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Technology in anesthesiology: friend or foe?

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The field of medical technology has undergone significant advancements over the years, from the use of ancient scalpels, forceps, and sutures to complex devices like intraoperative MRI suites, artificial intelligence-enabled monitors, and robotic surgical systems. These advancements have had a profound impact on the way we diagnose, treat, and prevent diseases, and have significantly improved the quality of life for millions of people around the world. As we move forward, it is important to reflect on the direction of medical technology and consider the potential risks and benefits of new advancements. We must also ensure that these technologies are accessible to all and that they are used ethically and responsibly. There is still much to be discovered and developed in the field of medical technology, and it is up to us to ensure that we are moving in a positive direction that benefits everyone.

KEYWORDS

technology in medicine, medical tools, medical equipment, medical skills, technology in anesthesia, artificial intelligence, monitoring, innovation

Introduction

Since the Stone Age, mankind has incorporated tools and "devices" to improve everyday life and augment their ability to carry out tasks. From primitive eating utensils and the first wheel all the way to modern-day high-fidelity simulators, wireless communication, space stations, and artificial intelligence, "technology" has become a constant companion to our human race continually extending a technological reach beyond our innate abilities. The healthcare industry in particular continues to produce innovative technology employing more accurate and less invasive modalities to detect, diagnose, monitor, and treat a multitude of conditions. While these tools may appear to be aiding physicians in their daily duties, some may argue that advancing technology is gradually leading healthcare providers down a path of machine reliance rather than the use of critical thought, basic skills, and traditional medical concepts. In this review article we aim to highlight some of these advancements with a discussion on the benefits and drawbacks of such technology in medicine, specifically focused on clinical anesthesia practice.

The stethosphone—"stethoscope"

Direct, also known as "immediate" auscultation was used by Hippocrates, who lived in 460–370 BC (1). The practice of percussion and direct auscultation by ear was commonplace until Rene Laennec's invention of the stethoscope in 1816. The stethoscope started out as cylindrically-rolled piece of paper and nowadays employs an array of enhancements that allow a clinician to amplify, record, visualize, and automatically analyze auscultatory findings (2).

Pros: The stethoscope has allowed caregivers to more accurately describe internal organ sounds and pathophysiology while avoiding the limitations of immediate auscultation. An enhancement is an adapter that connects to the stethoscope and compares the sounds to an online database of patient-specific recordings, allowing the clinician to detect new pathological findings they may have otherwise missed.

Cons: On the other hand, stethoscopes—as well as other clinician-held equipment—have been implicated as sources of infection as they are not usually adequately cleaned (3). Basic auscultation skills may be subjective and challenging to teach and hence erroneous conclusions may be made by a provider who is not well-trained.

Friend or foe? The stethoscope remains one of the most recognizable symbols for physicians and other healthcare staff and a useful tool for bedside examination and diagnosis. In some ways, the old stethoscope has been pushed aside by dramatic improvements in imaging and sound technologies which in many circumstances have allowed more precise diagnoses. In terms of infection control, the stethoscope—just like any other piece of hand-held medical equipment—must be cleaned routinely and appropriately.

Sphygmomanometry

Skin palpation as a proxy measure of pulse strength was described by the early Egyptians to quantify blood pressure and physicians have carried that practice into the 19th century. Currently used non-invasive blood pressure measurement was introduced in the middle of the 18th century by Stephen Hales (4). Beginning in the 1910s, systolic and diastolic blood pressures began to appear more regularly in clinical case reports. More recent advances include continuous and non-invasive blood pressure measurement through a device located on the finger, wrist, or chest.

Pros: Blood pressure measurement is a standard in medical management and is one of the modifiable risk factors against morbidity and mortality. Continuous blood pressure measurement provides more information than single time-spaced values and reveals the trend especially in a critical care setting. This allows real-time titration of crystalloids vasoactive medications and prompts for an earlier interventions to improve perfusion of end organs (5).

