Artificial intelligence in anesthesiology: Moving into the future

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Paul Kim
University of Toronto

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Clémence D Côté (MSc) [1]*; Paul J Kim (BSc)[1]*

[1]Department of Medicine, University of Toronto, Medical Sciences Building, 1 King's College Circle, Toronto, ON, Canada, M5S 1A8.
These authors contributed equally to this work.

Abstract

The applications of artificial intelligence (AI) and machine learning (ML) have shown promising results in healthcare. However, while many advances have been made to incorporate AI into the field of anesthesiology since it was first used to automate anesthetic delivery, it is still not commonplace. Previous studies have demonstrated that ML algorithms are useful in perioperative management, and the contributions of AI to general anesthesia have yielded advancements in closed-loop systems. Although these tools may ultimately help anesthesiologists guide clinical decision making, it is still unknown how ML-based predictions should be managed in real-time. The fields of postoperative pain management and chronic pain have benefited from AI by developing software capable of predicting pain level and analgesia response, allowing for increasingly individualized care. Importantly, data amalgamation and ML techniques may not solely be useful in direct patient care, but will also increase the training power of simulations by providing high fidelity clinical scenarios and unbiased feedback, thereby improving education in anesthesiology. It is clear that AI will find many applications in anesthesia care, in delivering real-time results and patient assessments to enable physicians to focus on higher-order tasks. However, much more work is required to understand exactly the scope that AI will play in anesthesiology.

Introduction

The full impact of artificial intelligence (AI) and machine learning (ML) in medicine has yet to be realized. In anesthesiology, the concept of AI has existed for decades. Indeed, early machines in the 1950's by Mayo and Bickford were used to automate anesthetic administration by reading electroencephalograms (EEG) to monitor depth of anesthesia (DOA) and subsequently deliver volatile anesthetics.[1] While computational advances have enabled target-controlled infusion systems that deliver drugs to reach algorithmically-derived target blood concentrations, this bears the limitations of an open loop system wherein the anesthesiologist must decide when to turn off the infusion system at the appropriate time.[2] On the other hand, simple closed loop systems are exemplified in cruise control in modern cars or temperature control by a thermostat: both are programs that carefully monitor a target variable to modify its output action. Simple open and closed loop systems with stricts rules are not considered AI due to their inability to form malleable perceptions, opinions, and outputs through modifiable rules according to the given input. However, to develop the highly sought-after closed loop system in anesthesiology, AI and specifically its subset of ML will play a major role as they will aid in the integration of numerous and complicated inputs such as those found in the operating room. While the excitement surrounding AI and ML in anesthesiology has mainly stemmed from integration into general anesthesia, these technologies have the capacity to influence all aspects of the field. This commentary describes the most recent contributions of AI to general anesthesia, and also touches upon its roles in preoperative assessments, postoperative and chronic pain care, and anesthesiology education in order to hypothesize their evolution as AI becomes more commonplace in medicine.

Corresponding Author:
Clémence Côté
clemence.cote@mail.utoronto.ca

Paul Kim
pauljun.kim@mail.utoronto.ca

Preoperative Assessment

In anesthesiology, the preoperative assessment includes a thorough surgical overview, medical history, physical exam, lab tests, and identification of specific cardiac and pulmonary risk factors, with the goal of reducing perioperative risks and improving outcomes.[3,4] This is a crucial aspect of presurgical care that has evidence-based prognostic consequences. For example, postoperative lung complications can be predicted by preexisting chronic lung disease, severe asthma, smoking status, and other relevant characteristics, allowing physicians to stratify patients into risk levels.[3] Subsequently, anesthesiologists may opt to modify their anesthetic choice and dosage, or perhaps attempt to optimize the condition of the patient before proceeding with the surgery according to the characteristics obtained in the preoperative assessment. While the process of knowledge integration for risk stratification was traditionally the sole responsibility of the physician, digital preoperative assessments have made their way to the bedside in hopes of increasing efficiency and accuracy. In brief, the automated workflow could shift to the process shown in Figure 1.

In this model, automation has freed time for the anesthesiologist to focus on "higher-order" clinical decision-making and patient care. With AI and ML, this process is taken a step further. If a

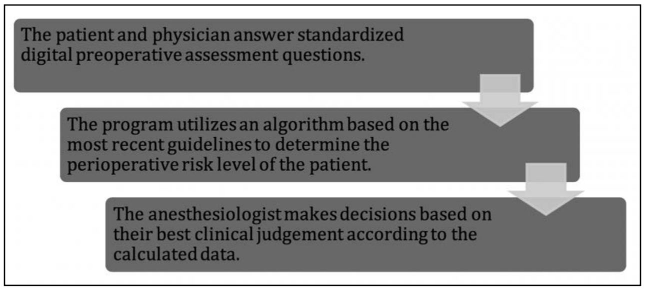

Figure 1. Automated preoperative assessment workflow.

