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WHAT'S NEW IN INTENSIVE CARE

Intensive care medicine in 2050: towards critical care without central lines

Jean-Louis Vincent[1*], Frederic Michard[2] and Bernd Saugel[3]

Central venous catheters (CVCs) are still widely used in critically ill patients to enable certain drugs to be administered safely, to facilitate blood sampling, and for the measurement of central venous pressure (CVP) and central venous oxygen saturation ($ScvO_2$). They are also used occasionally to perform transpulmonary thermodilution measurements and to calibrate devices that use pulse wave analysis. Although CVC-related infectious complications have decreased over time and CVC placement is safer with ultrasound guidance [1], CVC use is still associated with potential traumatic, hemorrhagic, thrombotic, and infectious complications. Recent and continuing technological innovation now makes it possible to imagine an intensive care world without central lines.

Alternatives for drug administration and blood sampling

By 2050, it is likely that some solutions (including vasopressor agents, parenteral nutrition, or irritant drugs) will be given via peripheral venous or "midline" catheters, even in critically ill patients. Insertion of these catheters will be safe and easy—even in obese patients and when veins are not visible through the skin with the naked eye—because it will be facilitated by visualization technologies (Fig. 1). Transillumination or near-infrared light will help to identify poorly visible veins of small diameter in challenging situations, e.g., in critically ill patients with edema or circulatory shock [2]. Automatic robotic systems combining infrared light and ultrasound will be available that rapidly and safely insert peripheral venous catheters and draw blood [3]. Working under aseptic conditions, these robots should help to minimize the incidence of peripheral venous catheter-related infections.

To limit the need for parenteral infusions, it is likely that many pharmaceutical compounds will be administered as liposomes, proliposomes, microspheres, gels, prodrugs, cyclodextrins, or nanoparticles using alternative routes (e.g., nasal, pulmonary, or transdermal drug delivery) [4]. If administration via peripheral venous access is unavoidable, active agents (e.g., vasoactive or chemotherapeutic agents) will be encapsulated and only released when they reach the central circulation.

By 2050, the need to withdraw blood in critically ill patients will probably be greatly reduced, because it will be possible to monitor concentrations of multiple substances in the blood in real time using electrochemical sensors that will either be patient-attached (ex vivo) or biocompatible and implantable (in vivo) [5]. Advances in nano-engineering will result in the availability of implantable nanosensors with a size of less than 1 μm that could even circulate in the blood and produce optical, acoustic, or electrical signals to provide the results of blood analysis [6]. Further technical developments of sensor materials may enable crucial blood values—such as blood gases, hemoglobin, glucose, and lactate—to be monitored continuously in a completely non-invasive manner using wearable and wireless transcutaneous sensors (Fig. 1) [7].

Alternatives for hemodynamic monitoring

The CVC plays an important role in current hemodynamic monitoring, including for measurement of CVP and $ScvO_2$. By 2050, hemodynamic monitoring will have changed dramatically, as broadly summarized by the NEWS mnemonic (Non-invasive, Ergonomic, Wearable, and Smart) [8]. Echo-Doppler techniques will have decreased the need for CVP measurements to reflect right ventricular function. Pocket echo devices

*Correspondence: jlvincent@intensive.org
[1] Department of Intensive Care, Erasme Hospital, Université libre de Bruxelles, Brussels, Belgium
Full author information is available at the end of the article

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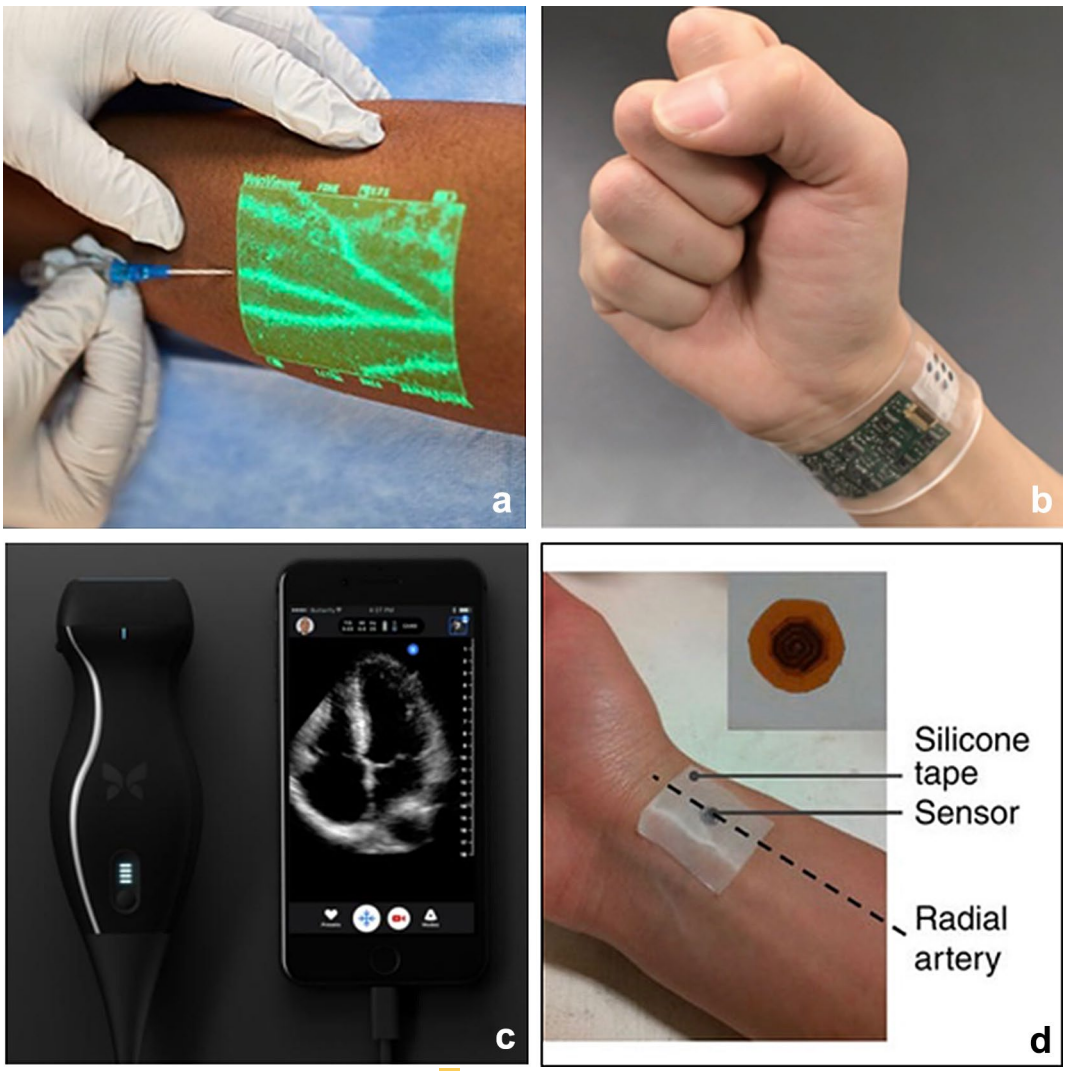