Cons: Aneroid manometers where the pressure is measured with an analog needle system may require more effort to read and calibrate (6). Invasive arterial blood pressure measurement clearly introduces the risk of infections, thrombosis, and bleeding and it usually carries the debate of whether invasive values correlate with non-invasive ones (7). The choice of sphygmomanometer cuff size and location may also influence measurements (6, 8).

Friend or foe? In some cases readings can be influenced by psychological states within the patient as happens in "white coat hypertension". In the PAMELA study, individuals with "white coat hypertension" were found to be about 15% of general population (9). The ability to use technology to track a patient's blood pressure at home can significantly increase a provider's ability to notice successes and failures in their hemodynamic management and thus direct therapy accordingly. Postoperatively, continuous blood pressure measurement may be the answer given that significant postoperative blood pressure perturbations are missed nearly half the time (10).

Tissue oxygenation monitoring

In the early days of interventional medicine and especially anesthesia delivery, tissue oxygenation status was determined by observing the skin tone and evaluating the degree of cyanosis. The next best option was to perform serial blood drawings with laboratory analysis, a method that was superior but did not realistically provide real-time monitoring. This evolved into non-invasive peripheral oxygen saturation monitors which became a standard monitor in all anesthetic interventions. More advanced technologies lead to the utilization of near-infrared spectroscopy (NIRS) and cerebral oximetry.

Pros: Non-invasive peripheral oxygen saturation measurement has been shown to improve outcomes and decrease adverse events in patients. This monitor has undergone several upgrades over the years and can provide information on heart rate, oxyhemoglobin saturation and concentration, pulse pressure variation, as well as peripheral arterial resistance and potentially cardiac output. NIRS has been demonstrated to predict postoperative neurological outcomes in some literature (11).

Cons: For non-invasive oxygenation monitoring the main problems are limitations of sensors. A peripheral oximetry probe using light as a measurement modality may be limited particularly in patients with darker skin color, topical dyes (nail polish), peripheral arterial disease, or presence of confounding elements in blood (as in gas poisoning) (12, 13). Oximetry monitoring systems also have differing program algorithms adjusting for movement artifacts, temperature fluctuations, and a variety of signal disruptions, with many of these unable to be independently validated. Since pulse oximeters are typically calibrated for SpO_2 between 70% and 100%, displayed values below 70% should only be considered qualitatively and not quantitatively (14).

Friend or foe? The introduction of non-invasive continuous pulse oximetry has allowed us to monitor trends of desaturation and re-saturation to guide our clinical management in real time. This is one of the essential monitors in a variety of clinical conditions and is unlikely to be phased out anytime soon. Advancing our technology to measure brain oxygen saturation non-invasively may have favorable implications on anesthetic monitoring and surgical recovery.

Electrocardiography

The first electrocardiogram (ECG) was presented as a room-full of bulky equipment. With time it has turned into ambulatory ECG monitoring and has undergone continuous technological evolution since its invention and development in the 1950s. Since commercial introduction in 1963, Holter monitors have advanced from single channel to 12-channel recorders with increasingly portable storage media (15).

Pros: Real-time monitoring of cardiac electrical activity (rate and rhythm) is indispensable especially in acute conditions. Current technology allows for more wireless integration of ECG monitors with mobile devices giving patients more control, input, and autonomy regarding their medical care. Aberrant heart rhythms can be detected long before cardiovascular collapse occurs, mitigating the delay in receiving appropriate care especially in potentially life-threatening conditions.

Cons: Reliance on portable and out-of-hospital cardiac monitoring raises the issue of accurate identification and triage of resultant monitor outputs. In the absence of a trained professional reading the monitor output in real-time, patients may be subjected to undue anxiety and present with more frequent false alarms due to artifacts. Also, medical personnel who are reading and monitoring ECG has to be aware that certain commonly used medications can cause ECG changes. Portable monitors are limited by the availability of a wireless connection to a server, cost, and compatibility with patient-owned devices.

