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EDITORIAL VIEW PERIOPERATIVE MEDICINE

Robotic anesthesia – how far from reality?

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Abstract

The modern practice of anesthesia is challenged with highly complex operating room environment and ever increasing number of tasks requiring the anesthesiologist's undivided instantaneous attention. Automation of repetitive tasks and risky procedures, coupled with clinical decision support, helps to improve safety and reduce stress. Varying degrees of progress have been made in developing robots to undertake various individual components of the anesthesiologist's multifaceted clinical practice; some semi-autonomous drug delivery systems have reached the stage of obtaining regulatory approvals, whereas fully or semi-automatic mechanical robots undertaking a few procedures are still under research. The current COVID-19 pandemic has highlighted the need to innovate machines to perform mechanical tasks avoiding proximity to the patient's airway to protect the anesthesia staff from catching infection. This editorial presents a snapshot of the current status of these devices, and attempts to envisage a roadmap for further development.

Key words: Robotic anesthesia; Singularity; da Vinci; Vascular access robot; Autonomous; Endotracheal intubation; COVID-19

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"Fiction reveals truth that reality obscures" – Ralph Waldo Emerson.

Travelling in a pilotless fully autonomous flying car was just a fantasy not very long ago; nonetheless, we witness that several automated commercial flying taxi services have started their service in many countries as early as this year.

Anesthesiologists have historically drawn parallels from the aviation industry due to the complexity of their working environment and a greater propensity of human factors compromising safety. They duly dream about an anesthesia machine that would skillfully perform repetitive tasks and risky procedures requiring precision, maintain safe anesthesia without the need for constant human intervention, and minimize their occupational hazards of exposure to dangerous drugs, radiation, infections, and stress of the work environment. When would this dream fully turn into reality? An overview of the current status of robotic anesthesia that follows may help to speculate.

An anesthesiologist is typically surrounded in the operating room (OR) by over a hundred parameters (Hemmerling, 2009)[1] and the numbers are ever expanding due to technological revolution; this translates into a highly complex working environment sustained by multitasking, examples of which include simultaneously administering drugs, performing clinical procedures, monitoring ever increasing number of clinical parameters and screens, titrating infusions in response to monitored clinical parameters, electronic record keeping, troubleshooting machines, supervising more than one ORs, teaching and training, and administrative tasks. Distraction, inattention, fatigue, and boredom, cumulating from these stresses may line up odds for human errors. Aviation industry faced with similar challenges, and it gradually developed a support system by automation and introduction of forced functions. The anesthesiologists as "pilots of the human biosphere",[1] have learnt lessons from the aviators and are keen to embrace the opportunities offered by innovation, technological progression, and robotic precision and reliability.

Robotic anesthesia, or anesthesia delivered by an automated control system, can be seen as the convergence of artificial intelligence (AI), medical informatics, and anesthesiology. The mainstay of AI is developing algorithms from very large databases as well as deep machine learning from repetitive patterns. The richer the database is, and the broader the range of observed parameters is, the more reliable the algorithms will become to govern increasingly autonomous machines. This leads to the utopic concept of 'singularity', whereby AI would surpass the combined intelligence of all human beings, when machines would become capable of emulating all human intellectual functions, with the additional capability for delivering projects with augmented precision, speed, and strength; while maintaining error-free performance. Experts have a range of opinions about when this would happen; the most conservative ones see it definitely beyond the current century or maybe never. [2]

Zaouter, et al. 3 classified anesthesia robots into three categories: pharmacological (calculating and delivering drug doses based on feedback parameters), mechanical (imitating manual gestures), and cognitive robots (guiding clinical decision making through pattern recognition in algorithms and clinical scenarios). AI has the potential to stitch up all of these together, to the point of building a fully autonomous system capable of safely inducing, maintaining, and reversing anesthesia in a patient away from the immediate presence of an anesthesiologist, in a range of scenarios such as battlefields, pre-hospital emergency care, rescue from disaster scene, interstellar journeys, etc. This ultimate goal is far from actuality at present, but how far, is the real question.

The first investigation for using pharmacological robots in anesthesia was performed more than 65 years ago; the field has been growing ever since, and has seen the best progress made out of all the dominions of robotic anesthesia. They have been used successfully to control conscious sedation, manage hemodynamic status, and administer anesthesia while keeping specific parameters of interest in target ranges (e.g., blood pressure, bispectral index, etc.) through microprocessor controlled intricate feedback loops. One such system, SEDASYS® (Johnson & Johnson, New jersey, USA), received regulatory approval from the Food and Drugs Authority (FDA) in the USA, but the manufacturer decided to stop selling it in 2016 due to non-profitability. A few others are in advanced experimental stages. Hemmerling predicted in his editorial that the availability of these systems in routine clinical practice was imminent; however he argued that newer parameters may need to be identified and validated to define the adequacy of anesthesia.[4]

Cognitive robots, also known as clinical decision support (CDS) systems, are divided into two categories: rules-based expert systems relying on algorithms created by the experts in the specialty, and machine learning systems that train themselves through identifying repetitive patterns in the data collected during the process of patient care. The first CDS was trialed in 1950s, and the most evolved format presently is the various 'Anesthesia Information Management Systems' (AIMS) in clinical use. They afford an invaluable role in advising the anesthesiologist for compliance with the given rules (recent guidelines, for instance), alerting against potential drug interactions or dosing violations, introducing forced functions (not authorizing administration of a substance with known allergy in the patient, for example), and maintaining record of monitored values and all events of interest during the anesthesia care episode. So far no clinical automation in anesthesiology has been attempted for suggesting or selecting the choice of anesthesia technique or the clinical end points.

