Review Article

Artificial intelligence in pediatric airway – A scoping review

ABSTRACT

Artificial intelligence is an ever-growing modality revolutionizing the field of medical science. It utilizes various computational models and algorithms and helps out in different sectors of healthcare. Here, in this scoping review, we are trying to evaluate the use of Artificial intelligence (AI) in the field of pediatric anesthesia, specifically in the more challenging domain, the pediatric airway. Different components within the domain of AI include machine learning, neural networks, deep learning, robotics, and computer vision. Electronic databases like Google Scholar, Cochrane databases, and Pubmed were searched. Different studies had heterogeneity of age groups, so all studies with children under 18 years of age were included and assessed. The use of AI was reviewed in the preoperative, intraoperative, and postoperative domains of pediatric anesthesia. The applicability of AI needs to be supplemented by clinical judgment for the final anticipation in various fields of medicine.

Key words: Artificial intelligence, intubation, machine learning, pediatric airway, pediatric anesthesia

Introduction

Artificial intelligence (AI) is tremendously evolving in the medical sector in the current era. AI is a range of processes and behaviors that are generated by computational models and algorithms. It supports evidence-based clinical decision making, leading to the development of novel clinical applications in various healthcare domains.[1] Different components within the domain of AI include machine learning, neural networks, deep learning, robotics, and computer vision.[2] Machine learning is a prominent subfield among the different taxonomies of AI. Machine learning, without needing specific instructions, facilitates the computer programs to learn and respond to data. It detects nonlinear patterns in the data, which distinguishes machine learning from traditional data analysis methods such as logistic or linear regression. Machine learning and Deep learning are domains of AI that are helpful in analyzing big data sets for setting new classifications and models predicting the targeted parameters.[3]

Machine learning utilizes algorithms to accurately categorize data and make precise predictions based on analysis of the provided data. It is generally categorized into three main types: supervised learning, unsupervised learning, and neural networks.[4] Supervised machine learning is predominantly used in medical applications, utilizing labeled datasets to train algorithms to establish connections between variables and adjust weights for accurate predictions.

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These models are validated for reliability, commonly employing classification (e.g., predicting diseases) and regression (e.g., forecasting numerical outcomes) tasks using various algorithms like logistic regression or random forests. In pediatrics, such methods are pivotal for prognosis, risk assessment in emergency scenarios, and predictive models aiding clinical decision making for patient response to treatment or identifying potential deterioration signs in real-time hospital settings.[5] Unsupervised machine learning is employed to unveil hidden patterns and groupings within unlabeled data, aiding in data exploration without necessitating manual labeling. While these techniques reveal new patterns, their clinical relevance may require additional insight from clinicians.[6] Artificial neural networks, inspired by biological neural networks, are a type of machine learning model that can be supervised or unsupervised, resembling gradient boosting methods and widely used as classifier algorithms. They consist of layered neurons processing input variables through hidden layers to predict outcomes, including recurrent neural networks for processing extensive data and learning from errors and convolutional neural networks specialized in analyzing imaging data. Artificial neural networks, inspired by biological counterparts, constitute a type of machine learning model that can operate under supervised or unsupervised learning. They share similarities with gradient boosting methods and serve as popular classifier algorithms, structured with layers of neurons, including input, hidden, and output layers, where input variables are processed through hidden layers to predict outcomes. Neural networks have the capacity to learn and comprehend a wide range of information, extending from fundamental upper airway physical examination results to complex diagnostic assessments of the lower airway. Deep learning, a subset of machine learning, emphasizes neural networks with multiple hidden layers, resembling the interconnected structure found in the human brain. These networks progressively learn and transfer information as data passes through each layer but demand a substantial volume of data to perform optimally and prevent inadequate fitting of predictive tasks.

Pediatric operating room requires high-stakes decisions to be made under strict time constraints and are frequently fraught with uncertainty. These decisions have a significant impact on patient outcomes. Multiple AI models have been developed recently, which include recognizing facial contours and predicting the difficult airway.[7] Many studies have approached the role of machine learning as a complement to physical examination, facial analysis, and the detection of morphological traits related to difficult airways.[8,9] The use of AI, specifically in pediatric airways, has been under-discussed. Although it has a lot of potential to improve child's outcomes in terms of better airway management, it has not been frequently used in clinical scenarios. The reason is its lag in clinical applicability due to insufficient data, lack of proper validation, and inability to generalize usage in different strata of settings. The applicability of AI is advancing nowadays due to the availability of robust data and advanced computing systems.[3] In this review, we have aimed to analyze the application of AI in pediatric airways and to discuss the obstacles to using these technologies in the daily clinical practice of anaesthesiologists.