Friend or foe? While portable ECG monitoring has found more uses in outpatient medicine, the technology itself remains necessary in the perioperative period. Continuous postoperative cardiovascular monitoring is the future and may be the ideal means to capture the more elusive postoperative complications we typically miss (10).

Electroencephalography

Electroencephalography (EEG) reads scalp electrical activity generated by brain structures. One of the fathers of EEG is Hans Berger (16). Bispectral index (BIS) monitors are generally developed with anesthesia providers in mind. They use empirical EEG measurements displayed as numerical values from 100 to 0, where 100 indicates full awareness and 0 denotes minimal cortical activity/brain death). BIS was initially developed to detect rare cases of patient awareness during surgery. Anesthesiologists also use BIS to titrate anesthetic dose based on BIS readings, commonly maintaining a BIS reading between 40 and 60 for surgical levels of anesthesia (17).

Pros: With brain electrical activity being continuously decoded, research has been conducted to develop EEG applications that go beyond cables and wires (controlling a wheelchair, moving the cursor of a screen, or diagnosing epileptic patients). It is known that patients with subarachnoid hemorrhage are at risk for seizures or delayed cerebral ischemia and they can be detected with continuous EEG monitoring (cEEG). Nowadays, cerebral ischemia can be easily detected with EEG at a reversible stage.

Cons: The main disadvantage of EEG recording is poor spatial resolution. As the electrodes measure electrical activity at the surface of the brain, it is difficult to know whether the signal was produced near the surface (in the cortex) or from a deeper region. Technical expertise of the EEG operator may also affect the quality of the recording, and hence analysis, of the data collected. The presence of hair can disrupt EEG recordings, sometimes necessitating head shaving or the application of a special gel to avoid errors in the EEG signal (18, 19). In some cases, over-reliance on the BIS number may lead to ignoring other important clinical signs of awareness (such as trends suggested by vital signs and correlation with surgical stimulation).

Friend or Foe? Electroencephalography is a rapidly developing science. It can aid in identifying previously less-understood brain dysfunctional states and guide treatment modalities for those conditions. Short of misinterpreting the recordings, EEG signals are a valuable addition to medical practice.

Laryngoscopy and bronchoscopy

Laryngoscopy is a practice that has been employed for decades and is vital for healthcare practitioners to effectively perform endotracheal intubation. Many modifications have been implemented since the laryngoscope was first introduced in the 1800s and the most readily recognized form is direct laryngoscopy (20). Video laryngoscopes have become a staple in advanced airway management worldwide and come in various shapes and forms.

Pros: Video laryngoscopes have been in use for several years now and have been shown to improve chances of endotracheal intubation and improved visualization of vocal cords (21, 22). Flexible bronchoscopes are routinely used by pulmonologists and are also an important tool in the anesthesiology armamentarium especially in cases of awake endotracheal intubation or distorted airway anatomy.

Cons: Mastery of direct laryngoscopy remains a must for all providers especially for emergencies and unplanned endotracheal intubations. By using only modern techniques, direct laryngoscopy skills may fade over time and lead to failed airway outcomes. Some evidence suggests that the use of video laryngoscopy can result in worse airway outcomes in certain scenarios despite improved visualization of the intubation route (23).

Friend or foe? It is important to highlight the value of basic examination and intervention skills, which applies well to direct laryngoscopy. A trainee routinely relying on video laryngoscopy at a tertiary care center may face difficulty with airways at a rural center where resources are limited. Basic direct laryngoscopy skill mastery is crucial, while using advanced tools like video laryngoscopy and flexible bronchoscopy is helpful when indicated.

Ultrasound

During World War II, John Julian Wild cared for many patients who developed fatal paralytic ileus secondary to blast injury. Finding it difficult to distinguish between obstruction and ileus, Wild resorted to ultrasound as a diagnostic tool to differentiate between these entities (24). Since then, ultrasonography has been improved to allow accurate evaluation of a wide array of physiologic and pathologic structures.

