ACCSCIENCE PUBLISHING

Cancer Plus

MINI-REVIEW

Artificial intelligence and surgical robotics in the future of head-and-neck cancer care

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Abstract

Artificial intelligence (AI) plays a crucial role in advancing head-and-neck cancer diagnosis and treatment, significantly impacting patient outcomes and healthcare efficiency. We explore how AI-driven technologies are revolutionizing clinical practices. AI-driven surgical robotics enables highly accurate, minimally invasive procedures by providing real-time intraoperative guidance and analyzing complex imaging data, thus improving surgical success rates and reducing complications. Similarly, AI-driven remote monitoring systems facilitate continuous, non-invasive tracking of disease progression, treatment adherence, and early detection of recurrence, allowing for timely interventions and personalized care adjustments. These innovations enhance diagnostic accuracy, therapeutic precision, patient engagement, and resource utilization, leading to a better quality of life. However, several challenges hinder widespread AI adoption, including concerns over data privacy and security, algorithm bias due to unrepresentative datasets, variability in data quality, and regulatory and ethical issues regarding accountability and transparency. Implementation barriers, such as that in integration with existing workflows, clinician acceptance, and resource limitations, further complicate deployment, especially in low-resource settings. Despite these hurdles, we demonstrate that the potential benefits of AI—improved diagnostic accuracy, personalized treatment, and proactive disease management—are substantial. Addressing these challenges through robust data governance, validation, and ethical frameworks is essential for safe and equitable AI integration. We conclude that ongoing technological and methodological advancements will continue to enhance the efficacy and accessibility of AI in head cancer care. We emphasize the importance of collaborative efforts, regulatory support, and ethical standards to fully realize AI's transformative potential, ultimately leading to more precise, patient-centered, and effective head-and-neck cancer management.

Keywords: Artificial intelligence; Head-and-neck cancer; Surgical robots; Remote monitoring systems; Healthcare technology

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Citation: Al-Raeei M. Artificial intelligence and surgical robotics in the future of head and neck cancer care. *Cancer Plus*. 2025;7(4):80-88. doi: 10.36922/CP025040006

Received: January 21, 2025

Revised: September 16, 2025

Accepted: October 10, 2025

Published online: October 31, 2025

1. Introduction

The field of medicine is undergoing a significant transformation driven by artificial intelligence (AI), opening new avenues for diagnosing and treating various illnesses. One notable area where AI demonstrates considerable potential is in the detection and analysis of head-and-neck diseases, especially head-and-neck cancer, which is a prevalent form

of cancer. Early diagnosis is crucial for effective treatment outcomes, and AI technologies, such as machine learning algorithms, are now enabling clinicians to analyze head scans and other medical images with enhanced accuracy and efficiency to identify and characterize abnormalities.[1-4] These algorithms are trained on large datasets of medical images to recognize patterns that may indicate the presence of head-and-neck cancer, often detecting subtle tissue changes that might elude human observation, thereby improving diagnostic accuracy. In addition, AI can assist in prioritizing cases based on the probability of malignancy, allowing healthcare providers to focus on the most urgent cases first.

Furthermore, AI also plays a role in developing personalized treatment strategies by analyzing patients' medical records, imaging data, and genetic profiles, contributing to tailored therapies that can improve outcomes and minimize unnecessary interventions or side effects.[5-8] Beyond diagnosis and treatment, AI contributes significantly to research and drug development efforts for head-and-neck cancer by analyzing large-scale genetic and clinical datasets, helping researchers identify new therapeutic targets and accelerate the discovery of effective drugs.

Overall, integrating AI into head-and-neck cancer care is revolutionizing the approach to managing this disease, offering more precise and individualized treatment options that enhance patient outcomes and reduce healthcare burdens. Despite challenges related to data privacy and algorithm bias, the advantages of AI in head-and-neck cancer management are compelling.[9-12] As AI technology continues to evolve, further advancements are anticipated to improve the quality of life for patients by enabling more accurate and effective interventions.[13-16]

This review article examines the transformative role of AI in the detection and diagnosis of head-and-neck cancers, highlighting the latest progress in this rapidly evolving area. It primarily concentrates on two key applications of AI: the use of surgical robotics and remote monitoring systems, as illustrated in Figure 1, both of which facilitate early diagnosis. By improving the precision and speed of identifying head-and-neck tumors, AI is revolutionizing healthcare practices and leading to better patient outcomes. The integration of AI into surgical robotics enables surgeons to perform highly accurate, minimally invasive procedures, while remote monitoring devices allow clinicians to track neurological changes over time. These technological innovations are opening up new avenues for more effective detection and management of head-and-neck cancer, ultimately elevating the standard of patient care.