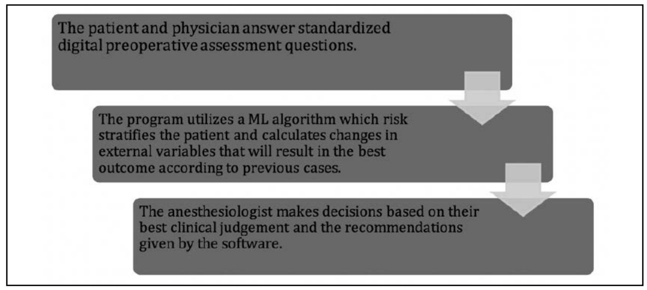

Figure 2. AI-based preoperative assessment workflow.

preoperative assessment program enhanced by ML was fed retrospective data from previous surgeries – not only regarding the type of surgery and patient risk factors, but also the clinical decisions made by the anesthesiologist and the post-operative functional outcomes – it could teach itself to make data-driven clinical recommendations concerning what anesthetics or other interventions would ensure the best outcome based on recent data from a vast array of similar cases. This form of bottom-up processing where various inputs are used to form a reliable perception and opinion of conditions is the cornerstone of AI. The literature concerning this type of software is in its infancy. However, there exist a few studies that have examined the performance of ML algorithms in regard to predictive accuracy, learning time, and error rate. As proof of concept, Karpagavalli et al.[4] integrated preoperative patient data into three well-known neural network classifiers and illustrated just how accurate these programs could be at preoperative risk stratification. For example, the Multilayer Perceptron, one of the most commonly utilized neural networks, accurately risk classified instances with a 97.79% success rate.[4] Nonetheless, the Naïve Bayes classifier had a 76.24% predictive accuracy, illustrating the importance of algorithm optimization and appropriate neural network matching according to the desired output. So far, feedforward neural networks appear to work well in this application. Thus, AI may assist the physician in higher order knowledge integration with the experience of thousands of medical procedures that a single person would not be able to integrate alone. AI also plays a crucial role in validating the robustness of its own outputs. In having access to limitless medical case studies, programs can be cross trained from various data sets to test predictive accuracy. The new workflow is now optimized as seen in Figure 2.

While the use of AI shows promise in this field, it will be necessary to develop AI networks that support any clinical outputs from software. Additional research must be done to validate the outputs of any preoperative assessment tool with AI. Software generated recommendations would need to be compared with those of anesthesiologists in practice today to ensure fidelity and best practice outcomes.

Intraoperative Management and General Anesthesia

Similar to its role in preoperative assessments, AI has the potential of guiding intraoperative management. Several studies published recently have demonstrated the ability of ML algorithms to predict intraoperative events, including post-induction hypotension[5,6] and hypoxia[7] with high sensitivity and specificity. The ability of AI to provide clinicians with an amalgamation of useful objective data in real-time may influence an anesthesiologist's clinical decisions. However, it remains to be determined how changes that are not detectable by the human eye should be acted upon. It is also yet unknown whether anesthesiologists will use such tools to proactively change a care plan, or as an adjunct to help predict intraoperative events and outcomes. At this time, it seems that ML will be used to reaffirm clinical decisions and provide second opinions. However, as further studies are performed investigating the outcomes of ML-based changes in care in real-time, ML programs may provide anesthesiologists with clinical recommendations. As the literature delineating the role of AI and ML in anesthetic care expands, it is important to keep in mind the success of these softwares compared with current methods. While ML may seem to yield fruitful results, the predictive capabilities of some models may not outperform those of logistic regression analysis.[5,8]. For example, in the previously mentioned study that compared the ability of several ML models and logistic regression to predict post-induction hypotension, a greater under the receiving operating characteristic curve (AUC) value, indicating higher predictive ability, was found for linear discriminant analysis (AUC 0.72), random forest (AUC 0.74), and gradient boosting machine (AUC 0.76) models compared with logistic regression (AUC 0.71). However, support vector machines, naive Bayes, and k-nearest neighbour models underperformed compared with logistic regression (AUC 0.63, 0.69, and 0.64, respectively).[5] Together, these studies highlight the potential ability of ML and AI to guide anesthesiologists in intraoperative medicine. But is also important to highlight some of the potential limitations of ML models, including overfitting of datasets due to insufficient testing and validation of complex models, poor generalization due to limited data sets, and poor performance if an unrepresentative training sample is used. With further research and development of predictive tools, ML approaches may impart more benefits than current methods, enabling clinicians to achieve greater productivity as "lower-order" activities become increasingly automated. However, interpreting ML-based results and determining how to change clinical decisions based on these remain a hurdle.

