; Giannini et al. 2019; Nemati et al. 2018; Shashikumar et al. 2017). They show good clinical application, including shorter ICU and hospital length of stay and lower hospital mortality (Shimabukuro et al. 2017).

Another good example of CDSS use within the ICU imply the management of mechanical ventilation (MV). There are basic computerised protocols that standardise and guide medical decisions using inputs generated by the ventilator or the other monitoring systems (Sorenson et al. 2008). More complex systems integrate data generated by the patient into physiological models. There are currently closed loop systems from different MV manufacturers: they do not require clinician intervention, and are currently being used in the transition to assisted modes and in automatic weaning (Rose et al. 2015). A compelling number of ongoing trials will assess its significant usefulness.

Moreover, new CDSS regarding management of MV can be integrated in a monitor. This software allows an electrical impedance monitor to semi-automatically recognise an optimal PEEP manoeuvre and present the overdistention and atelectasis information so that the clinician decides on the optimal PEEP level **(Figure 2)**. New machine learning applications manage to recognise asynchronies (Gholami et al. 2018; Sottile et al. 2018) and predict prolonged mechanical ventilation (including need for tracheostomy).

Conclusion

Clinical decision support systems are today a reality. More complex, useful systems will be developed in the near future, forging CDSS an essential part of ICU monitoring. However, we need to understand the algorithms embedded in CDSS and to assess them correctly. They will need to first prove their worthiness before becoming indispensable.

Conflict of Interest

Federico Gordo has performed consultancy work and formation for Medtronic and formation for Medtronic, Draguer and MSD. The other authors have no competing interests. ■

Key Points

- Clinical Decision Support Systems are defined as a process for enhancing health-related decisions and actions with organised clinical knowledge, to improve health care delivery.
- CDSS can be more specific by supporting a single specific task, such as anticoagulant weekly dosing, or more complex by integrating different aids.
- CDSS can improve data entry, data review, management and alerts.
- CDSS are a reality. More complex, useful systems will be developed in the near future, forging CDSS an essential part of ICU monitoring.

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The Future of Critical Care Ultrasound

Critical Care Ultrasound (CCUS) has progressed by leaps and bounds, and will continue to push boundaries, with techniques being modified to suit evolving clinical needs and new applications.

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Introduction

With roots traceable to sonar technology developed for underwater listening and submarine detection, the era of medical ultrasound began during the Second World War; the first research paper on brain ultrasonic transmissions was published by Dr. Karl Theodore Dussik in 1942. The 1950s saw the development of echocardiography and obstetric ultrasound, followed by pulsed Doppler and 3D ultrasound a few decades later, establishing the diverse applicability of ultrasound in medicine (ultrasoundschoolsguide.com/history-of-ultrasound/).

Thereafter came the technological advances in electronics, computing and transducer engineering which radically improved image quality and processing. The introduction of microbubble contrast agents enabled functional assessment of tissue beds at a microvascular level.

During this time, emergency ultrasonography had been gaining momentum; the Focused Assessment with Sonography for Trauma (FAST) examination is considered the first and most significant widespread application of ultrasound outside the radiology department, performed by emergency physicians at the point of care in trauma patients (Richards and McGahan 2017).

Critical Care Ultrasound (CCUS) has also become more commonplace, beginning with the extension of echocardiography beyond the remit of cardiologists. Increasingly considered a valuable tool for diagnosis, monitoring and guidance of practical procedures in critically ill patients, its applications continue to evolve. In recognition of the need for consistency and quality in practice, there now exist formal routes to CCUS accreditation (Galarza et al. 2017).

Given the rate at which ultrasonography has progressed in this short time, what can we expect next? We will consider two aspects likely to have the greatest impact in CCUS: the machine and the modalities.

The Machine

The ideal ultrasound machine is light, smart, affordable and accessible. Early prototypes took the form of large water-filled drums with a transducer passing along the circumference to capture images of the patient immersed within **(Figure 1)**. These days, having done away with water baths, the average ICU machine is the size of a large computer and can be wheeled to the patient's bedside **(Figure 2)**.

Pocket-Sized Portability

A huge leap in technology within the past few years has led to the development of handheld ultrasound devices with the processing power of a smartphone **(Figure 3)**. Despite miniaturisation and some limitation of functions compared to full-sized machines, these devices retain an impressive array of capabilities with image quality that is continually improving. Initially restricted to 2D or B-mode imaging, handheld devices now integrate more advanced functions such as Colour Doppler, with some running on artificial intelligence-powered software, though none of these incorporate spectral Doppler at present (Blood and Mangion 2019).

A fairly recent paradigm shift in the processes within critical care medicine has given rise to the concept of ICU without walls, an aspirational model of care intended

Figure 1. Early prototype ultrasound machine. Source: Medical Diagnostic Ultrasound: A retrospective on its 40th anniversary (1998) Kodak Eastman with National Museum of American History.

Figure 3. Handheld ultrasound devices. Source: becominghuman.ai.

Figure 2. Modern bedside ultrasound machine. Source: iusimaging.com.

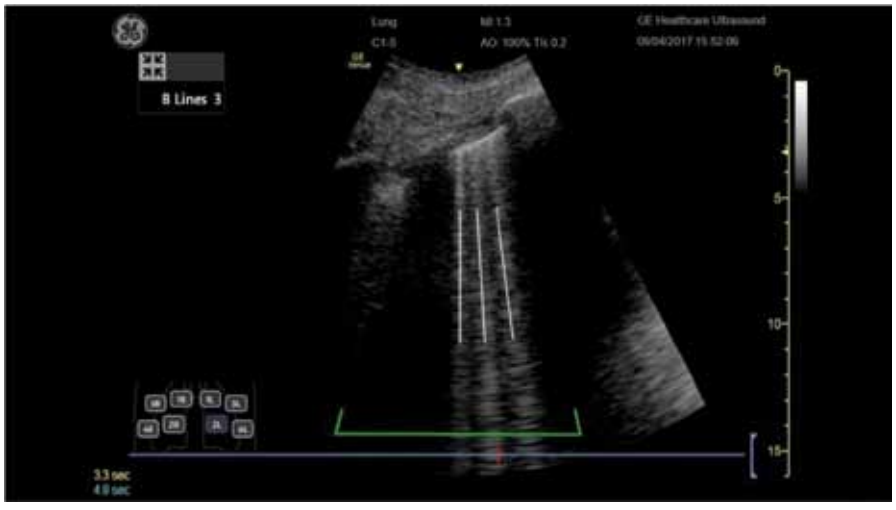

Figure 4. B lines detected during ultrasound examination of lung parenchyma, as delineated by white lines. The number of B lines in each examined zone can be recorded, allowing a comparison between zones. Source. gehealthcare.nl

to recognise and respond to critical illness early and rapidly. This concept proposes that the ICU is defined not by physical location but by a set of healthcare professionals with relevant expertise to care for the at-risk/critically ill patient even if they are located outside of the ICU. A handheld ultrasound device can be readily taken to the wards or indeed anywhere in the hospital by the intensivist for these purposes, aligning it neatly to the concept of ICU without walls.

Augmented Intelligence and Machine Learning

The use of artificial intelligence is expanding within critical care, an important example of which is a sepsis prediction tool that processes a large volume of patient-related data within an algorithm and alerts healthcare professionals to those at risk of developing sepsis (Desautels et al. 2016). The term 'artificial intelligence' in this instance alludes to the fact that machine has completely replaced mankind in the algorithmic prediction of sepsis. Where ultrasound is concerned however, the operator as yet cannot be replaced despite sophisticated software engineering, and therefore the term 'augmented intelligence' might be more accurate, reflecting an enhancement rather than replacement of the operator's ability. The ways in which augmented intelligence has revolutionised CCUS is two-fold: image optimisation and image analysis.

As machines become smaller, it is their computational ability that allows advanced image processing in order to minimise operator variability and compensate for limitations in image quality control. Through augmented intelligence, images can be automatically adjusted for noise while purposefully recognising relevant artefacts to provide the best quality of information to the practitioner, with little need for

manual adjustment or indeed in-depth knowledge of the controls.

With the addition of image analysis software packages, once the probe has been appropriately positioned for a specific view, the machine will detect and highlight structures/artefacts e.g. identifying left ventricular outflow tract in the apical 4 chamber view or B-lines on lung ultrasound **(Figure 4)**. Automatic calculation of indices is also possible e.g. estimation of ejection fraction.

Augmented intelligence does have its limitations and in its current iteration at least, machine learning does not replace clinical acumen; ultrasound findings still need to be integrated into the clinical context (arguably the most challenging aspect of CCUS). However, this technology can save valuable time during the scanning process, accommodates variability due to operator/patient/environmental factors and can increase diagnostic confidence of the clinician by providing a 'second read' on the image particularly if the practitioner is relatively inexperienced or unable to seek a second opinion. Remarkably, despite augmented intelligence being in its early stages, it has already been shown that machine algorithms are more reliable in detecting cancer compared to human operators (Ardila et al. 2019).

Cloud-Based Technology

The process of obtaining a second opinion has been revolutionised by cloud-based technology; long gone are the days of sending hard copy images by courier to a specialist centre or transmitting studies via the internet from a specified workstation. Through wireless capabilities, ultrasound machines, including handheld devices, are able to instantaneously upload ultrasound studies to the Cloud with unlimited storage capacity, enabling swift sharing of images and more convenient access to expert opinion. Individual manufacturers have proprietary platforms allowing remote review and discussion of images.

Akin to the concept of ICU without walls, cloud-based technology and the ability to remotely access large volumes of patient data appear to be a significant evolutionary step in telemedicine, taking patient care beyond the constraints of hospital walls. An excellent example of this is presented by the Emory Healthcare group whereby collaboration between ICU teams in Atlanta USA and Australia across a 12 hour time zone positively impacted upon patient care including health spending and 60-day readmissions (Trombley et al. 2017). The eICU platform allows distant monitoring, diagnosis and management with consultant-led reciprocal care for the partner group during overnight periods where senior-level staffing typically decreases; Cloud-based imaging data can be vital to clinical decision making in these settings.

Key issues such as patient confidentiality, consent, data protection across digital networks and ownership of data become of prime importance at this level of technological innovation and need to be addressed with care and transparency (Lui 2018). A detailed discussion of these issues is beyond the scope of this article.

> "a huge leap in technology within the past few years has led to the development of handheld ultrasound devices with the processing power of a smartphone"

Ultrasound as a Replacement for the Stethoscope?

Given its safety profile and real-time applicability, the potential of the ultrasound machine to replace the stethoscope has already been debated in educational and clinical circles.

A handheld device is as portable as a stethoscope while providing far more detailed diagnostic information in most clinical scenarios. It would not be far-fetched to predict the handheld ultrasound device may soon supersede the stethoscope in healthcare settings without budgetary constraints, although the practical considerations e.g. appropriate training, image documentation and governance should not be underestimated.

The Modalities

Standardising Training and Improving Access

International expert and consensus statements from nearly a decade ago had already made the case for ultrasound competency in intensivists, defining a core skill set and more advanced ones (Mayo et al. 2009).

It is generally agreed that the core CCUS skill set includes the ability to scan the heart, lungs, abdomen and vascular system, but the definition of these competencies permits flexibility of interpretation and therefore variations are common in skill sets of practitioners accredited in CCUS from different countries/regions/training centres (Malbrain et al. 2017). There also remain barriers to implementation of training programmes, with a recent international survey highlighting a shortage of trainers and mentors in many countries (Galarza et al. 2017).

To address the accessibility issues for novices seeking training in CCUS, there are now online learning platforms providing video-based lectures and demonstrations covering basic techniques, image acquisition and a range of common pathology as an alternative to a hands-on course in locations with limited access. Augmented reality will take this one step further, in the form of simulation training programmes.

In the future, we anticipate an improvement in the non-uniform distribution of CCUS trainers and mentors as increasing numbers of clinicians gain accreditation and become trainers within their regions. As more practitioners (including non-doctors)

gain 'core' competencies, we expect to see a push to explore beyond the boundaries of CCUS practice.

Whilst on the topic of CCUS training, we would be remiss not to mention the introduction of ultrasound training into the undergraduate curriculum in some institutions, although its value to (and hence inclusion in) undergraduate medical education is currently not supported by a sufficient base of empirical research (Feilchenfeld et al. 2017). As proponents of point-of-care ultrasound however, we believe that this skill is invaluable in many aspects of patient care and would welcome any measures that promote early exposure to foster interest in ultrasonography.

New Techniques

A previously underexplored territory in CCUS is the central nervous system— this is changing. Besides its obvious value in neuro-ICU, it may also have a role in the general ICU setting. Using optic nerve sheath measurements as a surrogate marker of intracranial pressure could translate to more timely detection of significant intracranial abnormalities (Robba et al. 2019), without the inherent risks and reliance on specialist expertise and equipment associated with invasive monitoring. Transferring patients to CT or MRI, which is time- and resource-consuming could be reserved for complex cases or where CCUS has not provided sufficient information.

More novel ultrasound techniques will find their relevance in CCUS. Within radiology, contrast-enhanced ultrasound is commonly used to characterise lesions and their vascularity. Within critical care, contrast-enhanced ultrasound utilisation currently focuses on assessment of organ perfusion, including the liver, heart, kidney and brain (Blomley et al. 2001; Harrois et al. 2018). A study investigating its value in the assessment of renal perfusion in shock is underway (Watchorn et al. 2019).

Early work assessing the value of VEXUS (venous excess ultrasound score) suggests that doppler analysis of the venous vasculature of specific organs may be useful in detecting and quantifying venous congestion (Haycock and Spiegel 2019).

Ultrasound-guided tonometry (based on an ultrasound probe connected to a pressure-transducing system which takes into account the physical pressure applied to the abdomen by the practitioner) may become a valuable noninvasive tool in the estimation of intra-abdominal pressure (Bloch et al. 2018).

It should be remembered that CCUS applications tend to evolve in parallel to developments in other specialties, an example of which is speckle tracking for strain analysis in echocardiography. As a highly sensitive measure of myocardial performance, it is sometimes used in cardiology to time invasive interventions. This technique could be similarly applied to detect myocardial strain in the context of critical illness (Orde et al. 2016).

Conclusion

CCUS has progressed by leaps and bounds in the last two decades. We believe what lies in the future is not a reinvention of the wheel, but rather a gradual pushing of boundaries as this skill continues to mature, with techniques being modified to suit our evolving clinical needs and new applications founded on the basis of current ones. We are certain that CCUS will become an indispensable part of critical care practice.

Ultimately, assessment and management of the critically unwell patient must remain holistic, with CCUS providing an additional dimension to diagnosis and monitoring. An excellent intensivist will be able to integrate the appropriate ultrasound techniques into the examination and interpret the images in the clinical context to provide the best care for the patient. ■

Key Points

- Critical Care Ultrasound (CCUS) is a valuable tool for diagnosis, monitoring and guidance of practical procedures in critically ill patients, and its applications continue to evolve.
- Two aspects are likely to have the greatest impact in CCUS: the machine and the modalities.
- A handheld ultrasound device can be readily taken to the wards or indeed anywhere in the hospital by the intensivist, aligning it neatly to the concept of ICU without walls.
- Through wireless capabilities, ultrasound machines, including handheld devices, are able to instantaneously upload ultrasound studies to the Cloud with unlimited storage capacity, enabling swift sharing of images and more convenient access to expert opinion.
- The potential of the ultrasound machine to replace the stethoscope has already been debated in educational and clinical circles.

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For full references, please email editorial@icu-management.org or visit https://iii.hm/105o

Future ICU Design: Return to High Visibility

Future ICU designs must feature high visibility to ensure safety.

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The ability for critical care nurses, physician intensivists, and other caregivers to visualise their patients has always been a high priority as it plays a major role in patient and staff safety. Architects and designers have responded with configurations for intensive care units (ICUs) to support the ability for staff to see their patients and each other. The focus on patient and family centred care and the shift from paper charting to electronic medical records enabled the overall design of an ICU to change from a centralised nursing station design to decentralised stations closer to the patient. A nurse, architect, and researcher offer their insights into how visibility will be considered in future designs for critical care units.

A Brief History of ICU Visibility

With a few notable early exceptions, wartime open bay recovery rooms in which multiple serious cases could be simultaneously observed and treated by limited numbers of clinicians were the model for ICUs springing up after WWII. The transition from recovery-like open wards to open bay suites, then multi-bed rooms occurred in the decades of 1950s through the 1980s (Kisacky 2017). Ultimately, North American ICUs and many others around the world have today largely transitioned to private rooms with glass walls and doors (Hamilton and Shepley 2010).

The history of ICU design has been powerfully influenced by the importance of the ability for nurses and other staff members to see the patients and their colleagues. Seeing the patients allows for rapid response to changing situations and seeing each other allows for staff to rush to help colleagues faced with a crisis. Also contributing to the need for greater visibility and coverage is the growing number of ICU patients and the declining number of highly skilled physicians and nurses

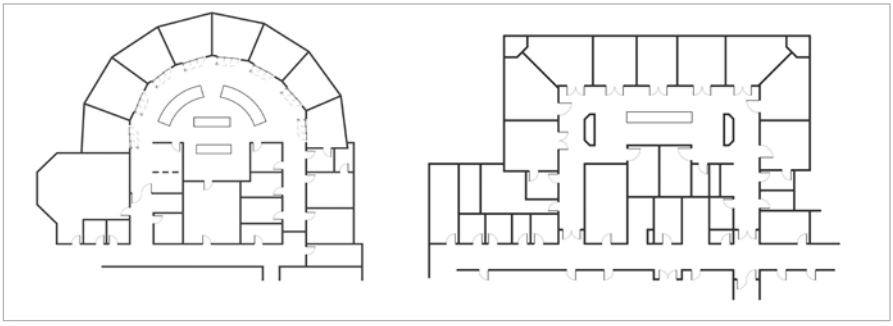

Figure 1: Typical high visibility unit configurations. Illustrations credit: Behzad Yaghmaei

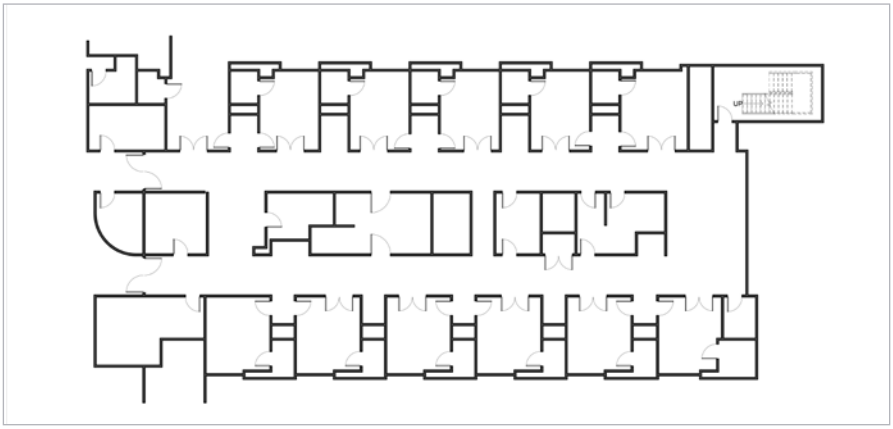

Figure 2: Linear, rectangular unit configuration. Illustrations credit: Behzad Yaghmaei

that care for them. ICU configurations have therefore usually been concentric, or shapes that promoted high visibility **(Figure 1)**. Recent rectangular designs that fit in the footprint of acute care patient towers have begun to offer less visibility of patients and staff members as result of reliance on decentralised nursing positions (Hamilton 2017b). Nurses have expressed concern about isolation from colleagues and backup in linear designs **(Figure 2)**.