Materials and Methods

Data sources and searches

Electronic databases like Google Scholar, Cochrane databases, and Pubmed were searched. The keywords searched were 'AI', 'paediatric airway', 'intubation', 'paediatric anaesthesia, 'machine learning'. A total of 3200 articles were retrieved. Data were searched by two authors (SN and SG) independently. A total of 1668 relevant articles sought underwent thorough screening of full text by both authors independently. Any differences in opinions were resolved after discussions. We conducted a literature search between the year 2010 to June 2023 and limited our search to studies published in the English language. As there was heterogeneity in the age group of children included in different studies, we opted to include all those studies with children of age group <18 years. Only peer-reviewed, published literature was included. After applying the exclusion and inclusion criterion, only 12 full-text articles could be included in our review [Figure 1]. We identified the authors, year of publication, and country of origin for each publication [Table 1]. We also documented the study design, age, and number of patients included in each study.

Discussion

The integration of AI into medical practice is on the rise, and there is growing interest in its application in the field of anesthesia, which is revolutionizing airway management. By imposing machine learning algorithms and advanced computational techniques, AI systems are being developed to enhance various aspects of airway management, including preoperative assessment, prediction of difficult airways, and decision making to handle the airway as per Difficult Airway Algorithm. AI can help in decision making but accurate predictions have to be corroborated by the clinical acumen of the anaesthesiologists.[10]

Application of AI in the preoperative setting

An educational review by Matava *et al*.[9] described artificial intelligence, machine learning, and deep learning relevant to pediatric airway. For the prediction of a difficult intubation

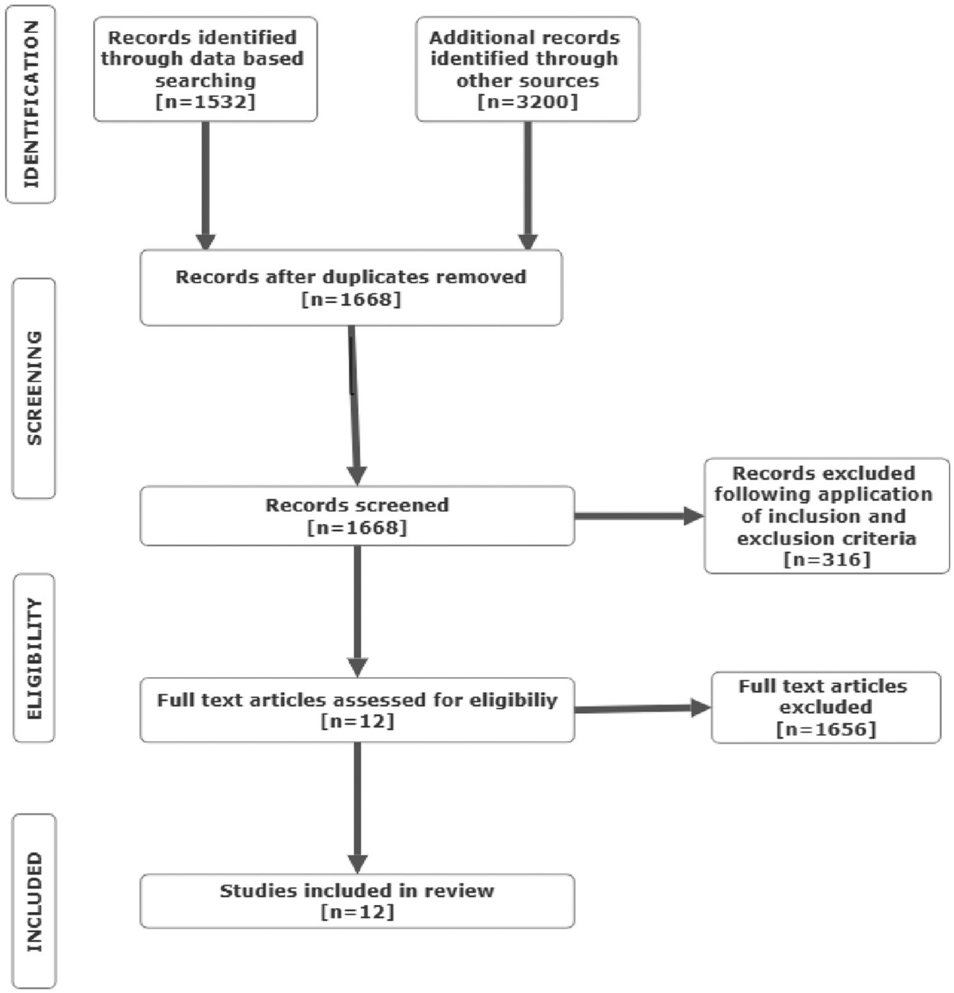

Figure 1: PRISMA flowchart of study selection

physical airway examination remains the primary tool of an anesthesiologist. Determining difficult airway during the preoperative assessment with the use of two-dimensional or three-dimensional facial analysis has been explained.