In addition to its role in perioperative medicine, AI and ML may also play a role in the actual induction and maintenance of general anesthesia. It has been previously hypothesized that AI could be the key to safe and automated anesthesia through closed loop feedback control during surgery. Closed loop systems modify and maintain a given variable at a target value according to the inputs they receive. An example is cruise control in modern cars.

The gold standard for automation in anesthesia would be a closed loop system for DOA. Today, the bispectral index (BIS) is used as a surrogate for DOA, which is processed from EEG data. Using this single variable to guide anesthetic titration, a closed loop system can maintain DOA under tighter BIS parameters than an anesthesiologist.[9] However, BIS has limitations in being the only factor to determine DOA, particularly due to confounding variables and accuracy of the EEG input. For example, the use of ketamine can increase the BIS, reducing the predictive accuracy of the index. Consequently, closed loop systems have the downfall of strict rules, which can be a fatal error with confounding factors. The anesthesiologist must keep close watch in case of input imprecision. However, the adaptable and integrative nature of AI and ML may prove useful in this domain. Standalone closed loop anesthetic machines will require integration of multiple signals, including BIS and hemodynamics amongst multiple others. Unfortunately, once a complex hierarchy of rules are required to control these systems, research has shown that they become less effective than humans.[10] AI comes with the promise of self-sufficient and adaptable systems that can teach themselves through a bottom up approach, one that is preemptively given medical information from previous surgeries and real-time data about the patient to form a perception and malleable output that makes sense according to prior evidence and the current condition of the patient. Through the course of a procedure, an AI-based closed loop system would make granular adjustments to the administered anesthetic in real-time according to changes in the DOA measured by the BIS, hemodynamics, electromyographic signals, and addition of new drugs. This type of AI would prove to be most efficient for an anesthesiologist who would now be able to monitor other key aspects of the patient's anesthetic condition during surgery.

Postoperative and Chronic Pain

The application of AI in chronic pain has yielded promising results. Analgesic response can be predicted using ML and more modern neural network architecture, not only to determine the specific drug and dosage required based on pain scores, but also to forecast potential adverse events.[11] This eliminates the need for trial-and-error in choosing appropriate drugs. Training these tools with other data such as vital signs and EEG data[12] in addition to pain scores may further increase their predictive abilities. Such tools would be beneficial in the context of post-operative pain, by helping anesthesiologists adjust analgesic dosages and patient-controlled anesthesia settings. They would also be useful in the management of chronic pain. Since myriad variables affect individual responses to pain, consolidating factors other than demographic and physiological factors that may contribute to pain experience will help to personalize pain management and improve patient satisfaction. The use of AI can also aid in determining responses to treatment, including objective assessments of physical functional performance, facial expressions indicating pain, and functional brain signatures for disease state, allowing for increasingly individualized and evidence-based treatments.

Regional Anesthesia and Maneuvers

Robots have been developed to automate performance with the goals of reducing anesthesiologist workload and improving patient care, and have been specifically applied to perform different types of regional blocks[13,14] as well as various maneuvers, such as intubation.[15] While the use of robotic needle drivers guided by real-time imaging seems promising, the incorporation of ML to guide these has yet to be realized. There is potential for AI to aid in performing dexterity-based maneuvers to optimize and improve the accuracy of blocks and maneuvers, as well as to improve their efficiency.

Anesthesiology Education

Lastly, while minimal research has been done on the topic, AI is expected to be useful in anesthesiology education and training, largely due to it's great potential to improve clinical simulations. Clinical scenarios can be improved using data from previous cases to better recreate realistic cases with high fidelity for the clinical environment. Moreover, AI could contribute to providing accurate patient models for cases that anesthesiologists may not encounter during their training. AI-based "patients" could realistically analyse and react to certain trainee actions. For example, although not specific to anesthesia, the AI virtual reality simulation tool AiSolve was used at the Children's Hospital of Los Angeles to help train medical students using realistic and reactive simulations in the area of resuscitation.[16] Moreover, training using AI can be evaluated objectively using standardized measures and outcomes amalgamated from real patient data without limitations from subjective assessments. In this way, individual performance, clinical outcomes, efficiency, and error rates can be identified, and bias can be eliminated, ultimately aiding the debriefing process. Incorporating AI in training would not only increase trainee satisfaction due to increased exposure to scenarios and the provision of effective feedback, but patient welfare may also be enhanced as skills and competency would be increased.