Visibility of Patients

Critical care nurses are responsible for routine assessments (minutes to hourly) depending on the acuity of the patient. Frequent documentation of vital signs and physiologic parameters allow for projection of trends and anticipation of interventions. Additionally, telemedicine technology and "machine learning" or artificial intelligence algorithms can support nurses work and predict trends or changes in patient status. Despite technological advances, nurses are expected to demonstrate awareness of the clinical situation (Abbey et al. 2012; Chulay et al. 2010) and interpret based on patient clinical presentation (Kwon et al. 2019). Situation awareness (Endsley and Jones 2012; Sitterding et al. 2012) allows anticipation of the lessening or improving of the patient's condition, and permits timely interventions. To maintain this awareness, patients must be easily visible to the nurses and other clinical staff.

The proximity of charting to caregiving influences the accuracy and completeness of the documentation. This suggests that decentralised charting, close to the bedside, is a desirable configuration for critical care units in which information can be recorded sooner than in centralised designs (Bayramzadeh and Alkazemi 2014; Fay et al. 2018).

Accessibility, like visibility, is important to the caregivers. The most common life support configuration is the headwall design in which the bed is arranged like a peninsula with the head of the bed against the wall and served by adjacent wall-mounted utilities, not unlike traditional acute care patient rooms. In a code or crisis situation, the bed must be pulled away from the wall and someone must step over the various cords, tubes, and umbilicals in order to access and protect the patient's airway. Life support configurations that don't require repositioning the bed or patient in the event of a crisis, such as overhead booms that allow complete 360° access to the patient, are desirable (Pati et al. 2008). The relationship to patient visibility in the case of booms and columns must be considered in design.

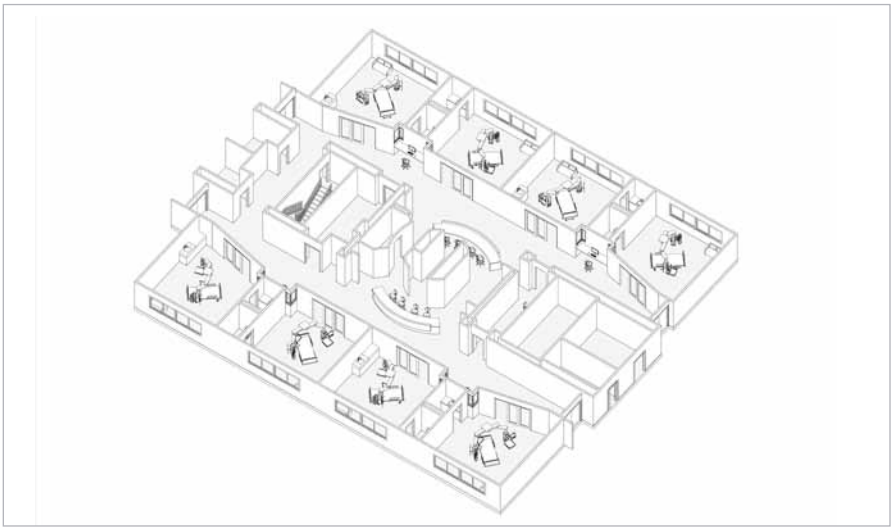

Figure 3: Concentric unit within bed tower footprint. Illustrations credit: Behzad Yaghmaei

A retrospective analysis of APACHE II data, mortality, visibility of the patient and patient outcomes revealed that the staff nurses' specific field of view to the patient from a central or decentralised station independently impacted patient outcome (Lu et al. 2014). It is important for staff to be able to visualise the patients and to be able to promptly recognise a change in patient condition. During an emergency or code situation, multiple staff members swarm into the room to provide assistance.

Visibility of Staff

The authors believe the greatest current threat to effective ICU design is the mistaken assumption that decentralised charting allows the unit to be configured like an acute patient unit with a linear, non-concentric organisation. Criticism of straight corridor designs is beginning to appear (Hamilton 2017b; Hamilton et al. 2018).

Decreased visibility impacts communication, teamwork, mentorship and collaboration among all members of the healthcare team. Staff, especially nurses, need to be able to see and communicate with their colleagues. They may need support or backup, as in the case of a code situation. Nurses may be able to observe the patients of others and to intervene when the responsible nurse is away seeking medications, supplies, or equipment (Wheelan et al. 2003).

One staff development and learning function of the unit is to provide mentorship opportunities in which experienced nurses provide support for less experienced nurses and other staff members. To do so requires the ability to see each other and speak to one another.

The ICU of the future needs to return to the high visibility configurations of the past: small units in concentric shapes that allow staff to see all the patients and each other. There are potential configurations that achieve the visibility goal while fitting into the footprint and structural grid of an acute bed tower **(Figure 3)**.

Visibility of Resources

An ideal design for critical care provides the nurse with directly visible resources to support caregiving, and minimal travel distances to medications and frequently needed supplies or equipment. Some contemporary designs feature supply carts in the patient room (Hamilton 2017a) where a position opposite the foot of the bed offers equal distances to both sides of the bed.

Design Recommendations for Future ICUs

For reasons of safety, the ICU of the future needs to provide high visibility for staff to easily observe patients and other staff members. Documentation, medications, frequently needed supplies and equipment should be located in proximity to the bedside, and decentralised or duplicated as necessary to reduce unnecessary travel.

Decentralised charting: The ICU of the future should feature decentralised charting positions allowing critical care nurses to be as close as possible to their patients. Charting in proximity to the patients will include fixed and mobile computers in the patient room, and just outside. At the same time, centralised functions should occur in a team work station supportive of clinical collaboration and full observation of the unit. Designs of the future should not mix the positives of decentralised charting and the negatives of poor visibility.

Central functions: There should still be a centrally located team station to serve the numerous staff members who are not resident in the unit. It also serves as a place for a unit clerk, telephones, and the charge nurse, along with pneumatic tubes, printers, and shared functions. Other common functions serving the entire unit include staff restrooms, locker rooms, staff lounges, and in some cases, on-call rooms. Satellite labs and point-of-care testing should be within, or convenient to, the unit.

Electronic consultation: While variations of providing ICU expertise via electronic means have been effective for multiple large system providers, the direct caregiving and medication administration is always local. Similarly, even when the expertise and consultation may have originated elsewhere, the documentation benefits from proximity to the bedside.

Pod and cluster configurations: In order to maximise visibility of patients and staff, the ICUs of the future should be designed in configurations of 8-12 bed pods with multiple pods assembled for units requiring larger numbers of beds. These pods should be designed to provide clear ability for nurses and other staff to see their patients and each other.

Life support configuration: The ICU of the future should feature systems other than the headwall configuration, such as overhead boom or bridge systems that allow full access to the patient, including the head. The future deserves a better solution than the headwall configuration.

Resource proximity to the bedside: The ideal location for needed medications and supplies is, of course, the patient room. The recommendation for future designs is to decentralise medication and supply functions as close as reasonably possible to the patient bedsides.

Conclusion

The ICU of the future will need to provide high visibility for critical care nurses, physicians, and other staff members. While the future will produce advances in technology and treatment, the requirement for someone to see the patient will not change. Electronic surveillance (Zhou et al. 2014), although desirable, will be no substitute for person-to-person, face-to-face observation and communication. Future ICUs should be organised in pods or clusters of smaller numbers of beds to permit the needed high levels of staff-patient and staff-staff visibility. These new units will need to have a mix of decentralised and centralised positions serving as workstations for the staff and will need to be organised to reduce travel distances as team members seek resources to serve their patients. ■

Key Points

- High levels of staff-patient and staff-staff visibility contribute to safety.
- Charting and staff positions should be both decentralised and centralised.
- Intensive care units should be configured in pods of smaller numbers of beds,
- Medications, supplies, and equipment should be proximate to the patient beds.
- Life support systems should offer complete access to the patient.

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A Framework for Addressing Seasonal Influenza: A Critical Care Perspective

Seasonal influenza remains a significant health burden and places tremendous and predictable strain on personnel and resources within a health system, specifically within critical care. Despite this, many institutions do not have a comprehensive influenza management plan. Effective and comprehensive critical care management of influenza requires centralised oversight and coordination, a robust electronic health record system, and a set of system-based practices, including infrastructures and protocols, which will match the burden of influenza with available resources. Standardisation of diagnostic and therapeutic practice habits are required to support adequate collection and dissemination of data, which can inform the nature and adequacy of any proposed system-based practices. A framework for the comprehensive management of influenza is presented.

Introduction

Seasonal influenza can range from mild to severe disease, the latter of which has been described as disease requiring hospital or intensive care unit (ICU) admission (Amini et al. 2017; Ku et al. 2017; Fitzner et al. 2018). Influenza infection remains a significant global health burden, with the number of deaths estimated to be 300,000-600,000 per year, and the number of hospitalisations estimated at 3-5 million (Iuliano 2018). In the U.S., the 2017-2018 season saw the highest rate of illness (48.8 million influenza diagnoses, 22.7 million people seeking care, 959,000 hospitalisations, and 79,400 deaths) since the 2009 H1N1 pandemic, which estimated 60 million illnesses (Shrestha 2010). Though the percentage of patients diagnosed with influenza needing ICU admission remains small (approximately 20% of hospitalised patients), there is still a sizeable impact on intensive care resources at many hospitals (Rodrigo et al. 2016; Hart 2018).

Despite this burden, rarely is influenza managed in a cohesive way within a health system, and levels of preparedness for outbreaks are poor (Gomersall et al. 2007). This is particularly frustrating given that influenza exerts a predictable seasonal strain on healthcare personnel and resources for four to six months out of the year. Moreover, the severity of any one influenza season is, at least in part, somewhat anticipated based on the seasonal effects felt in the opposite hemisphere (de Mello et al. 2009). As a contagion, influenza falls under the rubric of specialists in infectious disease. However, rarely is this specialty consulted in the management of hospitalised influenza patients. Severe influenza associated with organ failure certainly requires critical care, but milder cases are usually managed by the emergency department, internal medicine (in the inpatient or outpatient setting), or at home by the patient. In short, no one specialty "owns" influenza, making recognition, diagnosis, coordination of care, and tracking (all of which are essential for a readiness plan) difficult. Tracking and reporting of seasonal influenza in the U.S. is estimated by the Centers for Disease Control and Prevention (CDC) and globally by the World Health Organization (WHO) (cdc.gov; who.int). Rarely, however, are local influenza patterns disseminated in a meaningful way down to the level of the ICU. At the level of the health system, tracking may be fragmented by location of patient interaction (the emergency department, the hospital ward, the intensive care unit) and patient disposition (admitted versus not admitted). Further complicating this, many health systems use multiple diagnostic modalities with duplicative efforts, and treatment algorithms also tend to be

inconsistent, particularly because antiviral therapy is only moderately helpful (Dobson et al. 2015).

The current standard of care, from a critical care perspective, includes vaccination, respiratory isolation pending diagnosis, initiation of antiviral treatment, support for specific organ failure, and then discharge from the ICU once symptoms have abated (Wieruszewski and Linn 2018; Uyeki et al. 2018; Cowling et al. 2009; Napolitano et al. 2014). Adjunctive therapies include corticosteroids, antimicrobials, and intravenous immunoglobulin (IVIg), though data is lacking as to effectiveness of these specific remedies (Rodrigo et al. 2016; Chong et al. 2011; Lee et al. 2017). Where current standards are deficient, however, is in the establishment of a comprehensive approach in the management of influenza, including standardised diagnostics and treatment algorithms, succinct tracking and reporting of the disease, and system-based efforts aimed at matching scarce resources with greatest needs. While all of these elements of a comprehensive approach transcend the specialty of critical care, there are some critical care-specific aspects that bear exploration, specifically with regard to oversight, data management and system-based practices.

A Framework

Effective, comprehensive critical care management of influenza is reliant on the precondition of centralised oversight and coordination of critical care efforts amongst the many different ICUs throughout a health system. While a formal critical care organisation can fulfil this role, any entity that allows for centralised management, efficient dissemination of information, and standardised workflow is suitable, and can be as simple as an ad-hoc influenza committee (Moore et al. 2018). Upon this platform, a robust electronic health record (EHR) system must be deployed in order to streamline diagnostics, treatment, data collection and analysis. Finally, built upon all of these essential elements are a set of system-based practices, including infrastructures and protocols that are put in place to match the burden of influenza with available resources and a robust reporting system. A proposed framework is presented as **Figure 1**.

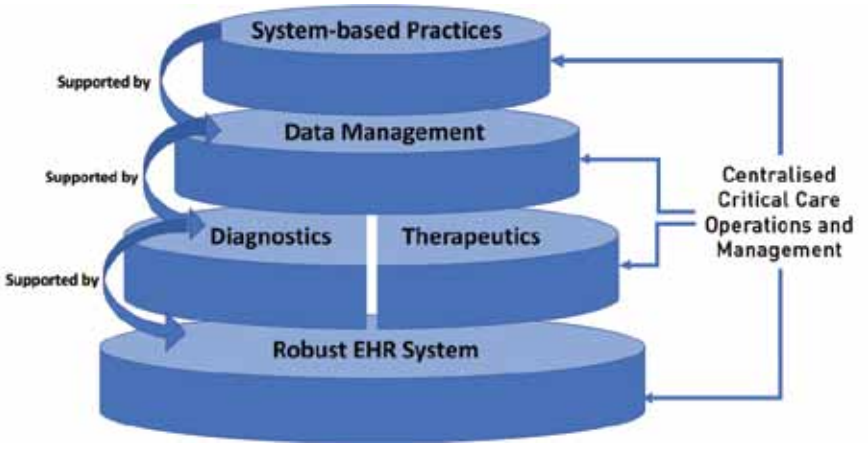

Figure 1. A proposed framework for comprehensive management of influenza. In the proposed framework, system-based practices are implemented based on accurate data collection and analysis, which is more feasible with consistent diagnostic and therapeutic practices. A robust EHR can facilitate the standardisation of both diagnostics and therapy. All aspects are effectively managed via a centralised critical care operations effort.

Diagnostics

Uncoordinated or inappropriate diagnostic efforts can lead to excess costs to the system and potential harm to the patient in the form of inappropriate treatment or expense. Uninformative tests, such as the enzyme-linked immunosorbent assay (ELISA), are no longer recommended according to the most recent Infectious Disease Society of America (IDSA) guidelines, but still widely used (Uyeki et al. 2018). Moreover, multiple platforms and modalities, as are common in many large health systems, can lead to excessive or duplicate tests. In an analysis of influenza (2017 season) patients from one hospital within the authors' health system, of those that received a respiratory viral panel (RVP) polymerase chain reaction (PCR) test for the diagnosis of influenza, 43% were tested by an ELISA rapid influenza test that preceded it (unpublished data). Current guidelines recommend PCR as the diagnostic modality of choice (Uyeki et al. 2018).

A standardised approach at the system level, using one universally accepted diagnostic algorithm, is essential for the elimination of waste and to assist in data tracking. This practice should be supported by the availability of ancillary tests (e.g. respiratory viral culture or expanded PCR and procalcitonin) and a robust, centrally coordinated education and outreach effort. Diagnostic options and their associated costs should be evaluated at the system level in order to identify the most informative test(s) at the lowest cost. For example, the procalcitonin test may be included in the influenza diagnostic algorithm to assist in delineating viral from bacterial infection (Muller et al. 2007). Finally, standardisation throughout the EHR, including elimination of misleading or duplicative testing options, is integral to success.

Treatment

While treatment of influenza is largely supportive, the use of antiviral therapy has been shown to reduce severity and duration of illness in patients infected with the virus (Dobson et al. 2015). According to current IDSA guidelines, antiviral therapy is recommended for any patient with

influenza severe enough to be hospitalised, has severe, complicated, or progressive illness; or is at higher risk for influenza complications (Uyeki et al. 2018). Risk factors for complicated or severe disease are indicated in **Table 1**. Antiviral treatment with neuraminidase inhibitor therapy is recommended as early as possible for any patient with confirmed or suspected influenza. Despite this, antiviral therapy is not universally used for seasonal influenza outbreaks (Kramer and Bansal 2015).

Table 1: Risk Factors for Influenza Complications.

- Children younger than 2 years
- Adults 65 years and older
- Chronic pulmonary (including asthma), cardiovascular (except hypertension alone), renal, hepatic, haematological (including sickle cell disease), and metabolic disorders (including diabetes mellitus), or neurologic and neurodevelopment conditions
- Immunosuppression, whether caused by medications or by HIV
- Women who are pregnant or postpartum (within 2 weeks after delivery)
- Younger than 19 years who are receiving long-term aspirin therapy
- American Indians/Alaska Natives
- Extremely obese (BMI >40)
- Residents of nursing homes and other chronic care facilities

Source: Adopted from the Centers for Disease Control and Prevention (CDC).

Any comprehensive influenza management programme should include the elucidation of a standardised treatment algorithm backed by a robust, centrally coordinated education and outreach effort. This algorithm should include any different options for antiviral therapy. A typical default treatment option may include oseltamivir, which has been shown to be effective against both influenza A and B, and comes in an oral as well as elixir form, and alternative treatment options, with associated restrictions, may include peramivir, which is intravenous and can be used in patients with at-risk airways, requiring non-invasive positive pressure ventilation, or without enteral access. As with diagnostic efforts, standardisation throughout the HER (including elimination of duplicative or misleading treatment options) is integral to success.

Data collection

A cohesive data collection and reporting system is essential for successful understanding of the impact of influenza on a health system. Inadequate efforts can lead to financial, time and resource inefficiencies (Chen et al. 2015). As a precondition to data integrity, a standardised diagnostic algorithm is crucial for the capture of all relevant encounters, especially when different workflow processes cause difficulty in comparing data from one site within a health system to another (Blijleven et al. 2017). Data collection and dissemination should be part of a centralised effort, which includes interaction with local and system laboratory personnel, recognition of diagnostic pathways (including the possibility of secondary or duplicative testing), and the leveraging of a robust EHR in order to track patient disposition. At a minimum, efforts should include a data warehouse query of any encounters where influenza is considered, compiled at the aggregate level, and a periodic reporting of positive/negative flu cases throughout the system. An example is included as **Figure 2**. A more insightful effort may include creation of an influenza dashboard, which would show, in real time, the locations and status of the patients currently being treated for influenza interposed upon local and national influenza data.