Cuendet *et al*.[8] proposed an automatic face analysis method for identifying morphological characteristics associated with challenging intubation procedures, aiming to enhance the accuracy of predicting difficult intubation cases. A database of 970 patients was collected including photos, videos, and ground truth data. Specific statistical face models were derived from this data, which provided an automated parametrization of facial morphology. A random forest algorithm was used to select the most discriminative morphological features through the important ranking.

Similarly, a study done by Connor CW *et al.*[11] classifies difficult intubation by facial analysis. In this study the quantification of the facial anatomy was done by a computerized algorithm. Each subject's photograph was analyzed by software, which uses an algorithm that models the face as a single point in a fifty-dimensional eigenspace and resolves each space into 61 facial proportions. They have concluded that computerized analysis of the facial structure and thyromental distance surpasses popular clinical predictive tests, accurately classifying intubation as easy or difficult. This advancement holds promise for improving intubation procedures and enhancing patient outcomes.

In children with difficulty breathing, stridor, obstructive sleep apnea, airway infection, and suspected foreign bodies, lateral neck radiographic examination plays a significant role. Somasundaram *et al.*[12] developed an automated deep learning (DL)-based AI algorithm to detect inadequate lateral neck radiographic images of the airway and soft tissues, allowing the technologists to make decisions at patients' point of care without the requirement of a radiologist's input.

Table 1: Details of various articles on AI in chronological order

Author, Year, Country	Study Design	Age Group	No. of Patients/ Studies	Outcomes/objectives	Results	Conclusions
Christopher W. Connor, 2011, USA	Cohort study	Age not specified	160	to derive a computer model that similarly classifies the ease or difficulty of endotracheal intubation from analysis of facial structure	Sensitivity, specificity, and area under the curve for the computer model were 90%, 85%, and 0.899, respectively.	Computerized analysis of facial structure and thyromental distance can classify easy versus difficult intubation with accuracy, significantly outperforming popular clinical predictive tests.
Gabriel Louis Cuendet, 2016, Switzerland		Age not specified	970	an automatic face analysis approach to detect morphological traits related to difficult intubation and improve its predict	The suggested method is applicable for real-world difficult intubation prediction, with AUC=77.9%.	The system performance is in line with the state-of-the-art medical diagnosis, based on ratings provided by trained anesthesiologists, whose assessment is guided by an extensive set of criteria
Jorge A. Gálvez, 2017, USA	Observational study	Age not specified	900	To describe a method to automatically distinguish between non-invasive and invasive airway device support in a pediatric surgical setting based on respiratory monitoring parameters.	The study utilized machine learning on 900 records to discern between noninvasive and invasive airway support, with a neural network achieving superior accuracy at 95.8%, demonstrating efficacy in classification compared to other classifiers.	The neural network classifier algorithm can accurately classify support for non-invasive and invasive airway devices.
Lisa D. Eisler, 2019, New York	Retrospective cohort	Infants		To identify risk factors for unplanned postoperative intubation and to develop a scoring system to predict this complication in infants undergoing major surgical procedures.	The area under the receiver operating characteristic curve of the final model was 0.86 (95% CI, 0.85–0.87) for the derivation cohort and 0.83 (95% CI, 0.82–0.85) for the validation cohort.	About 1 in 50 infants undergoing major surgical procedures experience unplanned postoperative intubation. This scoring system based on routinely collected perioperative assessment data can predict risk in infants with good accuracy
Somasundaram, 2020, Cincinnati	Retrospective cohort	Age not specified	1200	To develop and validate a deep learning (DL) algorithm to identify poor-quality lateral airway radiographs	The ResNet-50, the most effective DL classifier, exhibited robust performance in the study, showcasing high sensitivity (0.90), specificity (0.82), and an area under the receiver operating characteristic curve (0.86) on a dataset comprising 961 training radiographs and 239 test radiographs.	The development and validation of DL classifiers to distinguish between adequate and inadequate lateral airway radiographs are reported. The classifiers performed significantly better than a group of technologists and as well as radiologists.
Clyde Matava, 2020, Canada	Educational review			To assess the current evidence on the use of artificial intelligence and machine learning in the assessment, diagnosis, monitoring, procedure assistance, and predicting outcomes during pediatric airway management	Machine learning-assisted diagnosis can serve as a second, quantitative opinion regarding diagnosis and can supplement rather than eliminate clinical decision making	
Clyde Matava, 2021, Canada			775	Development and testing of a convolutional neural network that can classify, identify, and label vocal cords and tracheal rings from live video.	The overall confidence of classification for the vocal cords and tracheal rings for ResNet, Inception, and MobileNet CNNs were 0.84, 0.78, and 0.64 for vocal cords, respectively, and 0.69,	The availability of artificial intelligence may improve airway management and bronchoscopy by helping to identify key anatomy real time. Thus potentially improving performance

Contd...