Pros: Real-time ultrasound scanning while performing vascular access, neuraxial access, or neural blockade has been implicated in fewer puncture attempts, reduced adverse events, smaller local anesthetic volume requirement, and faster conclusion of the procedure (25–28). Arterial and venous mapping can also be done prior to a planned arterio-venous fistula to evaluate vascular size and detect occult stenosis or occlusion (29).

Cons: Setting up the ultrasound machine, entering patient information, and optimizing operator position may all be significantly time-consuming on some models. Current devices may lead to erroneous diagnoses due to artifacts and suboptimal processing power. Some clinicians express concern that their landmark-based skills would diminish from lack of use which could potentially place patients at a disadvantage in centers where the technology is not available (26).

Friend or foe? Ultrasonography has proven to be a valuable tool in the clinician armamentarium. When proper training is performed, ultrasonography can sway the pendulum towards better patient safety and satisfaction and overall decreased cost from complications (26). That being said, it should not be imposed on clinicians achieving similar results with landmark-based techniques as long as the patient safety and satisfaction goals are maintained (30).

Neuromuscular blockade monitoring

The mechanism of action of curare was mentioned in western literature as early as the 1500s, at which time it was used in blowgun darts as a poison (31). Progression of technology has led to the adoption of train-of-four (TOF) stimulation to detect the degree of neuromuscular blockade. Newer monitors employ digital acceleromyography or electromyography to provide a truly subjective TOF output, hence eliminating the human factor in "reading" the degree of paralysis by sight or palpation. In modern medicine, reversal agents for neuromuscular blockade are helpful. For example, sugammadex is the first selective relaxant binding agent indicated to reverse the neuromuscular blockade induced by non-depolarizing neuromuscular blocking drugs during general anesthesia to facilitate surgical procedures.

Pros: Although many providers do not routinely monitor muscle paralysis after administering a neuromuscular blocker, this remains an important practice to properly reverse blockade (32). The use of newer monitors provides a more objective means of conducting these measurements and better guides the entire process of recovery from these agents. In one study of older adults who underwent prolonged surgery, sugammadex was responsible for a 40% reduction in residual neuromuscular block and a 10% reduction in 30 days hospital readmission rate (33).

Cons: Neuromuscular monitoring is not globally adopted, and some providers prefer relying on clinical signs. Hence, it may be difficult to promote their use in every case. There is also the theoretical potential for nerve injury when applying a current to a peripheral nerve as well as the pain experienced by a patient who is not properly sedated at the time of stimulation.

Friend or foe? Postoperative residual neuromuscular blockade has been reported to be as high as 40% with the use of reversal agents and 80% without reversal (34), leading to serious morbidity (35). Hence, utilization of TOF monitors must be maintained and improved in order to avoid serious and preventable complications attributed to residual neuromuscular blockade, especially in the perioperative space.

Anesthesia delivery systems

It was only recently (in the 1800s), that anesthesia was administered using a mask connected to an ether container. This mode of anesthetic delivery was revolutionary in its age and has paved the way for the modern anesthesia machine use on a daily basis (36). What started as a device primarily used to mix anesthetic gases is now a complex array of electronics that can automate ventilation, monitoring of vital signs, anesthetic delivery, and clinical decision support (37).

Pros: The use of closed and semi-closed mechanical ventilation systems has greatly reduced anesthetic gas leakage during procedures as compared to the original open systems. Added safety systems include hypoxic mixture alarm, intrapulmonary pressures, minute ventilation alarms, carbon dioxide absorber, pin index and diameter index safety systems, and backup oxygen and electrical power sources (38, 39).

Cons: Current anesthetic delivery systems have minimized leakage and environmental pollution potential though this risk is not abolished (37). The many machine checks and alarm troubleshooting events require increased attention and risk adding fatigue and stress to the providers. Routine anesthesia machine checks are essential to confirm the full readiness to operate (40). The machine and its tubing and valve systems may also harbor contaminants, potentially contributing to infections (41).