The accurate collection of patient encounter data may provide the backbone for future efforts in the development of predictive algorithms. Efforts at the predictive modeling of influenza have shown recent promise but have not been robustly studied at the health system level (Morris et al. 2018). However, with enhanced and improved data collection, this may be possible in the not too distant future. One of the major obstacles in dealing with seasonal influenza is the ability to predict the onset and severity of the season as well as the need for ICU resources (Hick et al. 2010). A better ability to forecast may lead to improved planning for diversion and bed management (Zhang et al. 2006). At the critical care level, where resources are especially scarce and costly, such predictive efforts would be extremely valuable.

System-based practices

System-based practices focus on the broader context of patient care within the multiple layers of a healthcare system (acgme.org). Such efforts should lead to improved patient outcomes while simultaneously minimising waste, and inefficiency. Standard of care influenza related system-based practices include prevention strategies via vaccination, visitation restrictions, and isolation precautions. Additional efforts include patient or employee cohorting as well as creative staffing options in the event of employee illness.

Cohorting may provide an additional level of system-based infection prevention, but this practice remains controversial. The practice involves co-location of patients with a known common pathogen, thus minimising spread of infection by virtue of geographic separation. Evidence for cohorting is relatively limited to a few studies, a couple of which include influenza (Pelat et al. 2016; Islam et al. 2013; Youngs et al. 2019; Ong et al. 2001). While patient monitoring may be easier and there may be economies of scale in the supply chain for isolation equipment, patient movement and relocation may cause a transient loss of bed space and may be disruptive to both patients and care providers. Employee

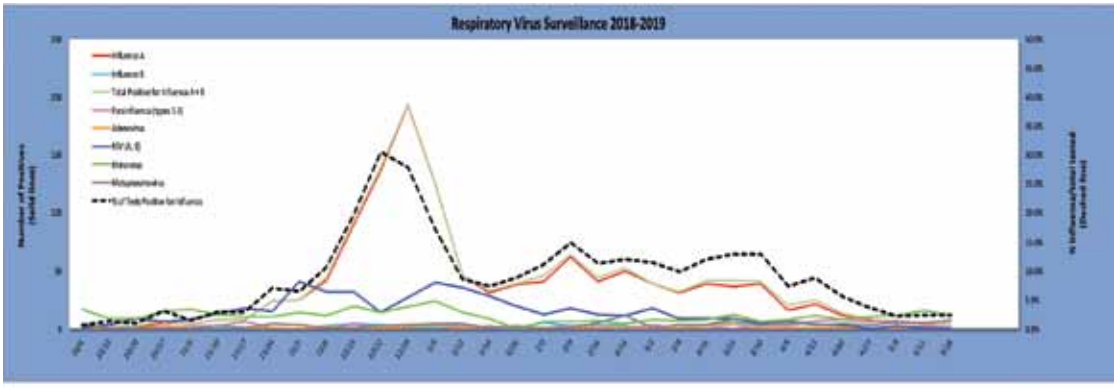

Figure 2. An example of a data warehouse report regarding respiratory viral infection at one large U.S. health system. Such reports can be updated and disseminated on a weekly basis, such as this one. A more advanced report may consist of delineation of patient disposition (admitted versus discharged from the ED) as well as inpatient location (ICU versus medical ward).

cohorting, or the delineation of defined health care workers assigned to care for influenza patients, may minimise the risk of excessive employee call-outs due to illness (Palmore and Henderson 2013).

Staffing remains the single most vulnerable resource in general in critical care, and risks are amplified in the event of a surge in illness during seasonal influenza (Holdorf and Lilly 2015). Notably, a critical care bed shortage can be a significant obstacle during influenza season, but is a static limitation, not subject to change from season to season. In fact, critical care capacity strain is often obviated in the context of staffing shortages (Bagshaw et al. 2017). Staffing crises during influenza outbreaks are well described (Fowler et al. 2003). Centrally directed and managed creative staffing options may provide a buffer in the event of employee illness and borrows from disaster preparedness models (Daugherty et al. 2007). These considerations include the deployment of flexible or shared coverage plans, the utilisation of advanced practice providers (APPs) and attending physicians across neighbouring units within a hospital, and the assistance and support of a robust electronic ICU (eICU). The standardisation of the critical care work week across a health system may help to alleviate the difficulty in coordinating emergency coverage amongst intensivists from different ICUs with variable start days and duration of service.

Conclusion: A Comprehensive Approach

Successful preparation for the eventuality of an influenza outbreak is contingent upon proper protocols and infrastructure, such that patient and staff safety are ensured and that there is benefit to the patient (Gomersall et al. 2007). Standardisation of processes, including diagnostic and treatment protocols, are essential for the adequate collection of data regarding influenza. Succinct and meaningful acquisition and dissemination of data (including predictive efforts) allow for the comprehensive understanding of the impact of influenza on a system in general, and a critical care department in particular. Such an understanding will allow for efficient and cost-effective utilisation of resources. ■

Key Points

- Influenza remains a significant global health burden, with the number of deaths estimated to be 300,000-600,000 per year, and the number of hospitalisations estimated at 3-5 million.
- Though the percentage of patients diagnosed with influenza needing ICU admission remains small, there is still a sizeable impact on intensive care resources at many hospitals.
- Rarely is influenza managed in a cohesive way within a health system, and levels of preparedness for outbreaks are poor.
- Uncoordinated or inappropriate diagnostic efforts can lead to excess costs to the system and potential harm to the patient in the form of inappropriate treatment or expense.
- A standardised approach at the system level, using one universally accepted diagnostic algorithm, is essential for the elimination of waste and to assist in data tracking.
- The accurate collection of patient encounter data may provide the backbone for future efforts in the development of predictive algorithms.

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Will Artificial Intelligence Change ICU Practice?

An AI-enabled ICU is coming in the not-too-distant future, but it requires strong partnerships between clinicians and engineers.

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Spoiler alert. The short answer to this question is **yes**!

Artificial Intelligence (AI) is not new. The Dartmouth Summer Research Project on Artificial Intelligence (DSRPAI) took place in 1956 (Moor 2006). In Europe, the "Conference on Artificial Intelligence in Medicine" has been taking place biannually for the past 28 years (Patel et al. 2009).

What is new, however, is the cross-industry exponential growth in awareness of, and interest in, AI over the past decade. In addition to the stimulus provided by our ability to generate, gather, organise, store and access enormous amounts of digital data, the growth of AI in medicine has been facilitated by three major developments:

1. The proliferation of electronic medical records (EMRs) is the most obvious manifestation of the use of AI in medicine. Although EMR adoption is visible, by far the largest growth in the healthcare field is occurring in the realm of digital imaging and genomic sequencing. The wealth of data available has driven a need for innovation in the analytics space, while simultaneously fueling AI development which is highly dependent on the availability of large quantities of training data to produce reliable algorithms.
2. Advanced analytic methods demand significant computational resources. Increasing standalone computer power combined with the availability of state of the art cloud computing services from providers such as Google and Amazon puts the necessary computational resources to get started in AI within reach of anyone who is interested. The impact of this has been felt most obviously in the consumer space but in medicine, this resource is increasingly being applied to the enrichment and analysis of the glut of medical data flowing from #1.
3. Data transmission methods using mobile technologies such as 5G, smartphones and consumer wearables are advancing rapidly. These technologies enable in situ data capture/analytics, data sharing, knowledge delivery, synchronous and asynchronous communication and extended reality interactions with profound implications for traditional healthcare delivery models.

However, because of patient privacy issues, healthcare presents significant barriers to entry for those outside the health system firewall. Those driving innovation in the three areas outlined above have mostly remained outside of healthcare. Because of the firewall, AI development has started as a cottage industry run largely under the direct or close supervision of the healthcare stakeholders that collect and store the data. Efforts through this approach have, to date, produced little in the way of meaningful impact on patient outcomes. For example, despite an explosion of AI-related academic output, a recently published systematic review shows "no performance benefit of machine learning over logistic regression

for clinical prediction models" (Christodoulou et al. 2019).

Things are about to change. At this time we are witnessing the beginning of a revolution in healthcare AI. The rise of interest in healthcare from non-traditional stakeholders is palpable. Silicon Valley big technology companies (Google, Apple), hardware manufacturers (Philips, GE, Siemens), integration/consulting firms (Deloitte, Lockheed Martin, Leidos), employers (Amazon, Walmart), venture capital executives, and a myriad of experts in the financial and intelligence communities looking for new business opportunities are determined to enter the field and will drive innovation in the areas of advanced data analytic techniques and AI development. The evidence that the interaction between Big Tech and healthcare is happening now is all around us. At the beginning of 2019, it was reported that nearly 80% of healthcare executives said their organisations are exploring and investing in big data analytics and AI (newvantage.com/wp-content/uploads/2018/12/Big-Data-Executive-Survey-2019-Findings-122718.pdf).

Despite the investment, there are important reasons why we should continue to be cautious about the claims made for AI in healthcare in general, and the ICU in particular.

1. **Garbage in-garbage out:** Data used for training AI do not provide a perfect representation of the patient and rarely contain mechanistic insights into disease or health. Data are generated as a side effect of caring for patients or for payers' purposes. Diagnostic tests such as laboratory analyses for example, are ordered because of a clinical suspicion of some problem, to help the clinician resolve diagnostic uncertainty, or to monitor the impact of a treatment decision. In this situation, associations are easy to identify but causality is elusive and rarely "discoverable" within the data. This leads to a fundamental problem for this first generation of data scientists engaging in healthcare AI development – mechanistic understanding of critical illness takes time to acquire. AI models developed without mechanistic understanding embedded into them, will fail to breach the threshold of usefulness for a clinician.

> **artificial intelligence will play a significant role in the ICU of the future not as a standalone tool, but as part of a smart ambient environment**

2. **Inconsistent evaluation and validation and absence of clinical trials:** The first generation of AI algorithms mostly fall into the category of "developed and validated on MIMIC II" or some other flavour of publicly available data. The area under the receiver operator characteristic curve, true and false positive rates, sensitivity and specificity are often reported. Thus far, follow-on prospective evaluation and validation of the safety and performance of these AI algorithms in real world operating conditions are largely absent. Clinical trials have not taken place and regulation is dismissed as stifling of innovation. All other diagnostic tests, devices and therapeutic interventions follow a relatively standard evaluation and regulation pathway. For AI to be embraced, it will also have to demonstrate real world operational safety, reliability, and efficacy.
3. **Implementation of science and stakeholder engagement:** We work within complex adaptive systems that have evolved over generations to care for critically ill patients. What we have in place in the ICU now is a collection of people, processes and technology that largely serves our patient population well. Lack of stakeholder engagement and a limited understanding of the socio-technical environment into which AI will be implemented severely limit the impact and sustainability of AI. If we fail to engage the stakeholders in a discussion about the risks and benefits of these disruptive technologies, we could cause widespread unintended harm and leave our patients worse off than they are in the current system.
4. **Alert fatigue, information overload and burnout:** With data accessibility, multiple alerts, reminders or scoring systems may be easily produced and deployed rapidly. Instead of minimising cognitive burden, however, there is more demand on bedside providers to respond to this information. The jump from "no data" to "all data" places an additional burden on clinicians. The development of user-friendly interfaces and rigorous testing are required to minimise alert fatigue before deploying these tools to clinical practice.
5. **Privacy and trust:** There is a growing suspicion surrounding big tech companies and the monetisation of personal data. Leaks, narrowly focused CEOs, security breaches, misuse of data, a culture of over promise/under delivery (anyone remember Theranos?) undermine public trust, and make new partnerships between health care organisations and AI innovators challenging. Technology companies need to cede control to healthcare providers if the full potential of partnership is to be realised.

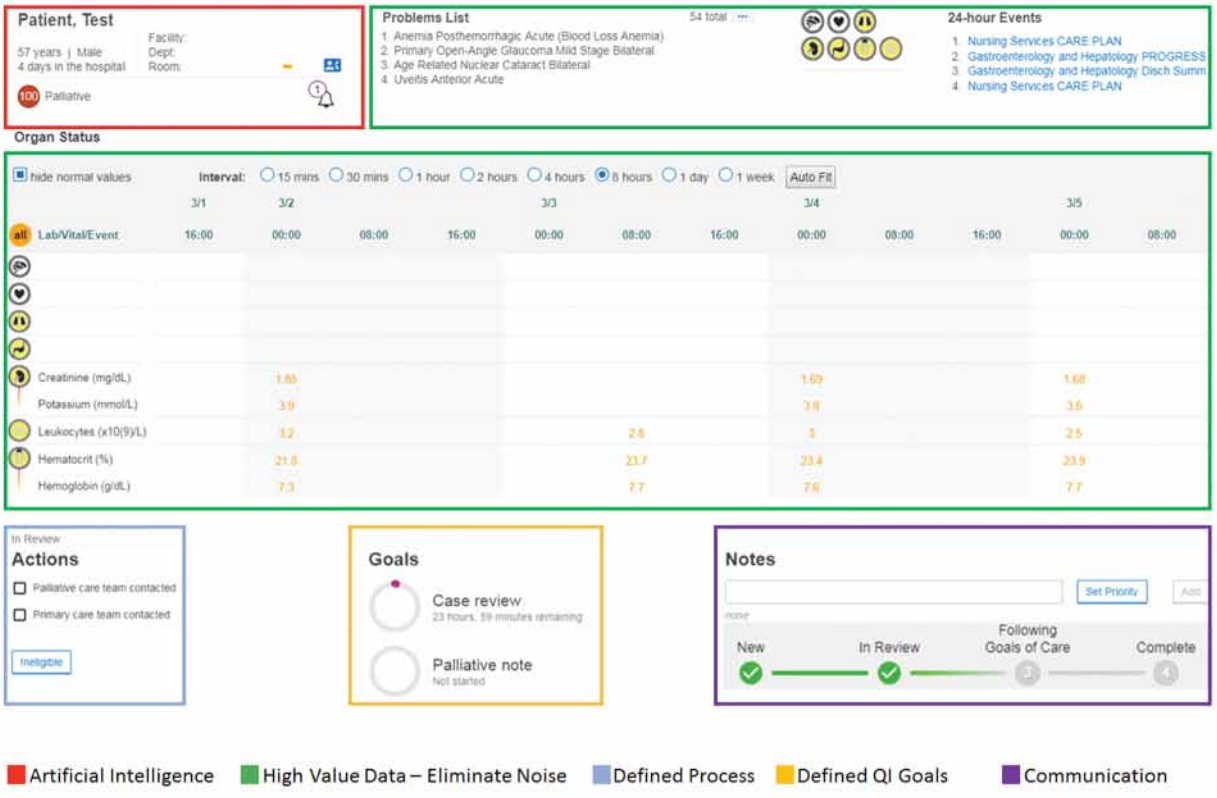

Figure 1: Control tower platform

In 2012 we published an article "The hospital of the future - building intelligent environments to facilitate safe and effective acute care delivery." This described an alignment of people, processes, technology and incentives to serve the interests of the patient (Pickering et al. 2012). We would like to revisit some of technologies in an attempt to demonstrate how we might harness the developments in AI for the benefit of patients and providers while avoiding some of the potential harms. Our prediction for the near future is that three AI-based ICU tools might be transformational:

Control Tower Platform

The modern EMR adds to information overload by overwhelming EMR "inboxes" and generating unnecessary alerts (nytimes.ccom/2019/11/01/health/epic-electronic-health-records.html). Clinical Control Tower is a newly-developed central alert-screening and implementation system developed at Mayo Clinic. The concept behind Clinical Control Tower is to serve as a centralised non-life-threatening alert and prediction "cockpit." This unified screening system is managed by a designated capsule communicator or "CapCom," analogous to the US National Aeronautics and Space Administration ground-based astronaut who maintains contact with astronauts during space missions. The CapCom in the healthcare context is the clinician responsible for screening incoming alerts and notifications. As no alerts have 100% accuracy it is essential to perform initial validation of notifications before activating specific workflows with bedside providers.

When the CapCom decides that an alert is valid, he or she communicates "down to the ground" to a bedside clinician and guides them through necessary and recommended tasks. Each step may be captured electronically in the control tower application. Workflow and actions are captured and analysed using a feedback loop tool. Deviations from intended care processes may be identified. Control Tower is a tool designed to minimise errors and information overload in hospital practice **(Figure 1)**.

Computer Vision

Platforms such as Control Tower will help deal with data management and representation, but will not change the fact that a significant portion of a clinician's time is spent on data entry to computers.

Computer vision is an area of AI development with a goal of enabling computers to gain high-level understanding from videos or digital images. Image reasoning and computer vision may be applied to healthcare environments to enhance diagnostic processes and optimise and automatise workflows. But computer vision alone will not be able solve challenging clinical

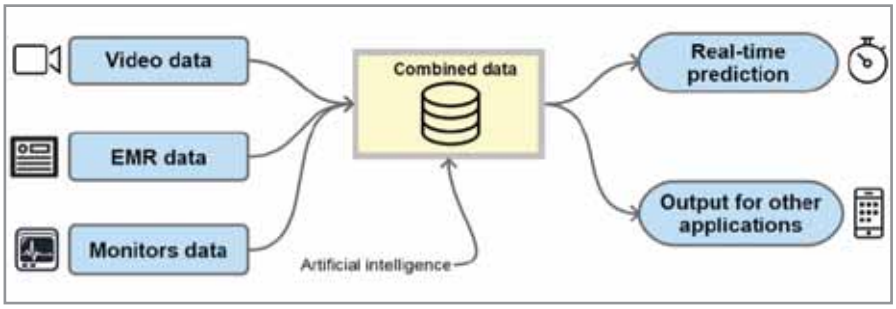

Figure 2: Computer vision

scenarios. For example, computer vision cannot distinguish anaesthetised patients from patients who are simply sleeping. Adding information from the environment (patient location, time of day) and EMR (medications given, orders) could augment camera data and elevate such systems to powerful clinical and workflow tools. The possibility for automatisation is truly enormous **(Figure 2)**.

Voice Recognition

The efficiency of human-computer interaction is greatly enhanced by high-performing voice recognition software. Chatbots and voice-activated computer interfaces (e.g. Alexa, Siri) are increasingly prevalent and increasingly reliable in everyday life. Such developments have not, as yet, been widely embraced in healthcare, but one can envision a future in which AI responds to physician or nurse voice command to change the rate of an infusion pump, order a medication or test, answer a clinical question or provide a diagnosis or prognosis.