Table 1: Contd...

Author, Year, Country	Study Design	Age Group	No. of Patients/ Studies	Outcomes/objectives	Results	Conclusions
					0.72, 0.54 for tracheal rings, respectively.	and outcomes during these procedures
Tatsuya Hayasaka, 2021, Japan	Observational study		202	an AI classification model was created using deep learning by linking the patient's facial image and the intubation difficulty	The accuracy of the best AI model was 80.5%; sensitivity, 81.8%; specificity, 83.3%; AUC, 0.864; and 95% confidence interval, [0.731-0.969]; the AI model recognized facial contours and identified intubation difficulties	If the AI model can predict intubation difficulty using the patient's face image, then it can help save patients' lives by enabling emergency airway management
Jae-Geum Shim, 2021, South Korea	A retrospective cohort study	<7 years	834	To construct a prediction model for optimal tracheal tube depth in pediatric patients using machine learning	The application of machine learning models and comparison of them with the accuracy of three formula-based methods, which were based on age, height, and tracheal tube internal diameter (ID).	The machine learning models predicted the optimal tracheal tube tip location for pediatric patients more accurately than the formula-based methods
Miao Zhou, 2022, China			990	To construct and validate machine learning models for endotracheal tube (ETT) size prediction in pediatric patients.	The random forest models had the best performance with minimizing prediction error for both uncuffed ETT size (MAE=0.275 mm and RMSE=0.349 mm) and cuffed ETT size (MAE=0.243 mm and RMSE=0.310 mm	Machine learning models help with excellent performance in predicting optimal ETT size in both cuffed and uncuffed endotracheal intubation in pediatric patients, which provides powerful decision support for clinicians to select proper ETT size.
Jung-Bin Park, 2023, Korea	Retrospective observational	<18 years	13130	To develop and validate a machine learning model that can predict intraoperative hypoxemia events 1 min ahead in children undergoing general anesthesia.	A model was built using data from 1,540 patients experiencing intraoperative hypoxemia, showcasing the Gradient Boosting Machine's superior performance with an area under the receiver operating curve (AUROC) of 0.904 (95% CI 0.902 to 0.906) over long short-term memo and transformer models, further validated with 200 patients where the gradient- boosting model maintained higher accuracy with an AUROC of 0.939 (95% CI 0.936 to 0.941).	Machine learning models can be used to predict upcoming intraoperative hypoxemia in real time based on the biosignals acquired by patient monitors, which can be useful for clinicians for prediction and proactive treatment of hypoxemia in an intraoperative setting.
Ryan Antel, 2023, Canada	Systematic review	<18 years	40 articles	aims to characterize the current use of AI in pediatric anaesthesia and to identify barriers to the successful integration of such technologies	Multiple domains of AI were discussed including machine learning, computer vision, fuzzy logic, and natural language processing	There is an emerging literature regarding applications of AI for pediatric anaesthesia, and their clinical integration holds potential for ultimately improving patient outcomes

Application of AI in the operating room and during the intraoperative period

Monitoring during anesthesia using artificial neural networks to recognize faults in anesthesia breathing circuits, breathing patterns, and airway obstruction has also been described. Gálvez *et al.*[13] retrieved anesthesia records of 900 children and classified them into invasive and non-invasive airway device groups. End-tidal carbon dioxide, tidal volumes, and peak inspiratory pressures of each patient were noted. A neural network classifier was developed incorporating these values into an algorithm to accurately identify the use of invasive versus non-invasive airway.

Selection of an endotracheal tube (ETT) is a challenge in the pediatric population, as overestimation of tube size can lead to airway injuries, and underestimation of tube sizes can lead to hypoventilation and anesthetic gas leakage. Zhou *et al.*[14] has developed machine learning models for predicting optimal ETT size in cuffed and uncuffed tubes in pediatric patients, providing valuable decision support for clinicians in selecting an appropriate ETT size. Python (version 3.7.1.1) was used to build the prediction model. The data of the children like age, sex, height, weight, body mass index (BMI), ideal BMI, and final size of ETT (internal diameter) were recorded, and tracheal data derived from chest X-ray were retrieved retrospectively. These variables were considered to propose novel formulas for cuffed and uncuffed size predictions.