Mechanical robots are designed to simulate manual gestures with varying degrees of automation. Initial efforts were made by Tighe, et al. to utilize da Vinci surgical robot system (Intuitive Surgical, California, USA) for performing popliteal nerve blocks on manikins[5] and for endotracheal intubations[6] (Figure 1) with the anesthesiologist operating remotely. Further efforts have been directed at producing robots that are smaller, reliable, and affordable, for gaining

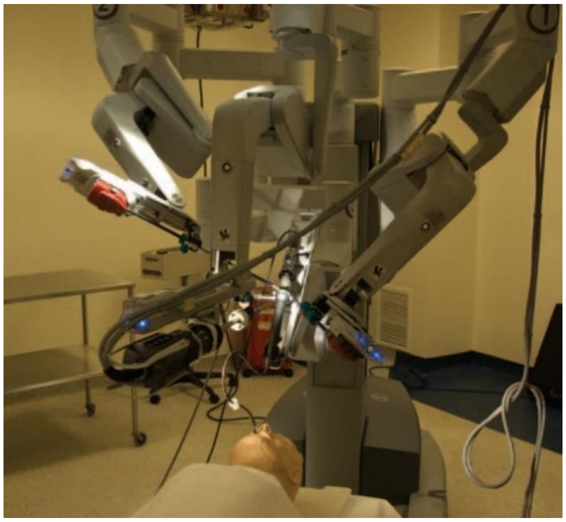

Figure 1: de Vinci intubation system

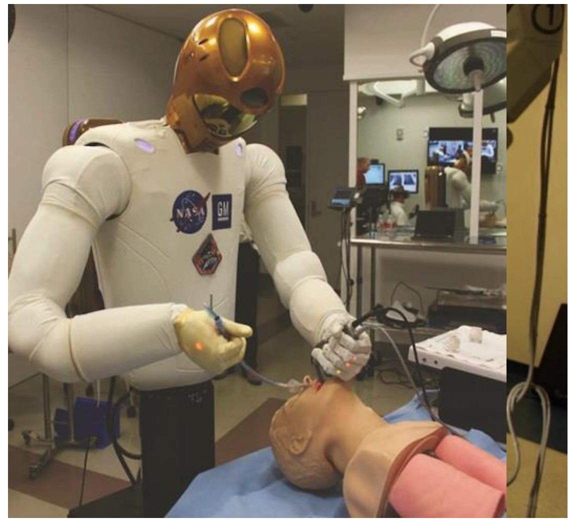

Figure 2: Robonaut 2

intravenous access (e.g. Haemobot®), performing ultrasound-guided nerve blocks (e.g. Magellan®), and undertaking endotracheal intubation (e.g. Kepler®, and REALTI®).

Safe and expert airway management is the cornerstone of the practice of anesthesiology. Recent COVID-19 pandemic highlighted the vulnerability of the unprotected operator to the contagion owing to their proximity to the infected patient's airway during aerosol generating procedures, such as airway management.[7] This has reinvigorated the quest for finding reliable remote controlled or automated mechanical robots to undertake such high risk tasks; intubating robots appear promising due to their purported capabilities with precise movement, accurate navigation, and ease of access around difficult bends in the air passages, all with the potential advantage of undertaking the procedure remotely.

Hemmerling, et al. designed and tested Kepler intubation system (KIS) on 12 patients with good success rate.[8] The KIS operator would introduce videolaryngoscope (VL) using the robotic arm controlled by a joystick, personally identify the anatomical features through the camera, and manually advance the endotracheal tube (ETT) attached to the VL. The study was limited due to small number of patients, prolonged intubation time (3-5 times longer than without KIS), and fogging of VL camera resulting in failure to intubate. Wang, et al. experimented their ‘Remote Robot-Assisted Intubation System’ (RRAIS) on pigs, with promising results; medical students with little previous experience in endotracheal intubation achieved higher first pass and overall success rates.[9] The system had a camera embedded at the tip of ETT to provide feedback to the operator, who would perform laryngoscopy and ETT advancement using the joystick. The limitations of the study were animal subjects, prolonged intubation time, need for repeated attempts, and mucosal trauma.

Biro et al. tested automated endotracheal intubation on a manikin with the ‘Robotic Endoscope Automated via Laryngeal Imaging for Tracheal Intubation’ (REALTI) system; the two operator groups (trained vs non-trained) had similar results for the success rate, the time taken for the procedure and the ease of use.[10] They used flexible endoscopic camera to identify facial and glottic features, and to advance the ETT over the flexible endoscope; if automatic mode failed, manual mode could be triggered by pushing a button. The study was limited by the distortion of images during movement resulting in failure of automatic recognition of anatomy.

Researchers at National Aeronautics and Space Agency (NASA) Johnson Space Center (JSC), Houston, USA, developed Robonaut 2 (or simply R2), a highly dexterous humanoid robot with cameras and other embedded sensors capable of multiple versatile applications. Fikfak, et al. presented their work on its applications for telemedicine;[11] amongst other tasks, use of a syringe for injecting, ultrasound guided cannulation of a central vein, and endotracheal intubation of a manikin (Figure 2), were performed. The design limitations identified included its lack of speed and a large hand size with poor grip for smaller instruments. Enhanced version with design improvements is being developed.

To date none of these airway robots have reached the routine OR clinical practice. More research and trials are needed to test and improve these machines with regards to their functionality, reliability, safety, and malfunctions. The anticipated and eagerly awaited robotic invasion of the perioperative space is likely to enhance the anesthesiologist's performance, consistency, and efficiency, through improving accuracy, preventing error, and reducing risk. At the least semi-autonomous systems may become incorporated in routine clinical practice in not too distant future.

Conflict of interest

None declared by the authors.

Authors' contribution

Both authors tool part in literature search and manuscript preparation.

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