Friend or Foe? The technology incorporated into modern-day anesthetic delivery machines far extends that we encounter in most of our devices, and this technology advancement does not show signs of slowing down. More advanced circuitry translates to safer delivery of anesthesia and more granulated decision support for a better patient outcome.

Patient-controlled analgesia

In more recent years having a physician or nurse remain at the bedside of any one hospitalized patient was deemed an inefficient use of resources. The introduction of patient-controlled analgesia (PCA) pumps has greatly reduced the workload of healthcare workers (42). PCA has progressed since then and electronically-controlled disposable infusion pumps are now commonly used with a potential for monitoring of oxygenation and ventilation (43). PCA devices can be used for intravenous, epidural, intrathecal, or peripheral nerve catheter analgesic administration.

Pros: Patients typically express better satisfaction with pain management when they are more involved in their own care (43). The use of a PCA device decreases the time from analgesic need to delivery as it eliminates the need to request a medication from a caregiver. Current devices have also been reported to decrease unwanted sedation, enhance mobilization, and reduce other post-surgical complications (44).

Cons: Before the current safety features of PCA devices, there was a constant concern for narcotic overdose or inadequate administration (44). Programming the device may introduce complications as mistakes can be made during setup. The use of an indwelling catheter poses a risk for infection, bleeding, and wound dehiscence. A malfunctioning PCA device might lead to significant patient discomfort and increased rates of pain-related readmissions. The most serious complication of PCA therapy is opioid-induced respiratory depression, particularly when a background non-demand opioid infusion is utilized. Although the incidence is low (2.3%), it may lead to respiratory arrest if not treated promptly (45).

Friend or foe? Current PCA devices are improving in terms of function, portability, and safety profile. Their use improves the ability of patients to be discharged earlier after surgery. While the cost of some of the devices may be prohibitive, the advantages they provide in terms of decreased pain-related length of stay, decreased pain-related readmissions, improved patient satisfaction, and enhanced clinician workload well justify their use in daily clinical practice.

Hemodynamic monitoring

Perioperative, and particularly intraoperative, hemodynamic monitoring has seen great interest recently after a period of relative quiet on that front. For the past several years, there has been at least one talk, discussion, or panel on intraoperative hypotension (IOH) and predictive modalities. Additionally, more discussion is being carried on postoperative and hospital ward monitoring of hemodynamics, along with other vitals, with the assistance of newer technologies. IOH is known to be associated with significant morbidity and mortality [A] (46), and its avoidance is a natural next step in the daily tasks of an anesthesia provider. Mitigating IOH, however, is no easy task, especially that it seems to be quite common both in academic and community practice (47).

Pros: The incorporation of technology into anesthetic practice has clearly shown benefit. Predictive algorithms, machine learning models, and sophisticated hemodynamic devices have enabled earlier detection and faster treatment of hypotensive episodes during surgery (48, 49).

Cons: Like all predictive algorithms, hemodynamic prediction models are reliant on primary training data. This data is assumed to be clean and optimized, although experience tells us that little is. The algorithms themselves can be quite complex and unusable by the general public, which renders them less available for scrutiny and improvement.

Friend or Foe? Anesthesia providers have honed their hemodynamic management skills for ages and feel confident in their ability to treat most episodes of IOH. The limitation, however, is the ability to predict the episode and preemptively intervene accurately and over a prolonged period of time. When technology is employed to assist and augment this role, patients are more likely to avoid IOH or spend less time under the threshold. Whether this translates to improved outcomes remains to be proven, although the likelihood of benefit seems to far outweigh that of harm (50).

Artificial intelligence and machine learning

Artificial Intelligence (AI) and Machine Learning (ML) have been developed over decades, but seem to have garnered the most attention in the past few years. All along this time, versions of AI and ML have been contributing to medicine in general and the field of anesthesiology in particular. Between sophisticated patient monitors, closed-loop pharmaceutical delivery systems, and decision support algorithms, few of the daily practices are entirely technology-free.