Fig. 1 Examples of innovations that may help to decrease the use of central venous catheters and their related complications. **a** New visualization technique to facilitate peripheral catheter insertion (VeinViewer®, with permission from christiemed.com); **b** wearable sensor enabling electrolyte monitoring from perspiration (from [7] with permission); **c** pocket echo probe for point-of-care ultrasound evaluations (iQ, with permission from butterflynetwork.com); **d** wearable sensor enabling continuous monitoring of arterial pressure (from [12] with permission)

are already available and affordable; some are wireless and can be connected to smartphones (Fig. 1). Intensivist training in echocardiography is more widely available and continuously improving with better simulation and virtual reality systems [9]. Hence, by 2050, all acute care clinicians should be qualified to perform qualitative evaluations and have an echo probe (if not an echo pen) in their pocket. Hemodynamic evaluation will also be routinely used on the regular floor, in the emergency room, and in the ambulance, so that valuable information will already be available at the time of ICU admission.

Even though a CVP value does not predict fluid responsiveness well, repeated measurements are useful to assess a patient's response to fluids [10]. By 2050, blood flow variables will likely be measured non-invasively, so that the effects of a fluid challenge will be easily determined by the automatic assessment of changes in stroke volume and cardiac output. As previously envisioned [11], it may be possible for passive leg raising maneuvers to be performed automatically by motorized beds, with computer-controlled infusion pumps that will not administer fluid (via a peripheral vein!) when patients are identified as non-responders. There may even be wireless and wearable sensors that can be positioned on the wrist or the neck to continuously monitor blood pressure [12] (Fig. 1) and compute stroke volume from improved pulse

wave analysis algorithms, or adhesive suprasternal Doppler sensors that continuously monitor ascending aortic blood flow.

Thermodilution measurements may no longer be needed, having been replaced by ultrasound, intracardiac sensors, electrical impedance tomography, and other 3D and holographic imaging techniques currently under development [13]. To measure cardiac output as accurately as by echocardiography, algorithms for pulse wave analysis will no longer need intermittent calibration, which could be done anyway with the aforementioned suprasternal sensors and automatic velocity–time integral (VTI) software.

$ScvO_2$ values will still provide valuable information about the balance between oxygen delivery and oxygen needs, but there will be no need to measure $ScvO_2$ directly with a CVC. Indeed, near-infrared spectroscopy (NIRS) sensors, which are already used today to monitor brain oxygenation through the skull, could also, when positioned next to the internal jugular vein, be used to measure $ScvO_2$ non-invasively [14]. More direct means of estimating tissue oxygenation may also be available; for example, techniques that measure mitochondrial activity through the skin are already emerging [15].

Conclusions

Technological developments are providing improved peripheral access, alternative methods of blood analysis, and new means of delivering pharmaceutical products, which will ultimately reduce the need for CVC insertion. Technological advances will also make it easier to monitor patients non-invasively while guarding the accuracy and reliability previously only possible with invasive devices. As use of these new technologies increases, prices will decrease and enable even more widespread uptake; by 2050, we believe that CVCs will have become obsolete and will no longer form any part of ICU patient management.

Author details
[1] Department of Intensive Care, Erasme Hospital, Université libre de Bruxelles, Brussels, Belgium. [2] MiCo, Denens, Switzerland. [3] Department of Anesthesiology, Center of Anesthesiology and Intensive Care Medicine, University Medical Center Hamburg-Eppendorf, Hamburg, Germany.

Compliance with ethical standards

Conflicts of interest
JLV has no conflicts of interest to declare. FM is the managing director of MiCo, a Swiss consulting firm specialized in medical e-nnovations. BS collaborates with Pulsion Medical Systems (Feldkirchen, Germany) as a member of the medical advisory board and has received honoraria for giving lectures and refunds of travel expenses from Pulsion Medical Systems. He has received institutional research grants, unrestricted research grants, and refunds of travel expenses from Tensys Medical (San Diego, CA, USA). He has also received honoraria for giving lectures and refunds of travel expenses from CNSystems Medizintechnik (Graz, Austria). He has received research support from Edwards Lifesciences (Irvine, CA, USA).

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