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Review Article

The emerging role of artificial intelligence in ENT surgery

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ABSTRACT

The field of otorhinolaryngology has undergone a dramatic transformation in the past few decades owing to advances in technology. Advances in endoscopic surgery, microsurgery, laser surgery, surgical navigation, robotic surgery, etc., have improved management of several diseases with increased safety and have resulted in optimal outcomes for patients. Artificial intelligence (AI) refers to the ability of machines to mimic human intelligence and solve tasks that require complex decision-making. Artificial intelligence (AI) has become possible owing to advances in the disciplines of computer science, mathematics, and engineering and involves technology that enables computers to carry out operations that need human intellect, such as discrimination of words and objects, visual perception, and decision-making. The use of computational methods that rely on collecting and processing data helps reduce human labour. The collaboration of such AI technology with a challenging field like ENT surgery is evolving in the present day and is bound to enhance clinical practice worldwide. This review analyses the emerging influence of AI in each and every sub-specialty of ENT practice and highlights the key points of how this merger can establish and benefit clinicians in the near future.

Keywords: Artificial intelligence, Technology advances, ENT

INTRODUCTION

Artificial intelligence (AI) is an umbrella term that encompasses computational frameworks designed to mimic human intelligence, including reading, comprehension, analysis, and creativity.[1] Machine learning (ML) enhances autonomy by enabling complex systems to identify key patterns within data without the need for explicit programming.[1] Deep learning (DL), a subset of ML, employs multi-layered neural networks to capture intricate patterns and data representations, increasing the adaptability of AI tools across various fields. A further, highly specialised facet of DL architecture is the Convolutional Neural Network (CNN), which uses convolutional layers to automatically and dynamically learn spatial feature hierarchies, enabling more advanced real-time image recognition capabilities, particularly useful in surgical technology.[2] These systems have gained significant traction in recent years, driven by advancements in machine learning and data informatics. From contributing to diagnostics and personalised healthcare planning to assisting with real-time image analysis and robotic surgeries, AI holds the potential to revolutionise healthcare and improve patient outcomes.[3] Synthetic biology can create biosensors that detect specific biomarkers in the ear, nose, or throat, enabling early and accurate diagnosis of diseases like infections, cancer, or hearing loss. It can be used to deliver genes to specific cells in the ENT area, potentially correcting genetic defects or delivering therapeutic proteins to treat diseases.[4]

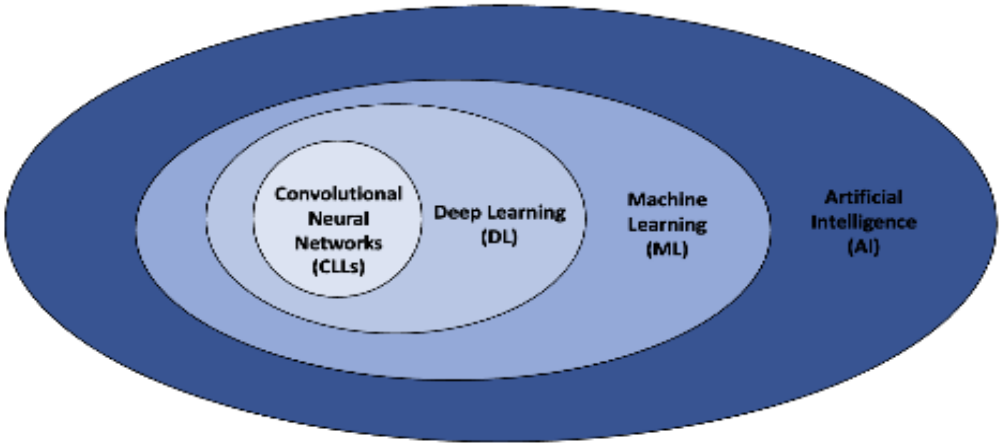

Figure 1: Diagrammatic representation of the hierarchical structure of key AI terminologies.