Pros: AI and ML allow for highly accurate diagnostics and predictions almost in real-time, especially when integrated with the electronic health record (51, 52). The combination of data feeds from a variety of sensors can prove mentally exhausting for a human but is handled in real-time, and quite gracefully, by newer technology (52, 53). The result can look like closed-loop medication delivery and personalized medical and anesthetic care, tailored to particular risk factors and driven by large data analyses (51). Another aspect is the development of high-fidelity, realistic training simulations especially with the aid of virtual reality (VR) and augmented reality (AR), along with detailed unbiased analyses of performance and potential areas for improvement. Last but certainly not least, the use of these integrated systems may prove crucial in the advancement of medical research and innovation (51).

Cons: The more we integrate technology into medical practice, the more vulnerable we are to its risks. Data privacy, data security, legal and ethical dilemmas take the front row. In addition, all algorithms are based on training data, which may not always be as clean and accurate as we presume it to be. And even when the training data is perfect, the algorithms can get complex enough to render them non-explainable and hence sacrificing at least part of their credibility. Furthermore, integration of newer technologies is bound to be limited by challenges posed by the existing healthcare infrastructure and increased cost of acquiring and maintaining these systems (54). On another level, patients may hesitate before trusting AI-driven decisions about their medical care.

Friend or Foe? The days of hoping technology would not seep into everyday practice are long gone. This step in the evolution of medical and anesthetic care is inevitable, but not perfect. The integration of AI and ML into clinical practice, daunting as it may seem, has great potential to assist—not replace—the clinicians (53). A salient discussion point is: When do we become over-reliant to the extent that we lose our basic skills?

When the goals are enhanced safety, improved patient outcomes, and support for healthcare professionals, these technological advances may be our best friends indeed.

Echocardiography

The first experiments in exploring cardiac structures using reflected sound waves were conducted by doctors Inge Edler and Hellmuth Hertz in 1954. The vital part of their success was their ability to record oscillations on a paper over time. Hertz designed inkjet recorders for that purpose. This was the birth of M-mode echocardiography. The development of the pulsed Doppler method in the late 1960s opened up new opportunities for clinical innovation (55–57).

Today, echocardiography has advanced far beyond the realm of cardiac anatomy, function, and perfusion at the bedside, competing closely with other imaging modalities such as cardiovascular magnetic resonance imaging and computed tomography. Our needs seem to be the only limiting factor for this technology.

Pros: Echocardiography is an essential part of practice in cardiology to track myocardial damage and prevent heart failure. Emerging 3D imaging technologies are further enhancing our understanding of the anatomy of cardiac structures and the spatial relationship among them. The assessment of mitral valve pathology by 3D transthoracic and transesophageal echocardiography has been incorporated into routine clinical practice (58). Stress echocardiography has demonstrated substantial clinical relevancy in ischemia detection because of its high sensitivity and specificity both in patients without antecedents of prior intervention and in those previously submitted to percutaneous coronary intervention or coronary artery bypass graft surgery (59).

Cons: The major disadvantage is the need for a learning curve for providing quantitative examinations and interpretations. Physicians must spend considerable time and effort to become expert in these new techniques. Two-dimensional stress echocardiography (2D-SE) has its limitations as multiple views of the left ventricle must be obtained within 90 s of peak stress from multiple windows to completely visualize all LV segments. 2D-SE is operator dependent and requires advanced skills to match the same myocardial segments during stress (60). Detection of ischemia with exercise electrocardiographic testing is not possible in patients with left bundle bunch block. It may also be limited in these patients because of the paradoxical motion of the interventricular septum. Pellika and colleagues showed that exercise stress echocardiogram in patients with left bundle branch block had 60% sensitivity for ischemia detection, compared to 88% sensitivity with dobutamine stress echocardiography (61).