Artificial intelligence will play a significant role in the ICU of the future not as a standalone tool, but as part of a smart ambient environment (Dybowski et al. 1996; Keegan et al. 2011; Fauw et al. 2018; Nemati et al. 2018; Parreco et al. 2018).

To be able to develop such tools, researchers require access to new widely available databases of clinical and non-clinical information. Connecting EMR data with clinically meaningful labels will help produce clinical tools that are based on causality. Augmenting EMR data with environmental and non-clinical data will enable researchers to build algorithms for public health and pre-hospital care.

An AI-enabled ICU is coming in the not-too-distant future, but it requires strong partnerships between clinicians and engineers. ■

Key Points

- The growth of AI in medicine has been facilitated by three major developments: electronic medical records, cloud computing services, and mobile technologies.
- Because of patient privacy issues, healthcare presents significant barriers to entry for those outside the health system firewall.
- We are witnessing the beginning of a revolution in healthcare AI: nearly 80% of healthcare executives said their organisations are exploring and investing in big data analytics and AI.
- For the near future, three AI-based ICU tools might be transformational: control tower platform, computer vision and voice recognition.

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Future Strategies in Sedation and Analgesia

From massive sedation in the past, through current patient-centred sedation protocols, the future may further improve sedation in the ICU.

Introduction

The concepts for an optimal sedation in the intensive care unit (ICU) should include:

- Definition of the optimal depth of sedation;
- The need for agents with on/off effects;
- The need for agents with dedicated effects on hypnosis, pain, and confusion;
- Continuous supervision and adequate monitoring.

In the ICU patients, sedation is used according to two different goals. For the patients with acute respiratory distress syndrome (ARDS) and/or intracranial hypertension, the goal is to obtain a perfect adaptation to ventilator; thus, a deep level of sedation is required, i.e. enough to obtain no response to external stimuli. To achieve such level of sedation, hypnotics and opioids are both required. Muscle relaxant agents can be added if muscle contractions do not allow efficient mechanical ventilation or intracranial pressure control.

In the other patients, the only goal of sedation, if required, is patient comfort. The patient should always be interactive, quiet and cooperative. Non-benzodiazepine hypnotics and non-opioid analgesics are the best choice, but no sedation remains the first option (Chanques et al. 2017).

Different scales are used to measure the depth of sedation. The Richmond Agitation-Sedation Scale (RASS) ranges from -5 (no response to voice or physical stimulation) to +4 (overtly combative or violent; immediate danger to staff). In patients requiring deep sedation, the RASS score is targeted at -4, while in those requiring comfort sedation, it is targeted around 0. Unfortunately, the monitoring of sedation level remains unsatisfactory in most ICUs (Leone et al. 2012; Payen et al. 2007).

Post-intensive care syndrome (PICS) depicts disorders including physical impairment, cognitive impairment and psychiatric impairment occurring in ICU survivors. There is an association between prolonged immobilisation and sedation and the development of PICS. Thus, we have moved from a utilitarian view of sedation to a global management of patients, aiming at reducing the burden of distress after ICU hospitalisation.

Current Practices

The ABCDEF bundle (Jackson et al. 2010; Pandharipande et al. 2010) recommends a daily check of the following items:

A: Assessment, prevention and management of pain.
B: Both spontaneous awakening trials and spontaneous breathing trials.
C: Choice of sedation and analgesia.
D: Delirium assessment, prevention and management.
E: Early mobility and exercise.
F: Family engagement and empowerment.

Sedation and analgesia are playing a key role at every step of this bundle. Most recent guidelines are mainly drawn from these six items (Devlin et al. 2018). Experts suggest using comfort sedation in place of deep sedation in the ICU mechanically ventilated patients only if indicated. Comfort sedation is associated with shorter time to extubation (Bugedo et al. 2013; Shehabi et al. 2013; Treggiari et al. 2009) and lower tracheostomy rates (Tanaka et al. 2014; Treggiari et al. 2009), as compared with deep sedation. Daily sedation interruption protocols and nurse-protocolised targeted sedation are both safe and make it possible

to reach a targeted level of sedation (Mehta et al. 2012; de Wit et al. 2008).

Regarding the choice of drugs, propofol and dexmedetomidine have interesting pharmacokinetic and pharmacodynamic profiles (Sahinovic et al. 2018; Weerink et al. 2017). Propofol use has been associated with shorter durations of sedation and mechanical ventilation, as compared with benzodiazepines (Mesnil et al. 2011; Zhou et al. 2014). The SEDCOM study (Safety and Efficacy of Dexmedetomidine COmpared with Midazolam), a robust randomised clinical trial (RCT), showed that dexmedetomidine reduced time to extubation and delirium rates (Riker et al. 2009). Moreover, associated harm with either propofol or dexmedetomidine was deemed to be minimal and not clinically significant. No significant differences were reported between propofol and dexmedetomidine. Nevertheless, propofol infusion syndrome limits the use of propofol as the main agent for sedation for longer than two days or at a dose above 4 mg/kg/h (Bray 1998).

In the ICU, up to 90% of patients receive opioids (Arroliga et al. 2005; Payen et al. 2007; Wøien et al. 2012) and these agents are associated with increased morbidity and mortality (Kamdar et al. 2017). The opioids crisis (Volkow and Collins 2017), although not discussed in the setting of ICU, should be kept in mind by intensivists. If required, opioids should be used at the lowest effective dose and the timing of administration should coincide with noxious stimuli. Acetaminophen, paracetamol, nefopam, ketamine and non-steroidal anti-inflammatory drugs (within the restrictions of use) can be used to decrease opioid needs in the ICU patients (Devlin et al. 2018). Multimodal analgesia should become a standard of care, since several alternatives to opioids have been studied and have been proven to be efficient in the ICU patient.

Future of Sedation

Target-controlled infusion

Intermittent boluses or continuous infusion are not optimal methods in the ICU setting. Indeed, intermittent boluses expose the patient to cycles of under-dosage and over-dosage and increase the load of work for the nursing staff. If continuous infusion is used, there is a delay to obtain the target; thereafter there is a risk of exceeding this target by a mechanism of drug accumulation.

"in the ICU, up to 90% of patients receive opioids and these agents are associated with increased morbidity and mortality"

The aim of target-controlled infusion (TCI) is to obtain the desired "target" concentration of an intravenous agent at the effector site (or in plasma), without delay. It also makes it possible to maintain the concentration at the target level by adapting the infusion rate to the predicted tissue or plasma concentration. TCI is based on predictive mathematical models, the computer calculating the amount of drug required to reach a desired target according to the patient features, including age, body mass index, and gender (Struys et al. 2016). TCI is widely used in the operating room due to the high precision of models, allowing an excellent quality of anaesthesia with fast onset and recovery. The principle of TCI is of particular interest in the ICU since the level of stimulation of an ICU patient changes over time. With TCI, concentration targets could be set in real-time, according to the stimulation provided to the patient.

Few studies have assessed TCI-delivered sedation in the ICU. In a small RCT, TCI was used to infuse sufentanil and ketamine, both of them combined with midazolam. The model was quite robust for sufentanil, but prediction was disappointing for ketamine and midazolam (Bourgoin et al. 2005). In an observational study, use of a TCI of propofol, which was used for sedation of neurosurgical patients, resulted in a bias of -34.7% and precision of 36% (Cortegiani et al. 2018). It seems that pharmacokinetic models are not suitable for the ICU patients. Indeed, admission to the ICU is associated with significant pharmacokinetic changes requiring to be considered in more complex models than those developed for the "standard" surgical patients. Those variables are, for example, creatinine clearance, liver function, distribution volume, concomitant medication, organ failure, SIRS, shock, etc.

Closed-loop systems

In a philosophy of time-sparing methods in ICU, strategies based on closed-loops systems are of particular interest. Indeed, light sedation requires frequent monitoring of sedation levels to maintain the patient in the optimal range of sedation. Those are time-consuming and prone to human error. A closed-loop system may facilitate this process, if clinically relevant variables have been targeted based on a robust monitoring, which should not be subject to artefacts.

In the ICU patient, the selection of the best variables is challenging since many of them are taken into account. For example, haemodynamic variables interplay with consciousness level since sedation will affect both systems. The challenge to use closed-loop control technology for the sedation of ICU patients is to identify the best variables to control several systems simultaneously. The most commonly used target for sedation control is the bispectral index. Bispectral index monitoring, albeit a low level of evidence, seems to reduce the amount of sedative drugs. However, artefacts are possible; ketamine, for instance, increases the bispectral index level due to its excitatory effects on the EEG (Johansen 2006). Ideal monitoring control should include, for instance consciousness, respi-

ratory rate and blood pressure or cardiac index (Haddad and Bailey 2009).

A closed-loop system requires a reliable algorithm that insures to obtain the desired target value. The algorithms are therefore complex and use modern mathematical and statistical processes. We can cite for example the dynamic learning strategy or fuzzy logic system (Le Guen et al. 2016), Bayesian networks and probability theory to extend deterministic rule-based expert systems (Gholami et al. 2012), or deep machine learning. The later one has been used to assess sedation levels and ICU delirium (Sun et al. 2019).

Today, to advance in this field, more data are needed for the elaboration of ICU-dedicated pharmacokinetic models, as well as the selection of best target values and the development of adaptive algorithms.

Regional analgesia

In the operating room, the development of regional analgesia was associated with improved outcomes in moderate to high-risk surgeries (Guay et al. 2014). One should note that poor pain control can be responsible for confusion and agitation. Regional analgesia is probably the best strategy for pain control, and depending on the way to administer it, the haemodynamic effects can be quite limited. The development of regional analgesia should be under the responsibility of an anaesthesiologist, experts in this field. This highlights the interplay between the practice in operating room and ICU (Tankel et al. 2019). Thus, regional anaesthesia should also be used when feasible. A recent multicenter retrospective cohort study showed a diminution of mortality in acute pancreatitis patients admitted to ICU receiving epidural analgesia (Jabaudon et al. 2018), without significant harm (Jabaudon et al. 2015). Regional analgesia makes it possible to introduce early rehabilitation in the ICU patients by reducing the level of pain and the use of opioids.

Conclusion

In the past, ICU patients received massive sedation for long period of time. We already are in an era of drug-sparing methods to improve short and long-term outcomes of our patients. Guidelines recommend the use of short-acting agents and a daily assessment of the opportunity to decrease or stop sedation. Opioids are also to be spared with the use of multimodal and regional analgesia. The first option should always be to avoid sedation. With the development of powerful computing capabilities, the future will bring ICU-specific target-controlled infusions within adaptive closed-loop systems, to keep improving ICU outcomes.

Conflicts of interests

Marc Leone declares fees from MSD, Pfizer, Orion, Octapharma, Aspen, Aguettant, Amomed. Bruno Pastene has no conflicts of interests to declare. ■

Key Points

- In the ICU patients, sedation is used according to two different goals - deep sedation in patients with ARDS and/or intracranial hypertension; and comfort sedation in other patients.
- There is an association between prolonged immobilisation and sedation and the development of post-intensive care syndrome.
- Experts suggest using comfort sedation in place of deep sedation in the ICU mechanically ventilated patients only if indicated.
- Opioids should be used at the lowest effective dose and the timing of administration should coincide with noxious stimuli.
- Regional analgesia makes it possible to introduce early rehabilitation in the ICU patients by reducing the level of pain and the use of opioids.
- Guidelines recommend the use of short-acting agents and a daily assessment of the opportunity to decrease or stop sedation.

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Critical Care Telemedicine: A Management Fad or the Future of ICU Practice?

Critical care telemedicine is likely to be a key feature of the future ICU, but its success will hinge on the development of a sophisticated and robust implementation roadmap.

Introduction

The future ICU will shape the future of the modern hospital, and the future of healthcare in the wider sense. This responsibility cannot be taken lightly. In this paper, we draw from our experience in London and the international literature to discuss how critical care telemedicine is not only a likely feature of the future ICU, but an inescapable reality. We caution, however, that the success of critical care telemedicine, as of much of ICU innovation, will ultimately hinge on the development of a sophisticated and robust implementation roadmap.

Background

As Vincent et al. (2017) eloquently described, the future of ICU is full of potential. Technological advances in health informatics in particular will shape the size, space, number of personnel and the type of treatments available in the future ICU. Telemedicine, alongside artificial intelligence and management of big data could lead to more personalised treatment for better patient outcomes (Seymour et al. 2017).

It is now widely accepted that the burden of critical illness is growing rapidly and it is likely to be greater than currently appreciated. Critical care telemedicine has a special part to play in enabling access to scarce critical care expertise and reducing variability in treatment and care through clinical decision support enabled by the analysis of large data sets and use of predictive tools (Lovejoy et al. 2019). Technology and clinical informatics are evolving rapidly, and machine intelligence is here to stay; however, challenges with regard to how new technologies and devices are applied, overseen and monitored must be carefully considered (Vincent and Creteur 2017).

Critical Care Telemedicine

Medical advances and demographic shifts have contributed to an older and more complex ICU population, placing pressure on critical care services worldwide. In combination with a limited supply of critical care expertise, this situation leaves many small and rural hospitals feeling stretched and unable to cope with demand (Xyrichis et al. 2017).

Telemedicine has long been thought of as one way with which to overcome the lack of critical care resources, while at the same time improve access to critical care expertise, contain variance in clinical outcomes and foster a safety culture within and across ICUs (Mackintosh et al. 2016). We use telemedicine to refer to "a system to facilitate the remote delivery of critical care services using interactive audio, video, and electronic links" (Kahn et al. 2011). Applications of critical care telemedicine range from continuous e-surveillance by a remote team of experts to bedside support of patients with specific clinical conditions through interaction with bedside providers.

Evidence of Effectiveness

Adoption of critical care telemedicine has been associated with lower ICU and hospital mortality, and with reduced length of stay (Wilcox et al. 2012; Lilly et al. 2013), although this is based on suggestive rather than definitive evidence. For example, in instances where telemedicine interventions allowed for an increase in timely involvement of intensivists, there was higher utilisation of ICU best practices and lower rates of complications (Lilly et al. 2011). However, methodological limitations of available research, in combination with challenges in evaluating its clinical and economic impact, limit our ability to support the efficacy of telemedicine with high confidence. This cautiousness notwithstanding, it is important to note that to date there has been no evidence of harm associated with the adoption of critical care telemedicine.

Makintosh et al. (2016) looked at the effect of 24-hour critical care telemedicine with standard ICU care for acutely ill adults and children. They concluded that although there was some evidence for the impact of telemedicine on hospital mortality (reduction from 13.6%, [CI, 11.9–15.4%] to

11.8% [CI, 10.9–12.8%]), further multi-site experimental studies are urgently needed to inform future investments. Moreover, a recent systematic review concluded that research studies in telemedicine should do more to clearly define the study population, the intervention elements, and the organisational context in which telemedicine is implemented; specifically, it is important to note the staffing models and healthcare infrastructure involved in the delivery of any telemedicine intervention (Flodgren et al. 2015).

Utilisation and Implementation

Even though telemedicine is understood to be a potentially effective tool, and its adoption is increasing rapidly, reliable data on its real cost and its acceptability by ICU staff, patients and carers is limited. Qualitative data from Thom et al. (2017) revealed considerable variation on how bedside ICU staff utilise critical care telemedicine across moderate/basic and complex ICUs. Quantitative and qualitative data from Mullen-Fortino et al. (2019) showed that contact with the telemedicine hub was less likely to occur if ICU bedside nurses did not know the telemedicine physician personally. In that study, the majority of nurses (79%) acknowledged telemedicine's positive impact on patient outcomes; however, they identified regular and personal communication between themselves and the tele-ICU staff as essential if telemedicine is to reach its potential.

Variations in the implementation of critical care telemedicine interventions within different hospital settings point to a need to understand how different contexts and management practices can influence performance, since what works in one setting may not work in another (Kringos et al. 2015). Thus, understanding whether, or how much, context explains variation in performance would help telemedicine intervention designers make changes and improvements, and disseminate these across settings (Ovretveit 2011). Xyrichis et al. (2017), in an attempt to understand contextual features affecting implementation of critical care telemedicine, have been undertaking a systematic implementation review to examine healthcare stakeholders' perceptions and experiences of factors affecting the implementation of critical care telemedicine. This work, due to be published early 2020, is designed to offer a greater understanding of issues affecting implementation of critical care telemedicine, which can enable the design and evaluation of approaches that are more likely to result in successful implementation.

Family-Centred Care

Research examining the impact of critical care telemedicine on clinical and organisational outcomes is slowly growing; however, little is still known about the perceptions, experiences and awareness of ICU patients, family members and carers with regard telemedicine. ICU family members experience high levels of anxiety and distress during, and long after, a loved one's ICU stay (Bench et al. 2016; Xyrichis et al. 2019). High levels of support and communication with the ICU care team is therefore of the outmost importance. Yet, a survey amongst ICU patients' significant others identified that the majority (66%) were not aware that their loved one was admitted in a tele-ICU (Jahrsdoerfer and Goran 2013). Moreover, in that study, families reported diverse information needs about critical care telemedicine; however, a primary and common concern was the presence of a live camera within the unit. Future research examining the views, experiences and perceptions of families concerning critical care telemedicine is desperately needed.

Conclusion

Critical care telemedicine is a potential solution to the scarcity of critical care expertise, while quality and safe care can also be promoted through off-site surveillance, early warning capabilities, clinical decision support and alerts for non-adherence to best practices. To date, data on its efficacy have been promising yet limited, partly because few studies consider baseline organisational and management factors such as the complexity of the ICU setting, type of interventions, staffing models, end-ICU users' perceptions and organisational readiness.

The potential of critical care telemedicine is too great to ignore, and it is therefore increasingly likely for it to be a key feature of the future ICU. We argue that if critical care telemedicine is to be successfully integrated into standard ICU practice, then its adoption needs to move away from the current haphazard approach of local initiatives towards the development of a more systematic and evidence-based implementation roadmap. ■

Key Points

- Medical advances and demographic shifts have contributed to an older and more complex ICU population, placing pressure on critical care services worldwide.
- Critical care telemedicine has a special part to play in enabling access to scarce critical care expertise and reducing unwanted variability in care.
- Although telemedicine is understood to be a potentially effective tool, and its adoption is increasing rapidly, high-quality data concerning effectiveness, cost and acceptability by ICU staff, patients and carers remain scarce.

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The Intersection of Big Data, Artificial Intelligence, Precision and Predictive Medicine to Create the Future of Critical Care

Over the next 50 years, critical care will evolve from a system that reacts to patient deterioration into a system that predicts and prevents these events. The application of real-time analytics to large-scale integrated ICU patient data will facilitate creation of learning healthcare systems and delivery of personalised and even predictive critical care medicine.