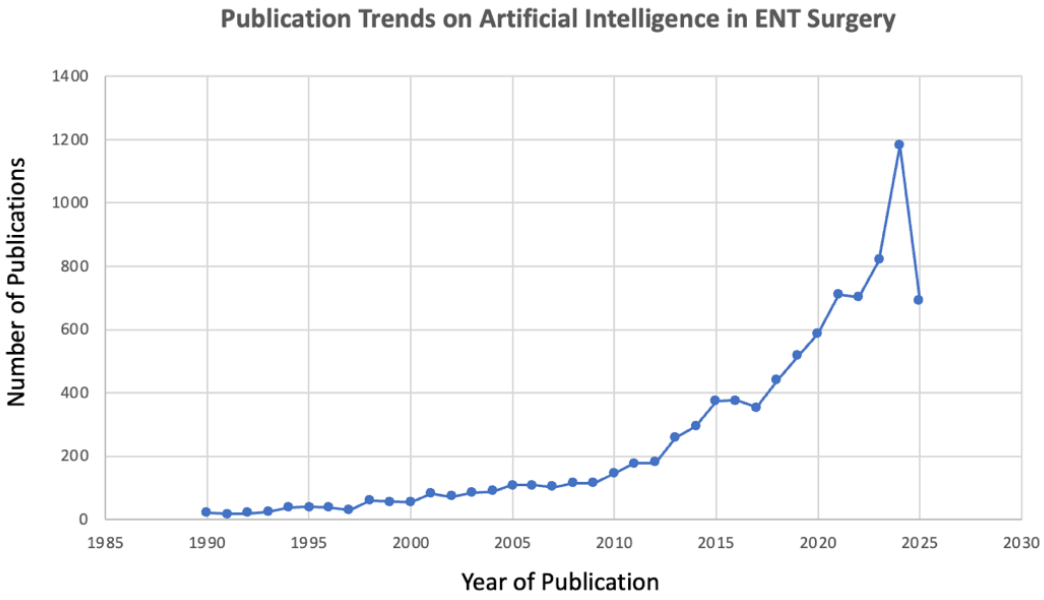

Figure 2: Trends in PubMed publications on artificial intelligence in ORL surgery (1990–2025).

ARTIFICIAL INTELLIGENCE IN OTORHINOLARYNGOLOGY

The recent emergence of AI in every aspect of science has also found its footsteps into modern medicine. Applications of AI in medicine include diagnosis of disease, treatment planning and management, drug research and development, improved clinician–patient communication, transcription of medical records like prescriptions, and remote patient treatment.[5] Otorhinolaryngology is a unique specialty which has always embraced technology; an example of this is the use of implantable hearing devices such as cochlear implants, auditory brainstem implants, and bone conduction implants. AI has the potential to improve diagnostics, treatment planning, and surgical guidance, thereby enhancing patient outcomes.[6] AI is to help surgeons to perform their tasks more effectively and not to replace them. The goal of AI is to make technology more useful by utilising large amounts of data about previous experiences and using the patterns learnt from that data.

ENT surgery presents distinct challenges, particularly due to the need to navigate complex anatomical structures using minimally invasive techniques with sub-millimetre precision. Delicate areas such as the cochlea, skull base, and sinuses demand extreme accuracy to avoid damagingcritical structures and causing irreversible complications like hearing loss or permanent nerve injury. Today, a subset of AI, which includes machine learning, deep learning, and the latest trend— generative AI, which is the basis of the widely used chatbot ChatGPT— can play a vital role in ENT. Artificial

Intelligence may play an increasingly important role in various subspecialties of ENT, especially in the diagnosis and management of skull base tumours and head and neck cancers.[7] As distinguishing between subtle pathologies, such as early-stage malignancies and mucosal lesions, can be difficult through visual inspection alone, convolutional neural networks (CNNs) and other AI tools are being integrated intraoperatively to enhance visualisation and support real-time surgical planning. These technologies are particularly beneficial in procedures such as transoral robotic surgery and endoscopic sinus surgery, where precision and accurate tissue differentiation are vital to positive patient outcomes.

AI in the diagnosis of otorhinolaryngologic disorders

Early identification of ENT diseases can enable early management, thereby improving outcomes. AI algorithms, especially in machine learning and deep learning, can help the otolaryngologist in detecting even subtle abnormalities in CT scans, MRI scans, endoscopic videos, etc., with greater accuracy and speed, resulting in early diagnosis and management of conditions such as malignancies.[8] Accurate diagnosis may be possible because of the ability of AI to analyse complex data from various sources, and this can help in administering appropriate treatment.[9]