Friend or Foe? In the new era of cost containment, because of lower cost and the potential to provide definite information, comprehensive and appropriate echocardiography is mandatory. Doing such studies should eliminate further need for more expensive and potentially harmful examinations in the majority of patients and should have a big influence on cost-effectiveness of patient care. The principal advantage of echocardiography is its outstanding versatile technology. The drawback is that the examination is quite advanced, and clinicians must constantly update their skills and remain informed of new approaches.

End tidal carbon dioxide

John Tyndall who lived in 1829–1893 is credited with making some of the first measurements of expired CO_2 in humans. He studied the radiative properties of various gases, and constructed the first ratio spectrophotometer which he used to measure the absorption of gases. John Scott Haldane developed the first version of a gas analyzer that employed chemical absorption. For many years thereafter, it was considered the reference method for measuring CO_2, subsequently known as the "Haldane method" (62). The capnometer was used in medicine for the first time in 1950 to measure the amount of CO_2 exhaled during anesthesia (end-tidal, or $EtCO_2$). However, it was not used in practice until the early 1980s and with development of smaller machines, capnometry officially entered the anesthesia field (63, 64).

Pros: The first sign of the return of spontaneous circulation during cardiopulmonary resuscitation (CPR) is increase in $EtCO_2$, therefore monitoring of this parameter provides very useful information to guide treatment during CPR (65–67). $EtCO_2$ is a reliable indicator with a high prognostic value in determining CPR outcome (68, 69). Xavier Monett et al. showed that $EtCO_2$ could be used as a noninvasive tool for assessing the response of cardiac index (CI) to volume expansion. They also noticed that the changes in $EtCO_2$ observed during a passive leg raising test allowed prediction of fluid responsiveness, and that $EtCO_2$ was better than arterial pulse pressure for this purpose (70).

Cons: Limitations of capnography use include conditions with mixed pathophysiology, patients with low tidal volumes, and equipment malfunction. False positive results might be caused by using a bag and mask for assisted ventilation or when patient consumes carbonated beverages or antacids (71), as the use of sodium bicarbonate leads to a higher level of $EtCO_2$ for 5–10 min (72). During a cardiac arrest, which leads to decrease in tissue-pulmonary CO_2 transportation, capnography can aid in differentiating a successful endotracheal intubation from a failed one (false negative) (73).

Friend or Foe? Capnography is more sensitive than clinical evaluation in diagnosis of respiratory dysfunction as it has been reported to outperform clinicians in detecting sedation-associated apnea (74). With continuous technological advancements, $EtCO_2$ monitoring has become a key component in the advancement of patient safety within anesthesiology, and the American Society of Anesthesiologists (ASA) has endorsed end-tidal capnography as a standard of care for general anesthesia and moderate or deep procedural sedation (75, 76).

Automated vs. manual defibrillation

It was only 1899, when independent research by Jean Louis Prevost, Frederic Battelli, and RH Cunningham demonstrated that strong electric shocks stopped the hearts of experimental animals. Also, they discovered that some of the animals with ventricular fibrillation were restored to sinus rhythm by applying further current through electrodes in the mouth and small intestine (77). By the 1920s, many arrhythmias had been described and, as the physiology of the heart became better understood, various researchers noted that there appeared to be a refractory period in the cardiac cycle where the ventricles were more susceptible to ventricular fibrillation from an electric shock. As electrocardiography was developing, research into resuscitation continued. By 1911, Louise Robinovitch had developed several pieces of apparatus, including a portable resuscitation device for use in ambulances (78). This led to development of manual and later automated defibrillation.

Pros: The development of automated external defibrillators (AEDs) has made defibrillation more readily available for patients in cardiac arrest. A number of studies have confirmed the safety and effectiveness of AEDs, and the importance of early defibrillation (79). AEDs will automatically analyze the patient's heart rhythm and decide how much power the shock should have. AEDs are nowadays commonplace in public areas and are meant to be used by non-medical personnel. On the other hand, manual defibrillators are preferred in cases of complex cardiac rhythms, as they allow the operator to adjust the energy level of the shock to the individual patient's needs.