Over the next 50 years, critical care will evolve from a system that reacts to patient deterioration into a system that predicts and prevents these events. The pathway to proactive critical care involves technical and computing advances that integrate large-scale clinical data from critically ill patients and applies complex analytics in real-time to personalise care and predict untoward events. These advances will facilitate creation of learning healthcare systems and delivery of personalised and even predictive critical care medicine. In the not-so-distant future, ICU patients will look vastly different than the patients we see today with multiple organ dysfunction, as we predict and prevent critical illness and become an environment where individualised care is delivered to patients recovering from unforeseen traumatic injuries, increasingly complex surgeries and unpredictable acute illnesses.

Already in the present day, patients in critical care units generate extraordinary amounts of data, from diagnostic and laboratory testing, provider notes, intermittent and continuous monitoring equipment, and myriad support devices such as mechanical ventilators. In the near future, the panoply of monitoring devices will take advantage of secure wireless connections to facilitate contactless patient monitoring that functions seamlessly across healthcare environments such as the ED, radiology, OR and the ICU. Outside of healthcare, in the consumer market we are already experiencing the explosion of internet-connected devices known as the internet of things (IoT). Those devices, estimated to be as many as 200 billion by 2020 (Intel 2019), are now using a small fraction of internet traffic but non-human, but the coming global rollout of 5G connectivity will increase exponentially machine-to-machine traffic to more than 50% of internet traffic by 2022 (Cisco 2019; McKinsey 2017a; McKinsey 2017b). The IoT already exists in healthcare, being used to track equipment, patients and even providers throughout the hospital. Although the evolution of IoT devices and other monitoring equipment complement the developments outside of healthcare, such as in computing technology and the consumer markets, they have unique needs in healthcare. For example, healthcare has greater demands on secure communications as well as reliability and safety across patient environments such as the ICU, OR, radiology, emergency department, pre-hospital setting and more.

Imagine for healthcare to adopt the manufacturing production principles of big data, where the introduction of comprehensive, real-time data collec-

tion and analysis results in fantastically more responsive production systems. In healthcare, in order for the growing constellation of monitoring, testing and data to be clinically valuable, it must be integrated in real-time with the entire spectrum of clinical data in order to ensure the delivery of timely, high quality patient care. An important next step in handling the impending explosion of data generated by critical care patients is data harmonisation. Our current lack of inter-operability between electronic health record (EHR) systems is confounded by multiple instances of duplicated data. For example, in the data warehouse for one of our hospitals, there are multiple entries for haemoglobin, each recorded with a different label: ED-Hgb, OB-Hgb, STAT-Hgb and regular inpatient-Hgb, outpatient-Hgb, neonatal-Hgb and point-of-care-Hgb! Harmonising data variables and concatenating these instances is one step towards clinically effective data reporting and utilisation.

Harnessing the full spectrum of clinical data needed to care for ICU patients requires advancing the underlying technologies that make it feasible. Computing power is now in the realm where basic streams of real-time data can be aggregated and reported, such as clinical lab testing, nurse-recorded vital signs and intravenous infusion pump data. The next steps require the computing and storage capabilities to handle the entire river of real-time data, and the associated analytic capacity to efficiently drive patient care. In the coming years, the application of artificial intelligence and machine learning will solve some of the vexing problems we experience in healthcare, such as early detection of critical illness, alarm fatigue, and variability or subjectivity in test interpretation. While advances in natural language processing may underpin the future of radiology and pathology data systems, AI will be used to solve some of our most challenging problems. For example, the inability to consistently acquire and interpret ultrasound images limits the application of one of our most available technologies. The ubiquitous nature of ultrasound in the future of critical care makes it necessary to solve this problem, and the combination of AI and computing interfaces makes this possible.

“in the near future, the panoply of monitoring devices will take advantage of secure wireless connections to facilitate contactless patient monitoring that functions seamlessly across healthcare environments”

The effective integration of clinical critical care data at scale with real-time analytics is the foundation for changes at each end of the medical care spectrum. At the level of *healthcare systems*, it enables iterative system-level improvements that produce consistent, cutting-edge, reliable, high quality care. At the level of the *individual patient*, it enables care to be customised for each patient according to the current state of their acute and chronic conditions, while taking into account other relevant factors such as social support and other determinants of health. In essence, aggregation and utilisation of clinical data promote the creation of *learning healthcare systems and personalised medicine*. Taken together, these embody the axiom that the public health is represented by the point estimate while each individual patient is represented within the confidence interval. In other words, data collected from groups of patients will appear as the mean (e.g. the point estimate from a clinical study) and are amenable to system-level interventions, whilst individual patients rarely fall exactly at the exact point estimate but are likely to fall within the range of results from the group (e.g. the confidence interval), and individual responses may be optimised or predicted by fully characterising each unique patient.

Integration of data permits the conversion of the traditional ICU to a learning healthcare system. A learning healthcare system (LHS) is defined by the Institute of Medicine as a system in which science, informatics, incentives, and culture are aligned for continuous improvement and innovation, with best practices seamlessly embedded in the delivery process and new knowledge captured as an integral by-product of the delivery experience (Institute of Medicine 2007). A LHS is a sociotechnical system with afferent and efferent components where the afferent component assembles, analyses and interprets data from various sources, and the efferent component returns these findings to the healthcare system in order to favourably change clinical practice. The afferent side is made possible by recent technical innovations such as EHR data and the IoT, and efferent side incorporates elements such as behavioural psychology, implementation science, behavioural economics, policy and organisational theory in order to effect change. The collision of big data harmonisation, EHR interoperability and AI will make easier the transition of each hospital from a traditional healthcare environment to a learning healthcare system.

The creation of learning healthcare systems sets the foundation for personalised medicine on an international scale. Personalised medicine is a medical model that individualises the care of patients according to their risk of disease or their predicted response to an intervention, and thus has the potential to ensure the best

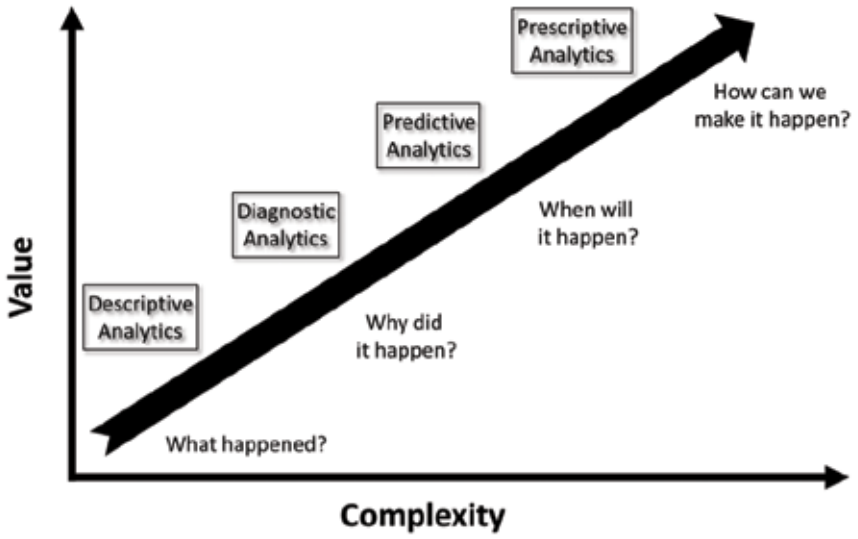

Figure 1. The penultimate approach to personalised medicine.

response and highest safety margin for patient care. This last feature is particularly important in critical care units, where medical care is often time sensitive, where high-stakes decisions are made with incomplete information and imperfect knowledge, and where "decision fatigue" may occur because of the large number of decisions made per hour (McKenzie et al. 2015). Ensuring the highest probability of a favourable response to an intervention effectively tailors medical treatment to the individual characteristics of each patient. While the claim that personalised medicine requires scientific breakthroughs in areas such as genetic profiling and molecular medicine to deliver individualised patient care, the earliest phases of personalised medicine already exist in oncology and in the treatment of rare diseases, whilst the fullest expression of personalised medicine requires both additional scientific discovery and the real-time integration and analysis of these large-scale data to overcome the human limitations of information overload and cognitive processing. For example, systematic application of surveillance and biomonitoring methods using the metabolome can measure 20,000 chemicals and combine that profile with genomic information for our 20,000 genes to provide an array yielding 400 million interactions, thus having sufficient resolution to define an individual as an individual (Martin and Jones 2013). This leads to an even more exciting element beyond personalised medicine – the advent of predictive medicine where we will predict human disease before it is clinically apparent. This characterises the penultimate approach to personalised medicine—the ability to predict disease in individuals and target interventions that restore and optimise health **(Figure 1)**. This approach has also entered reality, in the Emory Predictive Health Institute and with well-documented examples of high-dimensional phenotyping permitting early, effective interventions that favourably benefit human health (Chen et al. 2012). In critical care, predictive medicine creates opportunities across several time scales, from predicting arrhythmias or cardiac arrest in minutes, to respiratory or renal failure in hours, to hospital complications and readmissions in the months following critical care discharge.

Effectuating personalised medicine leads to, as one example, immunotherapy of critical illnesses like sepsis. Immunotherapy is already taking hold in oncology, with many of the latest and some of the most effective cancer drugs using this method, and drawing substantial public, private and philanthropic investment. As one of the most common conditions in critical care, sepsis has recently been redefined with a focus on the dysregulation of the immune system (Singer et al. 2016). We no longer consider sepsis to be a unilateral immunological response of hyperinflammation causing organ failure, but rather a dynamic immune response that continuously changes in the balance between inflammation and anti-inflammation (Pickkers and Kox 2017). In sepsis, personalised immunotherapy could address dynamic biological events such as T-cell exhaustion, decreased cellular expression of HLA-DR, and macrophage phenotypes shifted away from inflammation, each tied to an intervention that is individually tailored to the patient (Hotchkiss and Moldawer 2014). In combination with integrated big data and artificial intelligence, predictive medicine will lead to a landmark change in sepsis care. The ability to predict organ dysfunction changes the face of clinical sepsis care from one of reactive care to one of proactive and even preventive critical care (Kempker et al. 2018).

> **"we are now at the stage of predictive analytics, accurately predicting when an event will occur, and nearing the stage of prescriptive analytics: how can we control events or make events happen"**

The application of artificial intelligence

and advanced machine learning to the big data generated from myriad sources in the care of critically ill patients will facilitate the evolution of learning healthcare systems and predictive medicine. The combination of data and complex computer-assisted analysis will advance us from unsophisticated analytics where the goal is simply to describe what happened, through the more difficult phase of diagnosis where we seek to understand why something happened **(Figure 1)**. As discussed earlier, we are now at the stage of predictive analytics, accurately predicting when an event will occur, and nearing the stage of prescriptive analytics: how can we control events or make events happen. Taken together, these will change the face of critical care from our familiar systems that react to injury, illness, infection and organ dysfunction, to a system of prediction and prevention. With the power of analytics and prediction, we can advance to prescriptive medicine, effectively controlling the response of our patients starting with the earliest phases of an incipient critical illness and extending throughout the course of their care. With the prediction, prescription and prevention of severe illness and organ dysfunction, the most common and vexing problems of critical care medicine can be eliminated. We will no longer manage severe organ dysfunction, having effectively predicted and prevented it in most patients. In so doing, the ICU will become an environment where we care for the unpredictable and the unpreventable complications of life, such as traumatic injuries and recovery from complex surgeries and other insults.

Conflict of Interest

Greg Martin's institution (Emory University) has received funds from the National Institutes of Health, the Marcus Foundation and Cheetah Medical to conduct studies, and he has served as a consultant or medical advisor to Becton Dickinson, Grifols and Regeneron. ■

Key Points

- Over the next 50 years, critical care will evolve from a system that reacts to patient deterioration into a system that predicts and prevents these events.
- The effective integration of clinical critical care data at scale with real-time analytics is the foundation for changes at each end of the medical care spectrum.
- In combination with integrated big data and artificial intelligence, predictive medicine will lead to a landmark change in sepsis care.
- The application of artificial intelligence and advanced machine learning to the big data generated from myriad sources in the care of critically ill patients will facilitate the evolution of learning healthcare systems and predictive medicine.
- The ICU will become an environment where we care for the unpredictable and the unpreventable complications of life, such as traumatic injuries and recovery from complex surgeries and other insults.

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The Intelligent Intensive Care Unit: Integrating Care, Research and Education

Integration of care, research and education in the intelligent intensive care unit.

Patients admitted to the intensive care unit suffer from a variety of symptoms, pathologies, and comorbidities and are at risk of many adverse outcomes. Healthcare and technology for this vulnerable, heterogeneous patient group have immensely developed over the past decades, but even though mortality rates have fallen, they are still high. Caregivers should be informed about variables important for decision making as soon as possible after admission. Education on how to obtain and value important variables, how to use these variables for innovative research, and how to implement new knowledge into daily practice are upcoming challenges for the intelligent ICU.

Identification of critical elements of future research exists. The heterogeneous group of patients requires research in large sample sizes. Additionally, multicentre approaches become more standard as patient populations will differ between hospitals and countries, single-centre studies impair generalisability and external validation. Current research efforts do not yet cover the complexity of research in the ICU. For example, the extraction of retrospective data from Electronic Health Records is currently labourious, error-prone, and hampered by the official registration of data as plain text rather than discrete values. Also, datasets often are not interchangeable between hospitals and countries, and there is a lack of the practical application of guidelines for standardised data collection. One of the challenges is to reduce high variability and improve the quality of data. Collaboration between researchers is mandatory.

> "medical innovation could assist in achieving more efficient care, fewer and shorter hospital admissions, reduced costs and an optimal distribution of limited resources in health care"

Improving research is part of an ongoing strategy. The first step is to start at the inclusion of patients, preferably at the moment the patient enters the ICU. When assessing each patient in a structured manner, we can potentially decrease some heterogeneity by characterising specific processes. Improving characterisation could then aid in identifying which patients are eligible for specific trials and which are not, short after ICU admission. Currently, randomisation can be a challenging process in the ICU as critically ill patients are not a homogenous group, and two patients with the same disease are still very different and may respond differently to treatment and have various outcomes. An increasing number of trials correct for this heterogeneity, but this remains error-prone and does not appreciate the complexity of the patient population. The first step should be to investigate and characterise our patients during the early phase after admission to the ICU.

To look at patients shortly after ICU admission in a structured way is trainable. Obtaining simple variables according to a predefined protocol may better inform caregivers in their clinical decision making and will be useful for randomisation of

this heterogeneous group of patients. While research improves our understanding of complex diseases, the type and nature of the variables we should look at can evolve. By training caregivers in a structured approach, potentially with the use of newly developed technological tools, they can improve the identification of their patient in an earlier phase. When this becomes standard practice, the implementation of newly discovered characteristics or sub-phenotypes of clinical syndromes is feasible. For example, one study showed that a systematic application of a point-of-care ultrasound driven protocol shortly after ICU admission could guide diagnostic and therapeutic decisions in critically ill patients (Pontet et al. 2019). Applying their protocol resulted in decreased utilisation of conventional diagnostic imaging resources and time of mechanical ventilation and facilitated an acute intravenous fluid administration in critically ill patients during the first week of ICU hospitalisation.

Unfortunately, both development and implementation of new technological tools, such as ultrasonography, are often troubled and delayed by the lack of substantial evidence and proper research. Technological innovations can directly benefit critically ill patients by promoting a shift towards the use of more validated non-invasive techniques which may decrease the risk of complications typically associated with invasive techniques and improve patient comfort. As patients may be(come) haemodynamically unstable, high-quality monitoring of vital signs is needed but optimally while using low-risk devices to avoid any additional harm. At an organisational level, medical innovation could assist in achieving more efficient care, fewer and shorter hospital admissions, reduced costs and an optimal distribution of limited resources in health care.

New non-invasive devices are developed to streamline healthcare operations, lower costs, and enhance the quality of care. However, it is still unclear whether the currently used non-invasive measurement techniques measure is as reliable and precise as invasive measurement techniques in critically ill patients. Before increasing the use of non-invasive measurement techniques, or even develop new ones, it is essential to test these devices and compare the measurements to the clinical reference techniques. Fast yet accurate testing and validation of new non-invasive devices could aid in making more use of newly developed technologies in healthcare. Unfortunately, the road to appropriate implementation of these devices is fierce, and many fail to fulfil their purpose.

> **"development and implementation of new technological tools are often troubled and delayed by the lack of substantial evidence and proper research"**

Besides the direct benefit to a patient's health, accurate measuring of vital signs in further efforts could improve care for the critically ill. As algorithms and prediction models are evolving, implementing algorithms and models becomes likely in the foreseeable future. Current examples of commonly used ICU general risk prognostications scores are the Acute Physiology and Chronic Health Evaluation (APACHE IV), the Simplified Acute Physiology Score (SAPS III), and Mortality Probability Model (MPM III). These prognostic models have been extensively studied and validated but show variable results, and thus are still not commonly used in daily practice (Strand and Flaatten 2008; Salluh and Soares 2014). The first step into creating accurate models, however, with simple statistics or even machine learning, is to gather reliable measurements, and thus, data. Therefore, before we may develop reliable estimations of prognosis to inform caregivers adequately, patients, their families, and future research, values of vital signs used in these existing models must be reliable, available as soon as possible, easy to update and be informative for both short-term mortality and longer-term patient-important outcomes.

Besides simple data based on clinical examination and monitoring, prognoses made by physicians and nurses can be valuable for outcome predictions. Several studies have evaluated the predictive value of caregivers' estimations on clinical outcomes of critically ill patients (Scholz et al. 2004; Sinuff et al. 2006; Detsky et al. 2017). Outcome predictions are of great importance for treatment decisions in the management of critically ill patients and prognostic models based on clinical examination, and caregiver estimations might have an added value to existing scores. Predicting outcome in the first hours after ICU admission, however, remains a challenge.

The Simple Observational Critical Care Studies (SOCCS) was designed to compare the prognostic value of the students, nurses, and physicians' educated guess with currently available risk scores to predict short term mortality in the ICU (NCT03553069). Within this study, teamwork is very important; a team of over thirty students is available 24/7 to include all acutely admitted patients within the first 3 hours after admission. At admission of the patient to the ICU, the physicians, nurses and students are asked to estimate in-hospital survival based on gut feeling. The estimation, the risk assessment using, e.g. SAPS and SOFA, and the actual outcome, are collected.

We created the possibility to compare the performance of all models in our population. We will identify models that are useful to predict the severity of the disease in our setting.