Conclusion

Research to incorporate AI and ML in various aspects of anesthesiology has been performed with variable results. Concrete and promising findings have been obtained in the domains of intraoperative medicine and postoperative and chronic pain management, which may be further enhanced through the development of more complex software that can incorporate a greater number of parameters and diverse data to generate more powerful prediction models. However, further steps must be made for functional closed-loop systems and maintenance of general anesthesia, as well as to determine the exact scope of AI in anesthesiology. While the goal of incorporating AI into this field is focused on increasing the performance of anesthesiologists by automating more simple tasks, AI errors do have the potential of resulting in severe adverse patient outcomes, highlighting the necessity of perfecting any AI tool before implementing it in clinical practice. However, if done right, not only will AI help guide clinical decisions by using the most up-to-date patient data and providing evidence-based outcomes, but it may also result in increased patient safety. Indeed, anesthesiologists must monitor a large number of parameters at once, which is difficult for the human brain to do.[17] Automating control of some of these parameters would therefore result in reduced human error. Overall, AI and ML in anesthesiology are advancing, with many opportunities to bring the field into the future.

References

1. Mayo CW, Bickford RG, and Faulconer A. Electroencephalographically controlled anesthesia in abdominal surgery. JAMA. 1950 Nov;144(13):1081-3. doi:10.1001/jama.1950.02920130033008.
2. Guarracino F, Lapolla F, Cariello C, et al. Target controlled infusion: TCI. Minerva Anestesiol. 2005 Jun;71(6)335-7.
3. Garcia-Miguel FJ, Serrano-Anguilar PG, and Lopez-Bastida J. 2003. Preoperative assessment. Anaesthesia. 2003 Nov;362(9397):1749-57. https://doi.org/10.1016/S0140-6736(03)14857-X
4. Karpagavalli S, Jamuna KS, and Vijaya MS. Machine learning approach for preoperative anaesthetic risk prediction. Int. J. of Recent Trends in Engineering and Technology. 2009 Nov;1(2):19-22. doi: 01.IJRTET.01.02.206.
5. Hatib F, Jian Z, Buddi, S, et al. Machine learning algorithm to predict hypotension based on high-fidelity arterial pressure waveform analysis. Anesthesiology. 2018 Oct;129(4):663-674. doi: 10.1097/ALN.0000000000002300.
6. Kendale S, Kulkarni P, Rosenberg A, et al. Supervised machine-learning predictive analytics for prediction of postinduction hypotension. Anesthesiology. 2018 Oct;129(4):675-688. doi: 10.1097/ALN.0000000000002374.
7. Sippl P, Ganslandt T, Prokosch HU, et al. Machine learning models of post-intubation hypoxia during general anesthesia. Stud Health Technol Inform. 2017;243:212-216. doi: 10.3233/978-1-61499-808-2-212.
8. Lee CK, Hofer I, Gabel E, et al. Development and validation of a deep neural network model for prediction of postoperative in-hospital mortality. Anesthesiology. 2018 Oct;129(4):649-662. doi: 10.1097/ALN.0000000000002186.
9. Myles PS, Leslie K, McNeil J, et al. Bispectral index monitoring to prevent awareness during anaesthesia: The B-Aware randomised controlled trial. The Lancet. 2004 May;363(9423):1757-63. https://doi.org/10.1016/S0140-6736(04)16300-9.
10. Alexander JC and Joshi GP. Anesthesiology, automation, and artificial intelligence. Proc (Bayl Univ Med Cent). 2018 Jan;31(1):117-19. doi: 10.1080/08998280.2017.1391036.
11. Nickerson P, Tighe P, Chickel B, et al. Deep neural network architectures for forecasting analgesic response. Conf Proc IEEE Eng Med Biol Soc. 2016 Aug; 2966-69. doi: 10.1109/EMBC.2016.7591352
12. Misra G, Wang W, Archer DB, et al. Automated classification of pain perception using high-density electroencephalography data. J Neurophysiol. 2016 Nov;117:786-95.
13. Tighe P, Badiyan S, Luria I, et al. Robot-assisted regional anesthesia: A simulated demonstration. Anesthesia & Analgesia. 2010;111(3):813-16. doi: 10.1152/jn.00650.2016.
14. Hemmerling T, Taddei R, Wehbe M, et al. First robotic ultrasound-guided nerve blocks in humans using the magellan system. Anesthesia & Analgesia. 2013;116(2):491-4. doi: 10.1213/ANE.0b013e3182713b49.
15. Hemmerling T, Taddei R, Wehbe M, et al. First robotic tracheal intubations in humans using the kepler intubation system. British Journal of Anaesthesia. 2012;108(6):1011-16. doi: 10.1093/bja/aes034.
16. A.I.Solve. Using artificial intelligence to create virtual reality medical simulation [Internet]. Burbank, California. 2017 [updated 2017 Sept 19; cited 2019 January 12]. Available from: http://www.aisolve.com/using-artificial-intelligence-to-create-virtual-reality-medical-simulations/
17. Halford G, Baker R, McCredden J, et al. How many variables can humans process? Psychol Sci. 2005 Jan;16(1):70-6. doi: 10.1111/j.0956-7976.2005.00782.x.