Features
The future of intensive care

Peter Pronovost, director of the Armstrong Institute for Patient Safety and Quality at Johns Hopkins (Baltimore, MD, USA), starts with an example. "Imagine if Boeing were putting together an airliner and the maker of the landing gear were to say 'we're not going to send a signal to the cockpit to tell you if the landing gear is up or down, you're going to have to guess'." To state the obvious, a stipulation of that kind would stymie the whole deal. But what if it did not? "Imagine if Boeing said 'that will kill people and cost a lot of money, but if you don't want to send the signal, don't worry about it'", continues Pronovost. "That is essentially what we as health-care providers are doing when we buy devices for the intensive care unit that can't talk".

Preventable harm is thought to be the third leading cause of death in US hospitals. Mortality rates in most intensive care units (ICUs) hover around 10–20%, equating to roughly 200 000 patients per year across the country. It is impossible to define how much of this excess mortality is attributable to imperfectly designed ICUs—a category in which Pronovost believes all existing ICUs belong—but it is likely to be substantial. Take the example of acute lung injury, for which lung protective ventilation can reduce mortality by 10%; in practice, patients with acute lung injury in the USA receive this intervention only 20–40% of the time.

Of course, it could be argued that this failing is simply down to careless clinical oversight. But patients in the ICU are vulnerable to about 12 potential adverse developments (eg, sepsis), each of which has a checklist, and each checklist contains several items, each of which

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has to be done several times a day. Added together, there are some 80–150 precautionary measures that need to be undertaken for every patient every day. It is an awful lot for a clinician to keep in mind. "The amount of data you have to assimilate and pull together to help you make decisions is exponentially increasing", notes Carl Waldmann (Faculty of Intensive Care Medicine, London, UK). And, as things stand, the devices in the ICU are not easing this burden.

Creating a system whereby the mechanical ventilator can communicate with the electronic health record to ascertain the patient's height and thereby calibrate the requisite breath sizes for lung protective ventilation would be quite simple. But not only does such a system not exist, today's ventilators do not even contain built-in wireless cards. "Cameras have them, iPhones have them, Android devices have them, but ventilators do not; it is incredible—an absolute lack of connectivity", says Neil Halpern (Memorial Sloan Kettering Cancer Centre, New York, NY, USA).

Moreover, just as a manufacturer of landing gear has no reason to refuse to include a signal to the cockpit, manufacturers of medical equipment would not see their interests damaged by allowing their devices to communicate with other devices in the ICU, particularly the electronic health records. "Traditionally, vendors have been so focused on the performance of their devices, they haven't looked at other things", explains Halpern. "The need for interoperability between devices and middleware [software that connects two otherwise separate applications] has not been intuitively obvious to health-care device companies—they are only now beginning to recognise that the devices they manufacture are health informatics platforms with data that must be transmitted to other systems."

Pronovost and his colleagues at Johns Hopkins hope to change all that. In their Learning Lab, they plan to develop an ICU of the future, adapted from Lockheed Martin's Naval Submarine 'Area 51' lab. "This ideal ICU lab will allow rapid prototyping, testing, and iteration of ideas", explains Pronovost. The aim is to apply modern techniques of software engineering to the ICU. The Learning Lab, which receives funding from the Betty and Gordon Moore Foundation, will be a testing ground, simulating real-life experiences; successful ideas can then be further examined in the ICUs of Johns Hopkins Hospital.

"If you look at a cockpit today, it is much simpler than 30 years ago, when there were hundreds of knobs and dials; today, the pilot sees what he needs to see", Pronovost notes. "But ICUs are more dangerous than they were 30 years ago; systems are not integrated, and there is no sense of prioritisation." He cites the examples of alarms—ICU nurses

answer a false alarm every 94 s. In such circumstances, alarms cease to be galvanising forces, and clinicians start to ignore them. Vendors are aware of this problem, and they have responded by making alarms louder and more irritating. "You have this arms race, and the least important alarm can get the doctors' and nurses' attention because of the way it is configured", says Pronovost. Under the current system, vendors have no reason to work together, and this is clearly not in the patient's interest. An integrated ICU, such as that envisaged by the Learning Lab, in which the various alarms were appropriately prioritised would overcome this problem. "The lack of an integrated lab results in diagnostic errors, failures to identify deteriorating patients, communication errors, and inefficient work", concludes Pronovost. All of which contributes to worker stress and burnout, which itself leads to further error.