Furthermore, we show that using machine learning predictions made by caregivers can be predicted themselves (Kaufmann et al. 2019). Predicting predictions, either right or wrong, for the base for education on how to value variables more appropriate and in addition to that improve forecasting in individual cases. A next step might be to establish a collaboration between caregivers and machines to use the intelligence of both for further improvement. To get data for this process, implementing a systematic observational data collection is the first step towards making data-driven research possible. With a multicentre, multinational database for each setting, the best performing models can be identified, implemented, and over time, updated. The second step towards improving the use of technological innovations in the future ICU is a collaboration between multiple centres. (Inter) National collaboration could result in high-quality studies with large sample sizes and possibilities for external validation. A research platform that allows for standardised, scalable and reproducible observational research could improve the general quality of scientific research, and likely also the quality of healthcare in critically ill patients. Technological innovations will be necessary to support this infrastructure, allowing for simplified data exchange between systems, increasing interoperability and optimising data availability. Reliable, clean and complete database of reliable variables of patients admitted to the ICU should be available for research while complying with privacy and data storage regulations. Eventually, this will allow for validation of non-invasive devices and building accurate prognostic models, which both aid in clinical decision-making and quality of patient care.

In conclusion, innovation is the key to improve healthcare through an intelligent ICU. Physicians and nurses will go back to the bedside and investigate and characterise our patients in an early phase after admission to the ICU. We will train our caregivers to use a structured approach with the use of newly developed tools to improve the identification of patients in an earlier phase. To make more use of innovations and to eventually improve the quality of care in the ICU, teamwork and collaboration are necessary. Multiple centres will work together to conduct standardised, multicentre scalable and reproducible observational research in ICUs. High-quality research will directly benefit healthcare in critically ill patients, but also patients in general, and likely also at the level of organisations and scientific research. ■

Key Points

- Innovation is the key to improve healthcare through an intelligent intensive care unit.
- Physicians and nurses have to go back to the bedside and investigate and characterise our patients in an early phase after admission using a structured approach.
- Upcoming challenges are: education on how to obtain and use important variables for innovative research and how to implement new knowledge into daily practice.
- Teamwork and collaboration between researchers are mandatory.

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THE FUTURE ICU

KEY CHALLENGES IN CRITICAL CARE

- Ageing Population
- Severity of Illnesses
- Hospital-Acquired Infection
- Clinical Staff Shortage
- Technological Innovations
- Environmental Concerns

Source:
https://www.ncbi.nlm.nih.gov/pubmed/21921718

WHAT WILL THE FUTURE BRING?

- Hospitals will be smaller, but ICUs will be bigger
- Hospitals will focus mostly on acute patients
- Less severe patients will be managed via telemedicine or in less acute facilities
- Artificial intelligence will take over time-consuming tasks such as ordering exams, and blood tests
- Augmented reality will enable faster diagnosis and early treatment
- Virtual reality will bring families together
- ICU survivors will have an improved quality of life through early mobility and personalised rehabilitation

Source:
http://newsletter.esahq.org/the-future-of-the-icu/

APPLICATION OF AI IN THE FUTURE ICU

- Finding complex relationships in large volumes of data and improved analysis of multiple variables to predict outcomes
- Developing algorithms to increase prediction accuracy
- Personalised sedation and analgesia
- AI-powered alert system, patient monitoring, and alarm algorithms

Source:
https://www.researchgate.net/publication/330291640_Artificial_intelligence_in_the_intensive_care_unit

3P's

THE 3P's PYRAMID

- One therapy for all in **P**oorly characterised patient populations
- Appropriate therapies for small subgroups of patients in **P**ersonalised medicine
- Customised treatments for each individual in **P**recision medicine

Source:
http://newsletter.esahq.org/the-future-of-the-icu/

MORE POSSIBILITIES?

- Infusion pumps that eliminate manual dosage calculations
- Mechanical ventilators that track oxygen levels and recommend changes
- Sensors on compression devices
- Monitors to track optimal bed positioning
- Single, integrated alarm systems
- Stationary bicycles to fight ICU-induced weakness

Source:
https://www.hopkinsmedicine.org/news/publications/hopkins_medicine_magazine/features/winter-2017/tomorrows-icu

Introducing the Intubation Credit Card

A go-anywhere checklist format to improve emergency tracheal intubation.

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Introduction

Tracheal intubation outside the operating room is fraught with danger. According to the landmark NAP4 study, intubation in the ICU may be associated with 50 times greater risk of procedure-related death and brain injury compared to general anaesthetic practice (Cook et al. 2011). The primary risk factors included lack of planning, inconsistent immediate availability of equipment/drugs and poor team communication-coordination when managing extremely high acuity patients. Each of these deficiencies can be mitigated by consistent use of a well-developed pre-procedural checklist.

Checklists

Checklists have been used to reduce error rates in the aviation industry since the 1930s, when even then it was realised that situational and technical complexity meant that there was 'simply too much plane for one person to fly' (Gawande 2007). This approach has been widely adopted in acute medicine only in the last decade. Whilst not using a formal checklist, Jaber et al. showed a planned approach to emergency tracheal intubation significantly reduced the incidence of serious complications such as life-threatening hypoxaemia and hypotension (Jaber et al. 2009).

Intensive care practice can be understood as falling into three domains: accurate diagnosis, finding effective therapies and optimal implementation of these at the bedside. Whilst great strides have been made to tackle the first two, the third has been relatively ignored by government, the academy, healthcare organisations and educators. However, after 20 years of exponential increases in the numbers and types of airway devices available to clinicians, it is now widely recognised amongst the airway community that the greatest single impact on airway related mortality and avoidable morbidity will not be technical, but will accrue from optimising human factors (Donati 2013). These include the non-technical skills of communication, planning, team working/coordination and maintaining situational awareness.

As part of the development of the UK's first nationally endorsed airway guideline (approved by the Difficult Airway Society (DAS), Intensive Care Society (ICS), Faculty of ICM and the Royal College of Anaesthetists), a checklist specific to emergent intubation outside the Operating Room was developed (**Figure 1**) (Higgs et al. 2018). Success, however, depends on implementation: the phenomenon of so-called 'print and plunk' must be avoided and the challenge is how to embed it into every day, every time practice.

The relatively slow uptake of checklists in acute medicine may be due to several factors. Not least is cultural resistance: their use may be seen as a substitute for clinical experience/confidence. However, the strength of cultural resistance may be fading and Low suggests that junior doctors in particular do not think checklists undermine their professional credibility and are willing to embed them into their everyday practice (Low et al. 2011). But what is also important because of the emergent nature of ICU intubation is a checklist not being universally and immediately accessible when required.

Development of the Checklist Credit Card

In order to improve availability, an ICM trainee (SG) approached DAS wishing to share the concept of making the checklist universally and immediately accessible. This followed an incident when a vital drug was omitted during preparation for an intubation which led to a near-miss incident. The original prototype was simply a small checklist sticker enumerating a list of essential equipment, drugs and a prompt to consider calling senior help. The sticker was designed to go on the back of a doctor's identity card holder.

Prior to distributing the checklist sticker, an anonymised survey was conducted amongst junior ICU doctors in two hospitals: all performed emergency intubations outside

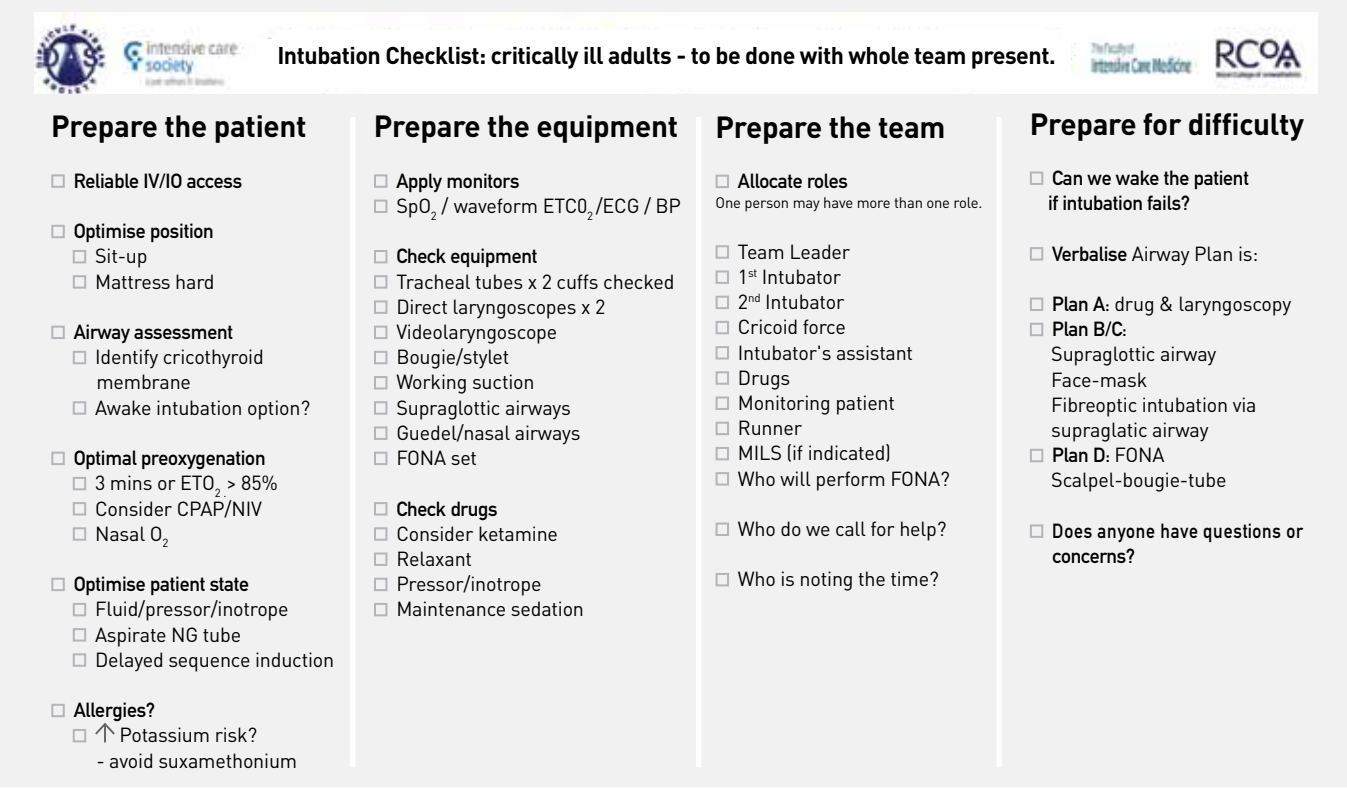

Figure 1. DAS-ICS-FICM-RCoA intubation checklist for critically ill adults. The Executive of the Difficult Airway Society has granted permission to publish this checklist.

the ICU, but only 36% used a checklist and 38% could recall incidents when they personally had forgotten essential equipment or medication. SG acted as a *Clinical Champion* who achieved buy-in from the target audience. Feedback regarding the sticker was universally positive. A follow-up survey three months after the sticker was introduced demonstrated that half the doctors had used it, all felt confident they did not inadvertently omit essentials when they used the checklist and 90% felt the sticker format had advantages over a larger version (Goodhand et al. 2018).

After this positive feedback, the junior considered how to extend the concept more broadly. The obvious choice was to use the national guideline checklist (**Figure 1**) to ensure a gold-standard approach and the format was changed from a paper sticker to a plastic 'credit card' to improve durability and life-span of the mini-checklist (**Figures 2 and 3**). The doctor realised that the single item which was always at hand wherever and whenever emergent

> **"intubation in the ICU may be associated with 50 times greater risk of procedure-related death and brain injury compared to general anaesthetic practice"**

intubation was performed in ICU, ED or the general wards was the duty airway operator's on-call electronic pager (bleep). The credit card has a means of attachment to the on-call pager (**Figure 2**), but can equally be carried in a personal wallet, mobile phone case or on the reverse of an identity holder (**Figure 3**). This process was done suis generis, but reflected recognised approaches for checklist implementation such as ImplementingEmergencyChecklists.org very closely.

The DAS Executive was approached to secure support for this initiative and gave the junior enthusiastic approval, financing a print-run of 250 mini-checklist cards for free-distribution at the DAS Annual Scientific Meeting in November 2018 (cost £99). The verbal feedback for the cards was overwhelmingly positive, with DAS receiving many enquiries regarding further availability/purchase. On that basis, DAS has decided to take the initiative further.

Best Practice Checklists for Emergency Procedures: Does the Intubation Credit Card Measure Up?

Poor design means checklists are not used (Mosier et al. 1992). In order to be effective, there are several important facets which must be considered:

1. Content

Marshall stated that content should be based on national guidance (Marshall 2013); a goal which is obviously met by the intubation credit card. Importantly the checklist covers all the areas which need

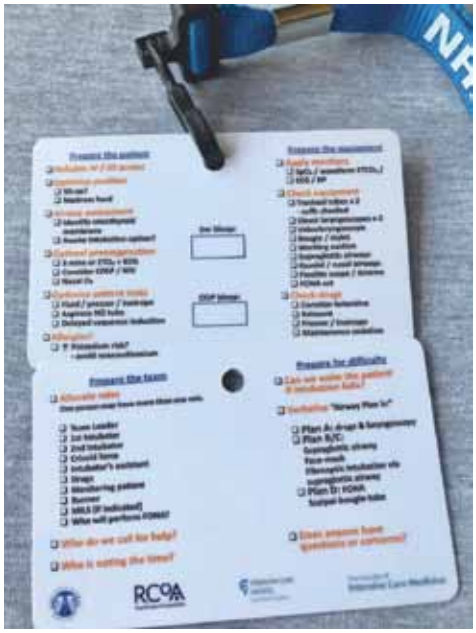

Figure 2: The intubation credit card mini-checklist

Figure 3: The intubation credit card mini-check list on the reverse of an identity holder

to be addressed prior to induction: namely, *preparation of the patient, preparation of all equipment/medications which might be required and preparation of the whole intubation team* rather than only the operator. Finally, the checklist guides the team in how to verbalise *preparation for difficult intubation*, if it arises, using the familiar Plan A, B, C, D approach (Henderson et al. 2004). The content should be familiar: again, using the national guideline template which was itself based on one of the most cited airway publications (NAP4) ensures this.

In training his department, the lead author plays to staff strengths such that senior nursing staff are encouraged to verbalise the first section (preparation of the patient) as this is criteria which must be addressed before intubation: nursing staff can be relied-upon to faithfully complete this task well. Much of equipment can be collected by nurses too. This facilitates early dialogue within the team when, importantly, staff should familiarise themselves with each other's names and roles. The Leader then takes over organising task allocation and individuals' responsibilities. It is worth noting that optimally trained teams using well-designed checklists don't delay the process of intubation (Thomassen et al. 2010).

The final section prompts the Team Leader to verbalise the airway plans (A-D) and the triggers for transition between these. This is vital, as smooth team dynamics are not a given: for instance, many ICUs have over a hundred staff and the chances of all team members having performed intubation together before may be less than 1 in 100,000. Talking through the plans are vital in order that the 'mental model' is shared by all team members. This is important because if difficulty is encountered, the stressed operator very rapidly becomes cognitively over-loaded: *they look but they don't see, they listen but they don't hear and they think but don't comprehend; that is, they lose situational awareness.* If this happens when the mental model has been shared beforehand, other team members can prompt the operator to move forward through the sequence. This cognitive unloading broadens the mental band-width of the operator (Brindley et al. 2004).

Vitally, such an approach turns the 'me' of intubation by a sole operator into the 'we' of safe airway management accomplished by a team.

2. Card design and ease of implementation: 'your flexible airway friend'

The innovative aspect of the mini-checklist is its credit card-like design. To make significant inroads into airway-related mortality and morbidity, a checklist must actually be used. In turn, it must be available each time intubation is performed. The sticker approach is one option, but was abandoned because new/locum doctors may not have received one at induction, some are lost, the expected life-span is short and inadvertent defacement is common.

The credit card design, attached to the on-call pager, is handed from airway operator to airway operator at shift change, ensuring universal availability whenever it is required and its durability is excellent: it withstands physical deformation and soiling. It is also very easily kept in the doctor's wallet.

Many airway trolleys have laminated full-sized copies of the DAS checklist, but these get lost or soiled and are not replaced; additionally, not all ward areas where intubation is performed have formal airway trolleys.

A commonly discussed alternative is a downloadable app. However, not all juniors will acquire it, especially locums, Wi-Fi and batteries may fail. Furthermore, DAS has provided a downloadable app for several years but has found uptake disappointing. The low-tech nature of the credit card style means the failure rate is very low. It is also cheap and can be taken from hospital-to-hospital by rotational trainees.

To date, only one cognitive aid can be claimed to have undergone a systemic design process like the intubation credit card (Ziewacz et al. 2011). Poor design may lead to poorer outcomes (Carthy et al. 2009). Indeed, 'usability' may be the major factor in their success or otherwise (Burden et al. 2012; Degani et al. 1993). It has been suggested that once new information to be used in an intervention is agreed, this should be passed to a human factors design team and thence design, testing and improvement should follow a similar heuristic evaluation to that actually used in developing the mini-checklist credit card (Marshall 2013).

3. Training

For a checklist to be successful, the end-users must have practiced using it (ideally in real-time simulations). The mini-checklist is ideal for this.

4. Improved outcomes

Whether use of cognitive aids generally, and airway checklists specifically, improves outcomes has not been shown conclusively, but many errors of omission and commission are definitely reduced which inevitably facilitates better process. Checklists such as the WHO Surgical Safety Checklist have been adopted globally following impressive results (Hayes et al. 2009). Other high-risk industries have incorporated their use wholesale. It is reasonable to expect that research enquiring into intubation checklist performance will show discernible benefit as they mitigate so many of the clear risk factors identified in the NAP4 study and others. Neale et al. suggest improved decision-making and team coordination using a local anaesthetic toxicity crisis checklist in simulations (Neale et al. 2012).

Dissemination

The mini-checklist has now been distributed throughout ICUs and anaesthetic departments in the Wessex Training Programme Deanery (South West UK), via trainee representatives. It was clear that usage of the mini-checklist led to raised awareness of the DAS-ICS-FICM-RCoA guideline. On the basis of this and the successful scientific conference free-distribution trial, DAS has made available a further 2500 cards (£658) and will distribute these to each of the c300 intensive care units in the UK free-of-charge.

Conclusion

It is intuitive that cognitive aids and checklists will improve outcomes in complex, multi-stage, multi-disciplinary interventions in acute medicine. To be successful, a checklist must be based on a thoroughly well-planned approach, be well-designed and immediately available. Real-world users' organically-developed innovations, like the intubation credit card mini-checklist, meet these objectives and we hope it will gain wider traction as DAS and ICS roll-out this project.

Acknowledgement

DAS is indebted to ICS for help in disseminating the cards to all the UK ICUs.

