Exploring Ongoing Challenges in Anesthesia Technology: A Proposed “To-Do” List

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Revision A
November 14, 2021

The year 2022 marks 50 years since I received my undergraduate physics degree and 40 years since my graduation from medical school and entry into anesthesiology training. Over these decades I have personally witnessed a great many technical innovations that have contributed enormously to improved perioperative patient safety. Hopefully, we will see further innovations that will also improve anesthesia delivery (Table 1). Such technological developments in patient monitoring have had genuine salutary effects on anesthesia safety and patient well-being, and this important fact is reflected in drops in medical liability insurance costs as new patient monitoring methods came into practice over time. This has been particularly true for pulse oximetry; in the “scale of honor” for patient monitoring equipment, the pulse oximeter ranks near the top, serving an inexpensive yet particularly useful tool to improve situational awareness and promote patient safety.

Still, all this marvelous technology gives the anesthesiology world some things to be concerned with. The cognitive load associated with "keeping all gadgets running smoothly" is higher than in the distant past when an eye on the chest and a finger on the pulse constituted the two main modalities available by early anesthesia pioneers. Not only do we now worry about whether our monitoring and drug delivery equipment are working okay and have been programmed correctly, but care must also be taken that when troubleshooting a piece of hardware that one's attention is not drawn away from the patient for too long a period.

In the perioperative world, many individuals find themselves frustrated that that are a still a great many practical problems related to Operating Room (OR) technology that remain to be addressed. In many cases the solution to these problems lies not in technical advances in fields such as AI but simply in better design and planning on the part of equipment manufacturers and operating room architects. Example problems include [1] procedure rooms and ORs too small to support the equipment used for modern endoscopy or similar procedures, resulting in poor workspace layouts that impair access to the patient or to needed equipment; [2] insufficient electrical outlets in which to plug in monitors, infusion pumps, video laryngoscopes, ultrasound machines, endoscopes and other mission-critical items; [3] electrical outlets with spacing such that plugging in a single "wall wart" type power supply brick prevents access to all neighboring outlets; and [4] electrical equipment such as OR tables with electrical cords too short to be plugged into local wall outlets without producing a tripping hazard.

The introduction of a C-arm X-ray machine into the Operating Room or procedure room can require wide-spread rearrangement of the anesthesia end of things, which may include moving the anesthesia machine, hot air warmer, sharps box, stands, stools and chairs in some cases. Moving equipment increases the risk of subsequent malfunction, such as power cords that have become dislodged with the move.

In addition to the need to tackle the above challenges, manufacturers should consider making their equipment easier to use by employing methods such as [1] placing QR code labels on equipment that directs users to a web page containing written and video instructions, or even embedding educational videos directly into the equipment itself; [2] conducting formal ergonomic testing on their products to avoid instances of "injury by ergonomic failure", such as occurred with the Abbott Lifecare 4100 PCA Plus II infusion pump (Vicente et al. 2003) [3] , standardizing the mapping of arterial blood oxygen saturation to tone pitch in pulse oximeter equipment (Loeb et al. 2016); and [4] offer secure remote controls like those used at home for televisions or other methods (e.g., secure smart phone apps) that allow clinicians to operate patient monitors more conveniently, for example avoiding the need to stretch into awkward positions to restart a BP cycle should the patient monitor assembly end up placed in an suboptimal location as a consequence of suboptimal workspace layout.

One technical innovation that I hope will come to be widely available is to use signal fusion algorithms so that (for instance) patient monitors will not display a false asystole alarm resulting from ECG technical problems when arterial pressure and pulse oximeter tracings are both present with normal waveforms (Tejedor et al. 2019). Signal fusion technology and related innovations would be expected to reduce the time clinicians spend dealing with false alarms and troubleshooting malfunctioning equipment, thereby allowing for improved patient vigilance.

Yet another poorly met need is for anesthesiology journals and anesthesiology society newsletters to publish Consumer's Report style reviews of anesthesia equipment to aid departments in informed equipment procurement (Doyle 2007). It is puzzling that while anesthesia journals routinely review inexpensive anesthesia books, I have rarely seen much more expensive anesthesia machines and patient monitoring equipment being similarly evaluated.

I like to teach anesthesia residents various practical techniques that can be used to improve situational awareness when technological failures occur. As an example, for various reasons automatic blood pressure (BP) modules occasionally fail to provide a measurement. One BP backup technique I teach is to place a manual cuff on the side of the arm holding the pulse oximeter. This arrangement allows for "quick and dirty" systolic BP estimate by noting the pressure at which the pulse oximeter tracing vanishes. Add a stethoscope to the setup and you can get diastolic pressure too. Such “practical tips” can be viewed as algorithms for obtaining data under adverse conditions.

It is worth pointing out that not all developments in anesthesia have passed the test of time, such as the use of hydroxyethyl starch products or assessing the depth of anesthesia using lower esophageal contractility measures. In addition, note that tests that are useful to some clinicians may be less so to others, such as the intraoperative use of BIS electroencephalographic analysis. Such realities demand a critical eye by anesthesiologists in assessing new clinical developments.

In conclusion, anesthesia technology is saving lives, but when this technology is not working properly the situation can dramatically add to the anesthesiologist’s task list.

- **Wearable sensors.** These sensors, now in various phases of development, include miniature devices worn on one's wrist that can monitor heart rate and rhythm, blood pressure, and arterial oxygen saturation. The latest Apple Watch does some of these things already. Research into non-invasive glucose, hemoglobin, cardiac output, and ejection fraction measurements are underway in laboratories around the world.

- **Cloud computing.** It is expected that wearable sensors will work in conjunction with local networks and cloud computing to facilitate remote patient monitoring, both in the hospital setting as well as at home and on the go.

- **The internet of things (IoT).** This technology will help ensure that conventional and wearable medical devices can communicate safely, securely, and reliably, allowing clinical data network systems to capture, share and analyze clinical data.

- **Machine learning (ML) and predictive analytics.** Mathematical models predicting poor surgical outcomes now exist, as well as models for predicting hospital length of stay, perioperative mortality, delirium, renal injury, and a host of other undesirable clinical outcomes.

- **Automated systems.** Artificial intelligence-based systems that maintain neuromuscular-blockade, hemodynamic or level of consciousness targets during anesthesia are in development; preliminary studies suggest that such systems may outperform humans acting alone.

- **Telemedicine in anesthesiology and ICU medicine.** Preoperative virtual visits with histories being done remotely and with electronic stethoscopes allowing teleauscultation have been a reality for some time. Satellite-based intraoperative teleanesthesia using a remote system that collects intraoperative physiologic data and supports videoconferencing has been used experimentally. Similar arrangements have been developed for the ICU setting.

Table 1. Some new technological innovations that will likely impact on future anesthesia delivery (Bitterman et al. 2020; Hofer et al. 2020; Seger and Cannesson 2020; Seshadri et al. 2020)

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