Underlying these problems is the issue of open application-programming interfaces. An early project in the Learning Lab will look at using such interfaces to permit communication between the electronic health records and infusion pumps. Currently, changes to the doses given by patient-controlled analgesia pumps have to be double-checked, meaning that a nurse has to spend 10 min or so hunting down a colleague; multiply this time by the number of dose changes across the ICU, and 16–20 nursing hours are wasted every day. Allowing the electronic health record to communicate directly with the infusion pump will have obvious benefits. There is, however, a sizeable obstacle. "The infusion pump and other health-care devices move data in proprietary languages", explains Halpern. "But the electronic health record is looking for data in a standardised language; the conversion of proprietary language to an acceptable language, that's the interoperability challenge, and to date there has been very slow progress." Johns Hopkins' software engineers believe that closed interfaces make it 100–200 times harder to extract information from electronic health records. Unless vendors move to a system of open interfaces, which could require some kind of regulation or incentive, an integrated ICU will remain a pipedream.

Halpern is confident that handing over control of the settings of important ICU equipment to computers, if properly handled, will not compromise patient safety. "Look at the alternative", he says, "harried nurses writing stuff down or manually inputting the data." In the case of the infusion pump, a nurse would still have to confirm and activate the device. Similarly, ventilators have to be set manually. Moreover, receiving information systems could easily incorporate a button used by nurses to validate the data as it arrives.

"The way forward is better informatics and there is a lot of automation that can take place in the ICU environment", agrees Waldmann. "But you would have to have clinicians intricately involved from the beginning."

Currently, vendors manufacture devices with scant clinical input; these devices can be purchased by hospital managers, who might not necessarily consult the ICU physicians. Furthermore, a device is not always tested under the conditions in which it will eventually be used. The first a clinician might see of it is when it enters the ICU.

There can be insurmountable usability issues; indeed the device might even make things worse—pulmonary artery catheters were used indiscriminately for about 20 years before evidence emerged that they might have been harming patients. If physicians are to consult with manufacturers, they would have to navigate issues related to conflicts of interest. But Waldmann believes that the only way to guarantee progress is for clinicians to collaborate with vendors. "If we don't work with industry, they won't develop the right tools—they need our advice, and we need the best equipment", he told *The Lancet Respiratory Medicine.*

Establishing several university-based mock ICUs, such as that at Johns Hopkins, bringing together multidisciplinary teams from engineering and medicine to identify problems and seek and test solutions would go some way to guiding the development of ICUs, the history of which has been largely characterised by incremental and accidental changes. "Last year, the US spent US$800 billion on health information technology, and the evidence is that it hasn't improved productivity or patient safety", notes Pronovost. The engineers at Johns Hopkins reckon that simply improving ICU design could raise productivity by half. The USA spends roughly 1% of its gross domestic product on ICU care (the UK, which has proportionately far fewer ICU beds, spends about 0·1% of its GDP on such care).

"At Apple, Steve Jobs brought together hardware, software, and content", says Pronovost. "That's what we want in protocols, displays, and checklists; the hope is that 3 years from now [a hospital or health-care provider] can go and buy an integrated ICU that won't harm patients." It is a huge task, necessitating collaboration between health systems, researchers, and private companies—"the hospital informatics teams would have to buy in, ICUs cannot do this on their own", notes Halpern—and an array of vendors. And bringing it all together would probably require a systems engineering company. But the first step has to be opening the programme interfaces.

"[This] will make it easier to write apps that predict patient risks, recommend effective therapies, and learn what worked and what did not work", says Pronovost. He compares the prevailing situation to Apple only allowing its own engineers to write apps. "If you free the data silos, innovation will just explode, and it will radically reduce health-care costs", he argues. "We could get enormous gains by linking the devices and being smarter about technology".

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