Conflict of Interest

Andy Higgs is Treasurer of DAS and the lead author of the Difficult Airway Society-Intensive Care Society-Faculty of Intensive Care Medicine-Royal College of Anaesthetists' guideline for tracheal intubation in the critically ill adult. There are no other conflicts of interest. ■

Key Points

- As part of the development of UK's first nationally endorsed airway guideline, a checklist specific to emergent intubation outside the Operating Room was developed.
- The relatively slow uptake of checklists in acute medicine may be due to several factors. Not least is cultural resistance: their use may be seen as a substitute for clinical experience/confidence.
- The checklist covers all the areas which need to be addressed prior to induction: namely preparation of the patient, preparation of all equipment/medications which might be required and preparation of the whole intubation team rather than only the operator.
- To be successful, a checklist must be based on a thoroughly well-planned approach, be well-designed and immediately available.

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Improving Recognition of Neonatal Sepsis

Improving early recognition of sepsis in the Neonatal Intensive Care Unit using machine learning models and electronic health record data.

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Neonatal Sepsis – Incidence and Outcomes

Despite advances in knowledge and medical care, sepsis remains a major cause of morbidity and mortality in infants worldwide, claiming the lives of one million newborn infants each year according to the World Health Organization (Liu et al. 2015;Vogel 2017). By definition, sepsis involves the immune response to invading pathogens, and is characterised by presence of a bloodstream infection accompanied by multi-organ system dysfunction. Although sepsis affects relatively few healthy, term infants, the incidence is significantly higher (200-fold) in those born prematurely or chronically hospitalised (Zea-Vera and Ochoa 2016; Liu et al. 2015).

Prematurely born infants experience the highest mortality, and among survivors, 30-50% incur major long term impairments including prolonged hospitalisation, chronic lung disease and neurodevelopmental disabilities (Stoll et al. 2004; Stoll et al. 2010). To date, despite increased understanding of the pathophysiology of sepsis and sophistication of neonatal intensive care strategies, there have been only modest improvements in outcomes (Wynn 2016).

Challenges in Neonatal Sepsis Recognition and Treatment

Early detection of sepsis, followed by timely intervention, is key to reducing neonatal morbidity and mortality. However, delays in recognition and treatment are common (Castellanos-Ortega et al. 2013). Infants frequently demonstrate subtle, ambiguous clinical signs, which overlap with other neonatal disease processes. Multiple diagnostic biomarkers have been studied, but none have yet achieved sufficient accuracy to be employed in clinical practice (Reinhart et al. 2012; Ng et al. 2018). In a retrospective review of infants in our level IV Neonatal Intensive Care Unit (NICU) at the Children's Hospital of Philadelphia (CHOP) who underwent sepsis evaluations with subsequent positive blood cultures, recognition was delayed more than 3 hours in 30% and a significant proportion progressed to severe sepsis and multi-organ system dysfunction. These findings reflect the challenge of interpreting non-specific clinical signs in the face of complex underlying conditions and support the need for improved methods for sepsis detection in infants.

As detailed in the Surviving Sepsis Campaign, early treatment such as timely antibiotic administration is associated with decreased sepsis mortality (Dellinger et al. 2013). Recent studies of infected adults and children demonstrate significantly increased risk of mortality and prolonged organ dysfunction when antimicrobial therapy was delayed (Seymour et al. 2017; Weiss et al. 2014; Evans et al. 2018). However, there is little evidence regarding optimal timing and consequences of delayed antibiotic administration in infants with sepsis. Recent work using our neonatal sepsis registry (see below) has demonstrated that prolonged time to antibiotic initiation was associated with significantly increased morbidity and mortality in infants with sepsis, highlighting the importance of rapid recognition of sepsis in the NICU (Schmatz et al. 2019).

To avoid adverse outcomes of delayed antibiotic administration while recognising the heterogeneous, complex nature of sepsis and the immune inflammatory response, empiric antibiotics are widely administered despite the modest prevalence of culture proven sepsis (Schlapbach et al. 2018) and the potential for overtreatment of non-infected infants (Squire et al. 1979). Infants with suspected sepsis are often managed conservatively and receive weeks of antibiotic therapy, often despite negative cultures (Gonsalves et al. 2009; Connel et al. 2007). Recent studies demonstrate that unnecessary antibiotic exposure in non-infected infants may worsen clinical outcomes and contribute to the development of antibiotic resistance (Ting et al. 2016; Cotten et al. 2009; Kuppala et al. 2011).

These findings underscore the importance of developing novel, improved methods for sepsis detection in infants with potentially life threatening illness while minimising the overtreatment of non-infected infants.

Neonatal Sepsis Registry at Children's Hospital of Philadelphia

In 2014, we established a sepsis registry in the CHOP NICU which provides automated identification and data abstraction from the electronic health record (EHR) of all infants less than one year of age who are evaluated for sepsis (EHR–Epic Systems Inc. Verona, WI). The CHOP NICU is a 100 bed quaternary unit that admits and treats roughly 1300 infants annually including outborn infants with complex medical conditions as well as inborn infants with surgical and other anomalies delivered in the Special Delivery Unit at CHOP. Infants are enrolled into the registry when clinical concern prompts the collection of a blood culture and initiation of intravenous antibiotics. The registry captures EHR data for variables including patient demographics, laboratory and vital sign data, medication administration records, respiratory and inotropic support, NICU length of stay and mortality. Comorbid conditions are identified based on EHR ICD-9/ICD-10 codes. Infants are then further classified when results of blood and other systemic cultures are known. Electronically abstracted data are intermittently evaluated by manual chart review to ensure accuracy. The registry currently includes data from 1,868 infants who experienced 3,384 episodes of sepsis evaluation. Of these evaluations, 336 (10%) resulted in positive cultures for bacterial pathogens. There were an additional 682 evaluations (20%), of "clinical sepsis" where clinicians nevertheless chose to treat with antibiotics for at least 5 days despite the inability to identify a bacterial pathogen.

Models to Predict Infant Sepsis

We used readily available EHR data for infants in our registry to develop prediction models that may be useful to improve the early recognition of sepsis (Masino et al. 2019). We demonstrated that several machine learning algorithms could achieve good performance to differentiate infected (either culture proven or clinical sepsis) from non-infected infants 4 hours prior to the time of clinical recognition (i.e. the time when sepsis evaluation was initiated). Six of the algorithms we evaluated achieved an area under the receiver operating characteristic (AUROC) > 0.8, with the best performing algorithm (gradient boosting) achieving an AUROC of 0.87 [95% confidence interval (CI): 0.82, 0.92]. At a pre-specified sensitivity of 0.8, the gradient boosting algorithm had a specificity of 0.74 [95% CI 0.63, 0.84]. Our results compare favourably with the few recent studies that have attempted to predict sepsis in advance of clinical recognition (Desautels et al. 2016; Fairchild et al. 2017; Shashikumar et al. 2017; Nemati et al. 2017). Only one of these studies was performed in infants, and that study required the use of high frequency vital sign data from bedside monitors, which is not readily available in most EHRs (Fairchild et al. 2017).

> "early detection of sepsis, followed by timely intervention, is key to reducing neonatal morbidity and mortality"

Path Forward to Precision Medicine Using Sepsis Prediction Models

Despite the promise of prediction models that have excellent test characteristics for discriminating infected from non-infected patients in advance of current recognition, there remain important barriers to translation into clinical practice. For conditions such as sepsis, where delayed recognition and treatment results in significant mortality, implementers typically favour sensitive alerts at the expense of specificity. However, even algorithms that achieve high levels of specificity will typically have low positive predictive values (PPV) in real-world clinical environments. To address this concern, two-phase sepsis alerts that use a highly sensitive initial alert to recommend additional evaluation, sometimes known as a "sepsis huddle," followed by a more specific secondary assessment have been used successfully in paediatric emergency departments (ED) (Balamuth et al. 2017). In these settings there is a specific moment in time, typically during patient triage, where the ED team decides whether or not to proceed with a sepsis evaluation.

In contrast to the ED setting, there is no single evaluation moment in an intensive care unit (ICU) setting, rather there is continuous patient monitoring and evaluation for sepsis. The frequent evaluations produced by a predictive model in an ICU setting may further compound the problem of low PPV, as it may lead to high false alarm rates and alarm fatigue which markedly decreases the likelihood that clinicians will respond to an alarm, especially when those alarms occur repeatedly for the same patient (Ancker et al. 2017). It is, unfortunately, not obvious how best to extend a two-phase approach that is effective in the ED to the ICU setting. An obvious alternative is to require models with both high sensitivity and PPV. However, this is a daunting challenge for rare event prediction; consider for example the difficulty of accurately identifying fraudulent credit card transactions despite the availability of huge amounts of data and resources (Fu et al. 2016). Clinicians are trained to view decision-making as a task that occurs at particular moments in time. They arrive at the patient's bedside with a collection of practice guidelines, decision rules, heuristics and instincts to establish a treatment plan. However, given the challenges above, it may be more useful to think of sepsis prediction in the ICU as "weather

forecasting" rather than as the familiar concept of "alarm systems" that have been used to support clinical decision-making for decades. Additional understanding of how clinical teams approach decisions related to sepsis is required before new approaches such as continuously available long- and short-range forecasts of sepsis probability estimates can be introduced in clinical settings. New approaches to estimating and reporting the uncertainty that is inherent in prediction models must also be developed. Clinical teams are also unlikely to accept "black box" model predictions without a way of understanding the key patient features that are driving a particular risk estimate. Our team's future work will focus on these challenges of determining how to best support clinical teams with imperfect forecasts of sepsis probability that are available continuously at the bedside.

Conclusion

Machine learning models can identify infants with sepsis in the NICU hours prior to clinical recognition and may be valuable as a clinical decision support tool. As discussed above, we anticipate significant challenges in translating retrospective sepsis decision support models into effective clinical tools. Nonetheless, given the significance of neonatal sepsis and the consequences of delayed recognition and treatment, we are committed to the performance of clinical trials to identify infants at highest risk of sepsis and provide clinicians and nurses with the decision support needed to improve the health and safety of these infants. ■

Conflict of Interest

The authors report no conflict of interest.

Key Points

- Neonates and infants are uniquely susceptible to infection and experience high morbidity and mortality from this disease.
- Rapid recognition and treatment are crucial to improve sepsis outcomes.
- Prediction models using EHR data may be useful in early recognition of infants with sepsis.
- Results support the future implementation of novel decision support tools in clinical trials to improve clinical decision making in infants with sepsis.

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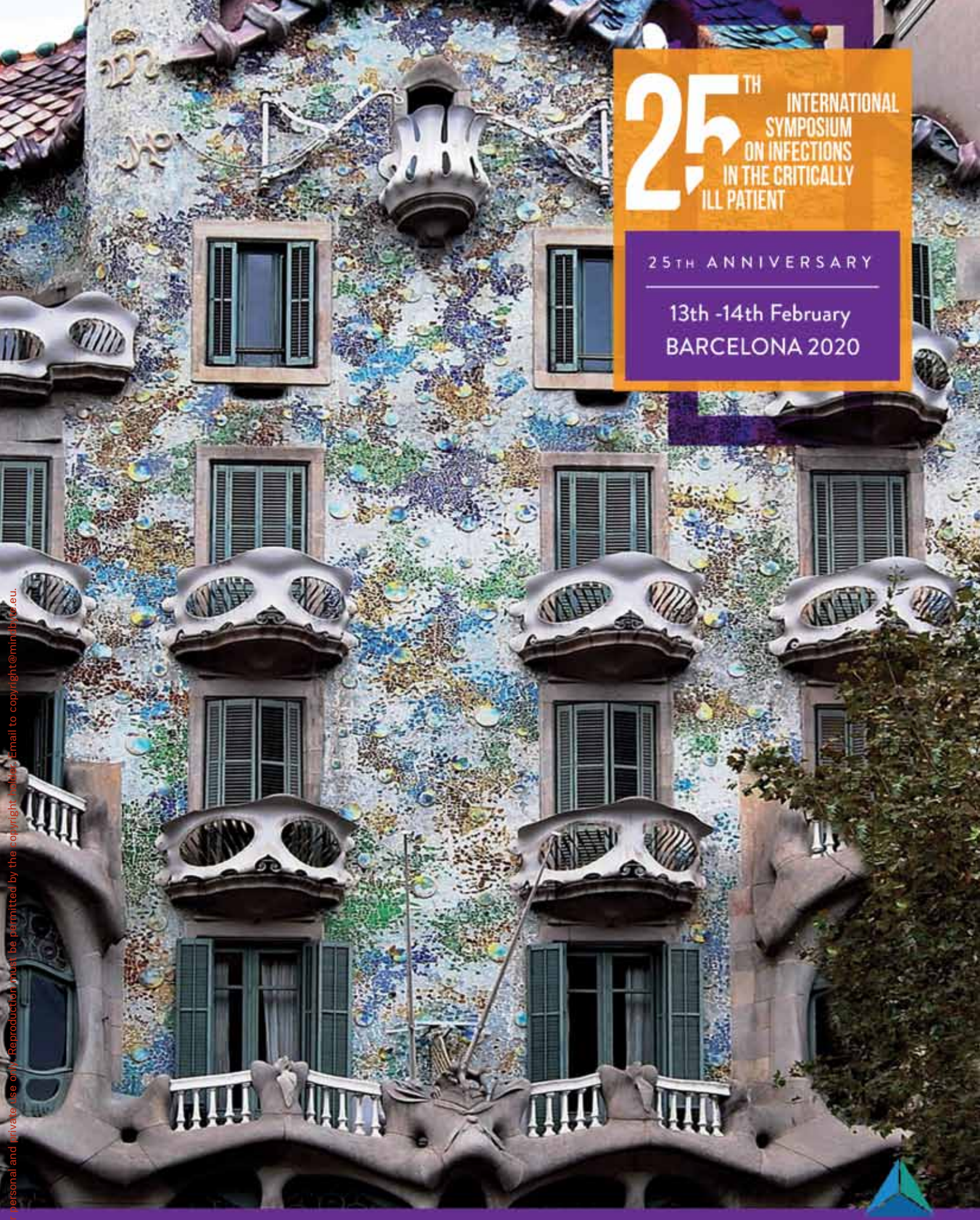

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Lifesaving Applications of Transoesophageal Echocardiography in Critical and Emergency Care

This article provides an overview of transoesophageal echocardiography training, programme development, feasibility and impact on the diagnosis and treatment of critically ill patients.

Recently clinicians at our centre managed one of the most critical patient emergencies. An elderly woman (Patient A) presented to our emergency department (ED) by ambulance with cardiac arrest of unknown aetiology. Information on her medications was initially unavailable and history provided by her family was nonspecific: she had experienced generalised malaise, diarrhoea and poor oral intake for several days. Patient A also had a history of hypertension, obesity, hypothyroidism, dyslipidaemia and atrial fibrillation.

Upon arrival, pulseless electrical activity (PEA) was detected and she was endotracheally intubated while cardiopulmonary resuscitation (CPR) and advanced cardiac life support (ACLS) protocols were initiated. After one round of CPR and resuscitative medications, Patient A remained in PEA. ACLS guidelines advocate for continued resuscitation while simultaneously considering and treating potentially reversible causes of the cardiac arrest (Sayre et al. 2010). Transthoracic echocardiography (TTE) was attempted, but it provided no meaningful information due to ongoing CPR.

This case illustrates several challenges clinicians face during the resuscitation of patients in cardiac arrest and how our team uses transoesophageal echocardiography (TEE) to reliably obtain high-quality images, guide decision-making and intra-arrest procedures, and monitor response - without interrupting lifesaving chest compressions. This article provides an overview of TEE training, programme development, feasibility and impact on the diagnosis and treatment of critically ill patients at London Health Sciences Centre, a tertiary care center consisting of two hospitals in Ontario, Canada with 50 intensive care unit (ICU) beds at two sites and two emergency departments (EDs) with 140,000 combined annual visits. Lifesaving applications of TEE in the ED and ICU are also reviewed.

A 97% Success Rate in Answering High-Stakes Clinical Questions in Critically Ill Patients

A TEE probe was inserted without difficulty to reveal a midoesophageal four-chamber view with no evidence of pericardial effusion or signs of cor pulmonale suggestive of pulmonary embolism (PE). Ultrasound-guided central venous catherisation (CVC) revealed a high-risk relationship between the internal jugular vein and carotid artery. The high risk of arterial cannulation was minimised by using TEE to confirm proper venous guidewire placement with a midoesophageal bicaval view.

ACLS and European Resuscitation Council guidelines have recently endorsed echocardiography in cardiac arrest resuscitation, as have earlier guidelines from cardiology and anaesthesiology societies (Cheitlin et al. 2003; Thys et al. 2010; Link et al. 2015; Soar et al. 2015). In 2017, the American College of Emergency Physicians (ACEP) published the first guidelines endorsing the use of TEE by emergency physicians (EPs), reporting that in up to 50% of cases, TTE provides inadequate images in critically ill patients and is even more challenging to perform in those receiving CPR (Fair et al. 2018). Moreover, TTE also risks interrupting chest compressions for more than the ten seconds advised in the ACLS guidelines, potentially leading to worse neurological outcomes in cardiac arrest patients.

The ACEP guidelines report that TEE "provides the logical solution to these limitations, given its ability for continuous image acquisition both during compressions and during pulse checks, its reliably excellent image quality and its lack of interference with chest compressions or other procedures needed during cardiac arrest." Indeed, TEE's superior image quality in nearly all circumstances and expanded diagnostic scope due to its indwelling location millimetres behind the heart have shown a very high success rate in answering high-stakes clinical questions in severely ill patients [97% for TEE versus 38% for TTE] (Vignon et al. 1994). For cardiac

arrest resuscitation, the ACEP guidelines cite the following benefits of TEE:

- TEE provides a valuable adjunct for diagnosing myocardial infarction, PE, pericardial effusion and hypovolaemia as causes of the arrest.
- Anaesthesia literature has demonstrated that TEE can reliably identify the cause of the arrest in up to 86% of cases, offering potential advantages in being able to confidently guide such treatment decisions as the use of thrombolysis, vasopressors, intravenous fluid or blood administration, or pericardiocentesis.
- TEE offers immediate, real-time feedback on the response to any intervention, such as visualisation of coordinated contractility after defibrillation or improvement in contractility after administering epinephrine.
- TEE provides immediate assessment of the quality of chest compressions. The 2015 ACLS guidelines advise a specific compression depth of 5 to 6 centimetres during CPR - a goal that can be hard to clinically evaluate without TEE.
- TEE can also assist with the proper placement of intra-aortic balloon pumps, transvenous pacemakers and other resuscitative devices.

A Safe, Clinically Influential and Easy-to-Learn Technique

With Patient A remaining in a persistent PEA rhythm of five beats per minute, transcutaneous pacing was attempted, but failed due to her body habitus. Placement of a 5F balloon-directed transvenous pacemaker was performed under direct visualisation using TEE, which proved very valuable in the context of difficult electrical capture. Once capture was achieved, good blood pressure was confirmed. The return of circulation post-capture enabled us to rule out acute coronary syndrome and PE as causes of the arrest.