AI in laryngology and head and neck surgery

In laryngology, with voice-based analysis, AI is used to evaluate pathological voice conditions associated with vocal fold disorders. Early glottic cancers can be diagnosed with high accuracy by combining voice analysis and video stroboscopy images. In the head and neck, identification of genetic profiles for predicting nodal disease in human papillomavirus-related oropharyngeal cancers, identification of high-risk patients, and deciding on the treatment is possible.[10] AI can compute the three-dimensional tumour volume and plan radiation dosing. In patients undergoing radiotherapy for head and neck malignancy, AI can help identify and spare critical structures from radiation exposure. AI with hyperspectral imaging can help with more precise resection as it helps in differentiating thyroid malignancy from normal tissue. Differentiating malignant from benign lesions pre-operatively can greatly aid in planning the management. AI can help link the outputs of genome sequencing with clinical outcomes, determine extranodal extension in tumours, identify anatomical details, stage or grade the severity of disease, and decide on surgical candidacy.[11] During rehabilitation, AI can help in the evaluation of voice and swallowing function and offer personalised approaches to management. AI can also help evaluate the outcomes of polysomnography in obstructive sleep apnea, giving insightful suggestions to the sleep medicine specialist to plan a holistic management plan ahead.

AI in otology and audiology

Applications of AI in otology include evaluation of hearing loss, vestibular diseases, image-based diagnosis, and hearing device technology. AI might be used to create more effective automated ABR algorithms for newborn hearing screening.[12] Machine learning can help identify patterns in cochlear imaging modalities. AI can help predict hearing outcomes after sudden sensorineural hearing loss, improve hearing aid performance, restore speech in post-stroke individuals, and predict speech and language outcomes in cochlear implant recipients.[13] Assessment of videonystagmography, differentiating the site of cupulolithiasis in patients with benign paroxysmal positional vertigo, helps in correct diagnosis of vestibular system disorders.[14] AI also plays a role in improving vertigo outcomes through interactive virtual reality vestibular rehabilitation. Synthetic biology can be used to improve the performance of hearing aids by optimising signal processing and feedback cancellation algorithms.

AI in rhinology and skullbase surgery

AI in rhinology has the potential to improve diagnosis and management of various rhinologic diseases, including sinonasal allergy, bacterial and fungal sinusitis, and sinonasal tumours.[15] It can improve and enhance the currently existing protocols for navigational rhinologic skullbase surgery by providing optimal guidance for the surgeons to navigate through the intricate corridors towards complex pathology while minimising collateral damage and achieving safe and effective surgical outcomes.[16,17]

ARTIFICIAL INTELLIGENCE IN PLANNING MANAGEMENT STRATEGIES

AI can be used in all four phases of surgery, including surgical planning, during surgery, after surgery, and in surgical training, education, and research. AI can help in optimising treatment, predicting outcomes, and providing custom-based treatment planning for skull base lesions, head and neck cancers, sleep apnea, hearing loss, etc.

Surgical planning

AI can help during pre-operatively in accurately diagnosing the condition, selecting patients for the right treatment, and helping patients to make the right decisions. AI can help in the analysis of medical images and gene profiles for tumour details and help in visualising skull anatomy.[18] These modules can help surgeons plan the surgery more effectively, identify potential challenges, and even simulate the procedure pre-operatively. Surgical planning in complex procedures like skull base surgery can help determine optimal approaches with minimally invasive surgery.[19] In head and neck implant design, AI can help in correct virtual

reconstruction of a defective lesion for successful surgery.

Intra-operative guidance

During the surgery, AI-powered image-based navigation systems can provide real-time guidance to the surgeon, helping them navigate through complex anatomy of the skull base and avoid critical structures, thereby minimising complications. Combining AI with robotic surgery will enhance surgical precision in ENT surgery because AI algorithms can help robotic systems perform precise and delicate movements. With AI, augmented reality is possible because AI can enhance surgical procedures by overlaying real-time patient information onto the surgical field, facilitating improved decision-making.

Thus, artificial intelligence can be of great help in complicated procedures such as skull base surgery. AI-integrated robotic platforms such as transoral robotic surgery (TORS) may enhance precision, stability, and control in minimally invasive surgery.[20] Artificial intelligence enhances intraoperative imaging modalities such as hyperspectral and narrow-band imaging, thus enabling real-time surgical guidance. Precise tissue differentiation and improved lesion identification aids in identifying mucosal lesions in oropharyngeal cancer intraoperatively.