Placing the tracheal tube at an optimum depth is important in pediatric intubations. Due to the shorter length of the trachea when compared to adults, the tracheal tip position has a narrow safety margin. Misplacement of the tip might lead to adverse events like hypoxia, atelectasis, hypercarbia, and even death. Shim *et al.*[15] developed a machine learning method by constructing a prediction model that estimates the correct depth of the tracheal tube insertion. Machine learning models like random forest, elastic net, support vector machine, and artificial neural network were used, and these were shown to be superior to traditional formula-based methods.

A conventional neural network was developed by Matava *et al.*[16] which can classify vocal cords and tracheal airway anatomy real time during video laryngoscopy or bronchoscopy. This machine learning algorithm is known to improve airway management by helping infrequent incubators and bronchoscopists identify key anatomy in real time, therefore facilitating performances and good outcomes during these procedures.

Intraoperative hypoxia plays a significant role in the pediatric population due to their physiological limitations concerning apnea tolerance. Due to the smaller functional residual capacity, increased metabolic requirement, and oxygen consumption, there is a faster progression of hypoxia and slower recovery. Park *et al.*[17] developed a machine learning algorithm using demography, vitals and other ventilatory data to predict hypoxemia under general anesthesia in children. A machine learning model was based on this, which can predict hypoxia 1 min ahead in the pediatric population during general anesthesia.

Application of AI in the postoperative period

Postoperative complications in children can occur from multiple factors, AI might be an accurate tool. Using machine learning algorithms, a part of AI, health care providers can examine extensive patient data, recognize patterns, and create precise predictions.[18] Ermer *et al.*[19] conducted a study that aimed to investigate the utilization of a machine-learning algorithm to measure the extent of opioid-induced ataxic breathing. This study suggested that machine learning algorithms accurately measure the severity of ataxic breathing, aligning with assessments made by a group of experts in this field. This method, along with the conventional approaches, might aid in identifying patients affected by opioid-induced respiratory depression. Unexpected post-surgery intubation is a key measure of quality and is linked to higher mortality rates in children. A study done by Lisa *et al.*[20] proposed a multivariable model for the prediction of unplanned intubation during the postoperative period in infants. Data from infants who underwent major non-cardiac surgeries was retrieved, and carefully defined variables like risks before surgery, events during the procedure, outcomes within 30 days post-surgery, and in-hospital mortality, spanning both inpatient and outpatient settings, were noted. A scoring system was developed based on the parameters derived.[20]

Artificial Intelligence – Limitations and Ethical Issues

AI has its own limitations. The expectations of end users, that is, Clinicians, patients, and those who regulate its use may not match the services provided by AI.[2] So, the feasibility of AI in clinical practice is questionable. The use of AI should be done to solve appropriate clinical conditions, but it may not be able to answer the problem accurately. Rather, it may not be superior to clinical judgments.

Clinicians sometimes cannot explain the predictions made by AI. The models made by AI should be more transparent in explaining the algorithms used to predict a particular clinical situation. This will bring more trust in clinicians on AI.[2] It can reveal associations and identify patterns but is barely able to establish causal relationships to the extent that can be implemented in clinical practice. Therefore, clinicians should have good communication with the data scientists for appropriate analysis and interpretation of data.

Future Implications

To date, the algorithms used by AI have not yet superseded clinical judgments. However, the patterns and models used by AI are taking care of those clinical areas that are beyond human intelligence and eventually take their place. AI used for assessing pediatric airways will help in managing clinically unanticipated airways in a meticulous way, reducing the chances of failed intubations. This will make the decision of anesthesiologists more efficient and appropriate. Efforts are required further to establish the patients' faith in AI in clinical decision making. We, as anesthesiologists, can also collaborate with surgeons, radiologists, technicians, nurses, and patients to optimally utilize AI.[2] We can further continue using AI for innovations in the field of pediatric anesthesiology and focus on improving children's safety while handling the challenging airways.

Conclusion

In conclusion, the incorporation of AI in pediatric airway offers substantial advantages by enhancing preoperative assessment and intraoperative decision making, as well as predicting complications through machine learning, advanced computational techniques, and predictive algorithms. Despite AI's potential to improve clinical outcomes significantly, its full integration requires aligning with clinical expertise and continuing collaborative efforts to optimize pediatric airway management in anesthesiology.

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Conflicts of interest
There are no conflicts of interest.

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