Studies by our team and other investigators reveal that TEE is safe, feasible and clinically influential in a range of emergency and critical care scenarios. In an ICU case series published by our team, 80% of intensivist-performed TEE studies at our centre have resulted in proposed changes in management (Arntfield et al. 2018), versus 60% of TTE studies as published in an earlier study at our centre (Alherbish et al. 2015). The TEE study analysed findings from 274 consecutive TEE examinations performed by 38 operators, with the most common indications being haemodynamic instability (45.2%), assessment for infective endocarditis (22.2%), poor TTE windows (20.1%), and cardiac arrest (20.1%). Some studies carried more than one indication.

> **“TEE is safe, feasible and clinically influential in a range of emergency and critical care scenarios”**

All TEE examinations were safely performed and produced interpretable images, with a 100% success rate for probe insertion (84% on the first pass) and no mechanical complications.

Our study found that TEE is a powerful diagnostic tool that can answer both advanced and basic questions essential for the daily care of the critically ill, including the determination of shock aetiology, preload sensitivity, procedural support (extracorporeal membrane oxygenation cannulation, central venous catheter insertion, cardioversion) and monitoring of haemodynamic interventions. In our study, we found that about two-third of the TEE exams addressed basic questions, using a limited number of views. In the 42% of cases in which TTE was performed prior to TEE, unsatisfactory image quality led to TEE in half of these cases.

Given the compelling evidence of TEE's superior performance in critically ill patients, and the availability of TEE-compatible portable ultrasound machines and high-fidelity simulators for training, broad dissemination of TEE training to EPs is now a realistic consideration. Our critical care team developed and evaluated a novel focused TEE examination tailored for use in the ED by EPs (Arntfield et al. 2015). TEE-naïve EPs were invited to participate in a didactic and simulation-based workshop where they learned how to obtain views from four vantage points (mid-oesophageal four-chamber, mid-oesophageal long axis, transgastric short-axis and bicaval views). After the training, their skills were assessed on a high-fidelity simulator and a six-week follow-up session assessed skill retention, demonstrating that EPs can successfully perform the focused TEE examination and retained those skills six weeks later.

Other investigators have reported that although use of TEE takes practice, since the user must learn to manipulate the probe remotely, mastering this skill is actually easier with TEE than with TTE, because the probe is well positioned simply by being in the oesophagus (Mayo et al. 2015). Unlike TTE, TEE is generally uninfluenced by positive pressure ventilation, obesity, emphysema, surgical dressings or wounds, and obstacles on the chest, such as defibrillator pads, or ongoing CPR. Many of the image planes and views generated by TTE and TEE are similar, differing only in how they are projected onto the screen. Moreover, the techniques used for evaluation of the cardiac anatomy and function are identical.

Impact of Focused TEE Examinations in the Emergency Department

Remarkably, after the return of paced circulation, Patient A began to move purposefully and required sedation. Time from the initial cardiac arrest until successful pacemaker capture was about 45 minutes. Ultimately, the cause of her cardiac arrest was found to be hyperkalaemia. Information on her

medications was obtained, leading to a diagnosis of acute kidney injury from a diarrhoeal illness in the context of use of one of her medications.

In a recent retrospective study of all ED TEE examinations performed by EPs at our centre between February 1, 2013 and January 31, 2015, this safe, minimally invasive tool imparted a diagnostic influence in 78% of cases and impacted therapeutic decisions in 67%. In all cases, probe insertion was successful and the views obtained were determinate in 98% of cases. Focused TEE exams demonstrated the most promise in patients who were intubated and had undifferentiated shock or cardiac arrest (Arntfield et al. 2016).

Patient A's case, which has been more fully described elsewhere (Arntfield et al. 2014), powerfully demonstrates the value of point-of-care TEE in rapid evaluation for reversible causes of arrest, guiding invasive procedures during emergency scenarios and providing continuous, real-time anatomic monitoring without pauses in lifesaving chest compressions to acquire images, as is necessary with TTE. Use of TEE during her resuscitation was like watching a live TV show in which we could actually see the heart of a patient who had been brought in with absent vital signs start to beat again. After correction of her potassium level, Patient A was no longer pacemaker dependent and was discharged to her home with full neurological and functional recovery six days later.

"the goal of our TEE programme is simple: to use the best available technology and techniques to help our sickest patients get back in the game"

When we telephoned Patient A to follow up on the case, we expected her to sound weak and fatigued after her near-fatal illness. Instead, she sounded joyful and full of life. "I was playing with my grandkids," she announced. In the background, we could hear the excited voices of children clamouring for Grandma to return to their game. It is countless stories like this that continue to inspire us to use point-of-care TEE in our ICUs and EDs to uphold and improve the standard of care for critically ill patients, provide diagnostic certainty in emergency scenarios, including cardiac arrest, and guide lifesaving procedures, even if the use of TTE is impossible. The goal of our TEE programme is simple: to use the best available technology and techniques to help our sickest patients get back in the game. ■

Key Points

- TEE provides a valuable adjunct for diagnosing myocardial infarction, pulmonary embolism, pericardial effusion and hypovolaemia as causes of the arrest.
- TEE can reliably identify the cause of the arrest in up to 86% of cases.
- TEE offers immediate, real-time feedback on the response to any intervention.
- TEE provides immediate assessment of the quality of chest compressions.
- TEE can also assist with the proper placement of intra-aortic balloon pumps, transvenous pacemakers and other resuscitative devices.

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Shaping the Human Side of Medical Devices in Critical Care: The Implication of Human Factor Studies in Clinical Settings

An overview of Human Factors Engineering (HFE), a multidisciplinary science in which human behaviour, capacities, and engineering principles are used to explore why errors occur, and how the likelihood of preventable harm could be reduced.

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What Do We Know About Medical Device Errors in Critical Care?

Adverse events and errors are frequent in technology-rich critical care environments, such as Intensive Care Units (ICUs). In such a clinical setting, patients are more likely to experience treatment- or procedure-related adverse events due to the complexity of their conditions, workload fluctuation and need for urgent intervention (Garrouste-Orgeas et al. 2012). A number of studies have reviewed incidents in critical care units including equipment failure, unplanned dislodgement or inappropriate disconnection of lines, catheters, or drains, and errors related to medication or airway complications (Valentin et al. 2006). For example, Welters et al. (2011) reviewed all critical incidents in 9 critical care units (level 2 and 3 beds) in UK and found that 30% of all incidents (the largest group) were related to medical devices. One third of these were due to faulty equipment followed by incorrect handling and unfamiliarity.

Implications of Technology Development

New technology does not always enhance safety in healthcare. Some studies report a positive outcome following introduction of new technology while others indicate no such benefits (Nuckols et al. 2008; Rothschild et al. 2005) or even adverse events related to new technology (Han et al. 2005). Human factor studies have an essential role to play in understanding these issues and facilitating these innovations whilst improving their safety.

It is well recognised that many errors are caused by poorly designed systems that fail to address the human actions and needs between people and the system in which they work (Garrouste-Orgeas et al 2012; Reason 2000).

Some advances in technologies have taken measures to mitigate these errors (e.g. electronic health records, computerised provider order entry system, bar-

code medication administration, smart infusion pumps (Hassan et al 2010). However, unexpected errors often occur when a new technology is introduced due to a number of newly generated, and sometimes unanticipated, human-device, device-device, and human-human interactions (Garrouste-Orgeas et al. 2012).

Role of Human Factors Engineering

Human Factors Engineering (HFE) is a multidisciplinary science in which human behaviour, capacities, and engineering principles are used to explore why errors occur, and how to reduce the likelihood of preventable harm to individuals (Russ et al. 2013). Studies in HFE have demonstrated that performance, efficiency, quality, and safety are the result of the interaction between people and the system in which they work (Scanlon and Karsh 2010). It has been argued that medical experts need further assistance in the adoption of HFE methods to avoid adverse events, to deal with errors, to optimise the relationship between humans and devices in the context of use and to support human performance (Borsci et al. 2016), especially in complex environments such as ICUs. Regulatory standards (e.g. IEC 62366, Medical Devices-Application of Usability Engineering to Medical Devices) have been developed and should be widely adopted to help medical device manufacturers understand and use HFE during the development and validation of medical devices (Hegde 2013). These standards aim to reduce the occurrence of unforeseen situations and require an understanding of the complex human-device-environment interactions.

In such a complex 'sociotechnical environment,' errors may occur in a variety of ways. This is due to the fact that operators with different skills, mental models and familiarity with existing devices are required to simultaneously use new technologies whilst adapting to a changing clinical environment. The term 'sociotechnical systems' (STS) has been used to pinpoint the role of choice and organisational design in the interaction between people (the social system), tools, technologies and techniques (Wilson and Sharples 2015) and in recent years has been applied to system ergonomics. This approach to the design of work systems, human task/job requirements, human-machine and human-software interfaces (Hendrick and Kleiner 2001) allows HFE to examine not only individual (i.e. micro) issues but also wider social and organisational factors (i.e. macro issues) (Wilson and Sharples 2015). Each sociotechnical context can be characterised by specific workflows, work cultures, rules and constraints of communication, social interactions along with a set of technologies. In these circumstances and within a clinical setting, human errors are rarely the 'fault' of the clinician. Rather, they emerge from the clinicians needs/expectations while using new technologies in a particular environment and doing a particular task (for example, the technologies may not be designed for the end user's mental model of what the technology is actually doing; the environment may not be adequate or filled with interruptions and tasks may require intense cognitive workload) (Scanlon and Karsh 2010).

> **many errors are caused by poorly designed systems that fail to address the human actions and needs between people and the system in which they work**

Key Variables in Human Factors Engineering for Medical Devices

At the individual level, the following factors are widely investigated to device evaluation in medical practice to fully understand and/or model the device use (Borsci et al 2016). These factors, in combination, impact upon the way in which care processes are delivered with promising outcomes for patient safety, quality of care and improved adoption of medical devices:

- Acceptance of the device use (Davis 1989), consisting of perceived usefulness, ease of use, and attitude towards a device;
- Usability, defined as effectiveness, efficiency, and satisfaction of product usage in the specific context (ISO 9241-11:1998);
- User experience, defined as a person's perceptions and responses that result from the use or anticipated use of a product, system, or service (ISO 9241-210:2010);
- Expectations before use of the device and the reaction of users to the device during and after use, including physiological reaction assessments (Shadbolt et al. 2015);
- Intuitiveness of a technical system when, in the context of a certain task, the particular user is able to interact effectively, whilst not consciously using previous knowledge (Naumann et al. 2007);
- Trust towards systems, including a set of beliefs that a person has before they use or experience a technology or system, built throughout the relationship between user and system, and dependent on the cumulative experience with a specific system (Borsci et al. 2018).
- Assessment of the simultaneous impact of individual, organisation, tasks and technology on quality of care and patient safety – System Engineering Initiative for Patient Safety - SEIPS model (Carayon et al. 2006).

Conclusion

Healthcare is a complex sociotechnical system. Healthcare innovation requires human factor engineers to help innovate safely and effectively to enable clinicians (and other users) to optimise their interactions with technology and reduce associated risks to patients. ■

Key Points

- Human Factors Engineering (HFE) is a multidisciplinary science in which human behaviour, capacities, and engineering principles are used to explore why errors occur, and how to reduce the likelihood of preventable harm to individuals.
- Medical experts need assistance in the adoption of HFE methods to avoid adverse events, to deal with errors, to optimise the relationship between humans and devices in the context of use and to support human performance.
- Healthcare innovation requires human factor engineers to help innovate safely and effectively.

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Diagnosis, Treatment and Management of the Critically Ill Patient

Interview with Professor Rui P. Moreno, Neurocritical and Trauma Intensive Care Unit, São José Hospital, Centro Hospitalar Universitário de Lisboa Central E.P.E, Lisbon, Portugal.

Professor Rui P. Moreno works at the Intensive Care Unit of the Hospital de São José (Centro Hospitalar Universitário de Lisboa Central E.P.E) as the coordinator of the Neurocritical and Trauma ICU. Prof. Moreno has been a member of the European Society of Intensive Care Medicine (ESICM) since 1995 and became President of the Society in 2008. He was also co-chair of the Surviving Sepsis Campaign from 2009-2011. Prof. Moreno has been interested in severity of illness scores. His description of the SOFA score is one of the most cited papers in this particular area. He also played a critical rule in creating, describing and validating the SAPS 3 scoring system. Prof. Moreno has been elected Council Representative to the World Federation, Chair of the European Board of Intensive Care, and has also chaired the Portuguese College and Board of Intensive Care. He has also published many papers in highly reputable journals and has made immense contributions to the field of intensive care medicine.

You have had a long-time interest in severity of illness scores. How important are these scores, in your opinion, and what role can they play in the management of critically ill patients?

As written by Hippocrates in Epidemics, Book 1, section 11 "The physician must be able to tell the antecedents, know the present, and foretell the future - must mediate these things, and have two special objects in view with regard to disease, namely, to do good or to do no harm. The art consists of three things- the disease, the patient, and the physician. The physician is the servant of the art, and the patient must combat the disease along with the physician."

Consequently, the development and application of severity scores are an obligation for the doctors, allowing them to foretell the future, to inform the patient or the family, and to apply the most effective approach at a certain moment in time to a patient consumed by disease and presenting with a given degree of severity.

Since there are so many types of scoring systems that are used in the ICU, which ones do you think are the most important? Also, do these scores complement each other, or are they mutually exclusive?

General severity scores that allow the user to describe the severity of groups of critically ill patients; General Prognostic Models that, based on the severity of illness and eventually in other variables, allow the computation of the probability of death; and Sequential organ failure scores that allow the user to describe sequentially the path of the organ dysfunctions/failures presented by the critically ill patient during the ICU stay.

SAPS 3 and APACHE II. How accurate are these scores? Is one better than the other? If yes, why?

Any general prognostic model (such as APACHE II or SAPS 3) is good when it reflects adequately the analysed population. SOFA should be used just to describe sequentially the path of the critically ill patient and not to make prognostications about the future.

Patient safety is an important element in healthcare, but medical errors are also a reality. In your opinion, which errors are most common in the ICU? How can the risk of errors be reduced?

Possibly the most common errors in the ICU are omission errors: late or missing diagnosis, late or missing therapies. The risk of errors can be reduced by creating redundant systems, and changing the safety

culture of the ICU.

Sepsis continues to be a lethal and complex disease. What are the contributing factors here? How do you think the burden of sepsis can be tackled?

The exponential increase in predisposition: older and more fragile patients, debilitated by chronic diseases and with a reduced margin to fight the acute insult. It must be addressed from a public health perspective: prevention, early and adequate diagnosis and early treatment, adequate rehabilitation after the acute stage. Always personalised (and not completely protocolised) and patient- and family-centred.

Recent findings suggest that sepsis is not one condition but that there are many sub-types of sepsis. Do you agree with this? And do you think the management of patients can be improved if treatment is based on subtypes?

Yes, certainly. Both prevention, diagnosis, and treatment should be based on sub-types, from which the most important are susceptibility and severity of illness.

Most of the time, quality of care is measured in terms of patient outcomes. But do you think there is a need to focus on the process of care itself? Do you think that should also be an important factor when measuring quality in the ICU?

Quality of care is a multimodal measure that encompasses effectiveness of care and safety of care. When measuring quality of care in the ICU, both dimensions are equally important. Outcome - seen exclusively as vital status at hospital discharge - in itself is important, but insufficient to evaluate the quality of care, since other factors, namely safety and effectiveness are crucial.

You are the co-author of the book Controversies in Intensive Care Medicine. Can you tell us something about it? What specific controversies are you referring to?

Our specialty is made of controversies. In our book we tried to visit the most important: those related to the creation and organisation of our specialty – Intensive Care Medicine - those related to the multiple options (antagonic or complementary) needed to provide safe and effective care to our patients, those related to the ethical issues of our practice and to the limits of our intervention. Since from debate comes the light, we focused on having these and other major issues discussed by the best experts on the topic. ■

Highlights from the I-I-I Blog (I expert, I question, I answer)

A selection from the ICU Management & Practice I-I-I blog. Have you got something to say?

Visit https://healthmanagement.org/c/icu/list/blog or contact editorial@icu-management.org

Jeremy M. Kahn

Professor of Critical Care Medicine and Health Policy & Management - University of Pittsburgh School of Medicine and Graduate School of Public Health, USA

What's the Future of Intensive Care Medicine?

"I envision a future in which there are not more, but fewer ICU beds. These will care for sicker patients than at present, but using the same technology in smarter ways. The story of technology in healthcare is that costs have been driven up, but outcomes for patients have only modestly improved. A few technologies such as mechanical ventilation and dialysis have dramatically improved outcomes, but the rest improve outcomes at the margins. I would like to see an ICU that is smaller, that cares for sicker patients, that emphasises inter-professional and family centred care, but in a human way that is less reliant on fancy bells and whistles, and is much more efficient and cost-effective."

See more: https://healthmanagement.org/c/icu/post/what-s-the-future-of-intensive-care-medicine

Flavia Machado

Professor and Chair of Intensive Care - Anesthesiology, Pain and Intensive Care Department Federal University of Sao Paulo; CEO - Latin America Sepsis Institute, Brazil

How Can We Improve Gender Parity in Critical Care Medicine?

"I think what is important is to have the leaders proactively thinking about the gender issue. Examples? Faculty members need to be inclusive and to mentor young women and to include them in their plans, creating the conditions to allow their participation in committees and boards preparing the next generation of leaders. Journals need to include women in their editorial boards. Conference organisers must include females in the scientific committee as this will naturally lead to a higher inclusion of women as speakers in the event. Societies need to include women in their boards and in their guidelines committees. Of course, all these processes need to be based on expertise. We do have enough experts in all fields of critical care to allow participation. We don't need to be patronised. We only need to get away from conscious and unconscious bias and to have people proactively thinking on gender balance."

See more: https://healthmanagement.org/c/icu/post/how-can-we-improve-gender-parity-in-critical-care-medicine

Bruno Tomazini

Attending Physician, Intensive Care Unit - Sirio Libanês Hospital and Hospital das Clinicas da Universidade de São Paulo, Brazil

How Can We Improve the Use of Antibiotics?

"Antibiotic Stewardship Programmes might be the answer we were looking for. For more than two decades this idea of a multidisciplinary and multifaceted strategy aimed to ensure rational antibiotic use among other things has spread, and its benefit has been proven, from reducing costs to decreasing *Clostridium difficile* infection rates, with everything in between. This makes perfect sense. A multilevel intervention to solve a huge problem. It's impossible to think we can overcome this issue with single-minded interventions like good doctors with some knowledge about antibiotic usage; there are too few of them. Like everything in critical care, this is a team effort."

See more: https://healthmanagement.org/c/icu/post/time-goes-by-and-antibiotics-linger-on

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30-1JUN Euroanaesthesia 2020
Barcelona, Spain
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