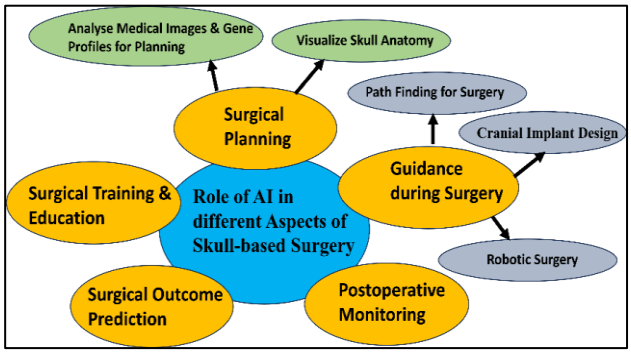

Figure 3: Flow chart depicting the role of AI in different aspects of skull-base surgery.

Postoperative monitoring

AI-based algorithms can analyse data from sensors and monitors during the postoperative period, enabling early detection of complications. AI can help in postoperative follow-up, including predicting prognosis, identifying potential postoperative complications, and tracking patient data.[21] This helps in better prediction in the postoperative phase and thus helps in improving patient care and reducing associated costs. AI-based tools have shown promise in monitoring recovery after cochlear implantation, enabling early detection of suboptimal outcomes.

Surgical outcome prediction

AI models can analyse patient history, surgical details, and postoperative outcomes to predict the likelihood of successful outcomes or potential complications. These predictive algorithms can help predict potential complications after surgery and improve patient care. The analysis can also predict the length of hospital stay and possible hospital expenses.

Surgical training and education

AI holds immense promise in surgical training. Realistic computer simulations and virtual reality (VR) environments could significantly enhance the training of surgeons, especially for complex skull-based procedures, resulting in a cost-effective, safe, and reproducible alternative to traditional training methods.[22] The virtual reality-based training allows surgeons to practice and refine their skills before performing the actual surgery in a safe and realistic setting, and the simulation tools enable the collection of valuable data such as optimal trajectory, forces that are imparted during a procedure, or the position of cameras or endoscopes.[23]

AI and integration with other technologies

The integration of AI with other technologies like 3D printing can help design better and customised prosthetics and implants. Telemedicine platforms, along with AI, can also improve patient adherence. Collaboration among clinicians, data scientists, and engineers is essential to improve AI accuracy and tailor it to specific applications in otorhinolaryngology. AI tools have been widely implemented across the preoperative, diagnostic, and postoperative stages, assisting in diagnosis and predicting patient outcomes through complication monitoring.

Limitations

Although AI has encroached into every field of science and technology today, almost condescended to as the God particle of the future, it has its precise limitations which need to be carefully understood and applied in the best way. AI is still a new technology which involves increased costs, and the cost-benefit ratio is a factor to be taken into consideration, especially due to the rising costs in healthcare. Machines lack the personal interaction that is so vital to the doctor-patient relationship, which is very important for successful surgeries. AI cannot work without data, but a large set of appropriate data may be unavailable, and this data is often incomplete, unobtainable, or biased. When using AI, there are always privacy issues where there is a risk of the leak of patient confidential data.[24] Another important challenge is the proper training of surgeons in using AI. There is always the risk of hardware and software malfunctions, which may result in the risk of misdiagnosis if not solved in time. Ethical aspects in the use of AI should always be taken into consideration. The lack of robustness can

result in manipulation. The large volumes of data and complex algorithms in AI can make them difficult to understand and interpret.

CONCLUSION

The integration of AI in ENT, head and neck & skull-base surgery has the potential to improve diagnosis, treatment planning and management, increase the accuracy and precision of the procedures, patient monitoring to reduce the risk of complications, and ultimately enhance patient safety and outcomes. AI-powered chatbots can be used for patient education, symptom assessment, and even scheduling patient appointments with otolaryngologists. Some of the future research directions include enhancing explainability and transparency of AI solutions and using AI to automatically design surgery to suit individual needs and for ensuring regulatory and ethical compliance and incorporating AI education for surgeons. Artificial intelligence may revolutionise the field of otorhinolaryngology, resulting in more personalised and effective patient care. Otolaryngologists should stay abreast of the potential applications and emerging role of artificial intelligence in ENT, while fully understanding that AI and ENT will evolve into a symbiotic relationship in the future, helping each other to benefit patient care, but AI will never supersede or negate the clinicians' conventional clinical acumen or surgical wisdom acquired through their years of experience and thereby inculcated robustly into the realm of modern medical practice.

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