Cons: Automatic defibrillation requires pauses in chest compressions during ECG analysis and charging. These interruptions are known to reduce cardiac output, coronary and cerebral perfusion pressures (80). Several studies have shown that even short pauses in CPR before defibrillation reduce the rate of survival and good neurological outcome significantly in animal models of cardiac arrest (81–83). More recently, Eftestol et al. reported a 50% relative reduction in the probability of ROSC in humans in cardiac arrest due to VF when defibrillation was delayed for more than 5 s after cessation of chest compressions (84). Because of that medical personnel trained in advanced life support are encouraged to use defibrillators in manual mode to shorten time used for analysis.

Friend or Foe? Chest compression and defibrillation are essential components of cardiac arrest treatment. A manual defibrillator is usually operated by a trained medical professional, whereas an AED can be used by anyone who has been trained to use it. Unlike manual defibrillators, AEDs have built-in safety features that would warn the operator if the shock is not needed. Manual defibrillators are often preferred in pediatric patients, as the energy level of the shock can be adjusted to a lower level which is appropriate for children. The use of drones for the rapid delivery of AEDs to patients experiencing out of hospital cardiac arrest (OHCA) is a relatively new strategy, but one that has shown promising results. Drones have several advantages over traditional EMS, including their ability to quickly navigate through traffic and reach remote locations. In addition, they can be equipped with advanced sensors and cameras that can help locate the patient and provide real-time data to medical professionals (85).

Discussion/opinion

It is evident that technology is an integral component of modern-day medicine, without which many diagnostic criteria and treatment modalities would not be attainable. The ongoing dilemma remains balancing this increased use of technology with clinical judgment. There is little benefit in increased technology if the cost of these advances is the deterioration of clinical skills and resultant patient care.

It could be argued that earlier physicians had sharper clinical skills and keener minds because they relied entirely on history and physical examination. Modern-day physicians are more likely to order more tests than needed, a luxury that was not available until rather recently. It must be emphasized that any and all testing can incur cost, effort, patient discomfort, and the potential for further testing, which may feed a vicious cycle of chasing incidental findings.

Alternatively, one may say that our current surgical tools considerably outperform the more primitive versions that were used "in the olden days". Combining technologies enables us to detect trends, intervene proactively, and deliver medical care in the safest way yet. Optimizing patient care should be a priority. Portable ECG, ultrasound, x-ray, magnetic resonance imaging, ventilators, and other modalities now enable us to deliver medical care to more patients in more locations, favorably impacting treatment, reducing mortality rates, and improving quality of life.

One aspect of advancing technology and increased monitoring is the issue of false alarms and alarm fatigue. Alarm fatigue has become a chronic problem for hospital staff resulting in many false alarms. Only less than 30% of alarms need any action and 6% need higher medical intervention (86). Between alarm desensitization, interrupted clinical workflow, and increased noise pollution, false-positive alarms are a serious condition in healthcare today and must be addressed as more monitors are brought on board (87).

In summary, technological progress is inevitable. While some clinical technology modifications are beneficial, others may have limited utility depending on their use. Considered use of technology to improve patient outcomes based on critical thought and best-evidence is required to ensure that innovation rather than commercialization drives the evolution of healthcare technology. Technology has allowed us to detect many medical parameters beyond our human senses and to perform interventions beyond our physical capabilities. The ultimate goal of health technology is to aid physicians in improving patient safety and quality of care. Judicious use of technology in healthcare can aid clinicians in assessing a patient's history, conducting the physical examination, and clinical planning and treatment.

Author contributions

WS: Conceptualization, Methodology, Resources, Writing – original draft, Writing – review & editing, Supervision, Project administration. ES: Resources, Writing – original draft, Writing – review & editing. MW: Resources, Writing – original draft,

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