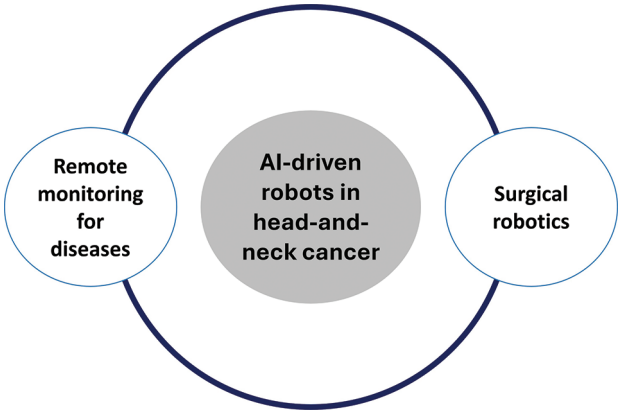

Figure 1. Artificial intelligence-driven robots for head-and-neck cancer. Image created by the author using Paint 3D.

2. Methodology

This systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. The aim was to identify, select, and synthesize relevant studies exploring the application of AI in head-and-neck cancer diagnosis and management, with a focus on surgical robotics and remote monitoring tools.

2.1. Literature search strategy

Multiple electronic databases, including PubMed, Scopus, Web of Science, and IEEE Xplore, were utilized to identify relevant studies. Keywords such as "artificial intelligence," "head cancer," "head and neck cancer," "surgical robotics," "remote monitoring," "AI in oncology," and related synonyms were used individually and in combination to maximize coverage.

Studies published in English from 2010 onward that focus on AI-based technologies in the diagnosis, surgical treatment, or remote monitoring of head-and-neck cancer were included. Both original research articles and systematic reviews were considered. In contrast, articles not directly related to AI applications in head-and-neck cancer, non-peer-reviewed sources, case reports lacking technological focus, and studies with insufficient methodological detail were excluded.

2.2. Data extraction and analysis

Identified articles were screened for relevance based on titles and abstracts, followed by full-text review. Extracted data points included the type of AI technology used, clinical context, key outcomes (e.g., accuracy, precision, procedure duration, and patient recovery), and reported benefits or limitations. The quality and validity of studies were assessed using appropriate appraisal tools (e.g., Excel

in Office 2019 and Origin, considering aspects such as study design, sample size, and technological robustness.

2.3. Synthesis approach

The gathered data were synthesized qualitatively to identify common themes, technological trends, and evidence of clinical efficacy. Particular emphasis was placed on technological capabilities, integration strategies, and reported clinical outcomes related to surgical robotics and remote monitoring systems. The review highlights the current state of AI integration, ongoing challenges, and future directions based on the analyzed literature.

Figure 2 illustrates the PRISMA workflow of the study. This systematic methodology ensured a comprehensive and balanced overview of the role of AI in head-and-neck cancer diagnosis and treatment, providing insights into technological advancements and their clinical implications.

3. Surgical robotics for head-and-neck cancer

The advent of surgical robotics has fundamentally reshaped the approach to minimally invasive procedures for head-and-neck cancer, particularly in cases involving tumors located in the cranial and facial regions. These sophisticated robotic systems incorporate cutting-edge AI algorithms that markedly enhance surgical precision and accuracy, thereby reducing the risk of complications and improving patient outcomes.[17-20] By offering real-time intraoperative guidance, analyzing detailed imaging data, and executing highly precise maneuvers, surgical robots have become integral components of modern operating rooms, facilitating more successful head-and-neck cancer surgeries.

For example, the use of the ROSA robotic system in skull base tumor resections has demonstrated improved navigation through complex anatomical structures, enabling surgeons to access hard-to-reach areas with greater confidence.[21] Similarly, the da Vinci Surgical System has been employed in oropharyngeal and sinonasal tumor removals, illustrating how robotic assistance reduces operative times and enhances recovery experiences for patients.[22] These case studies highlight the growing role of robotic technology in managing head-and-neck cancers.

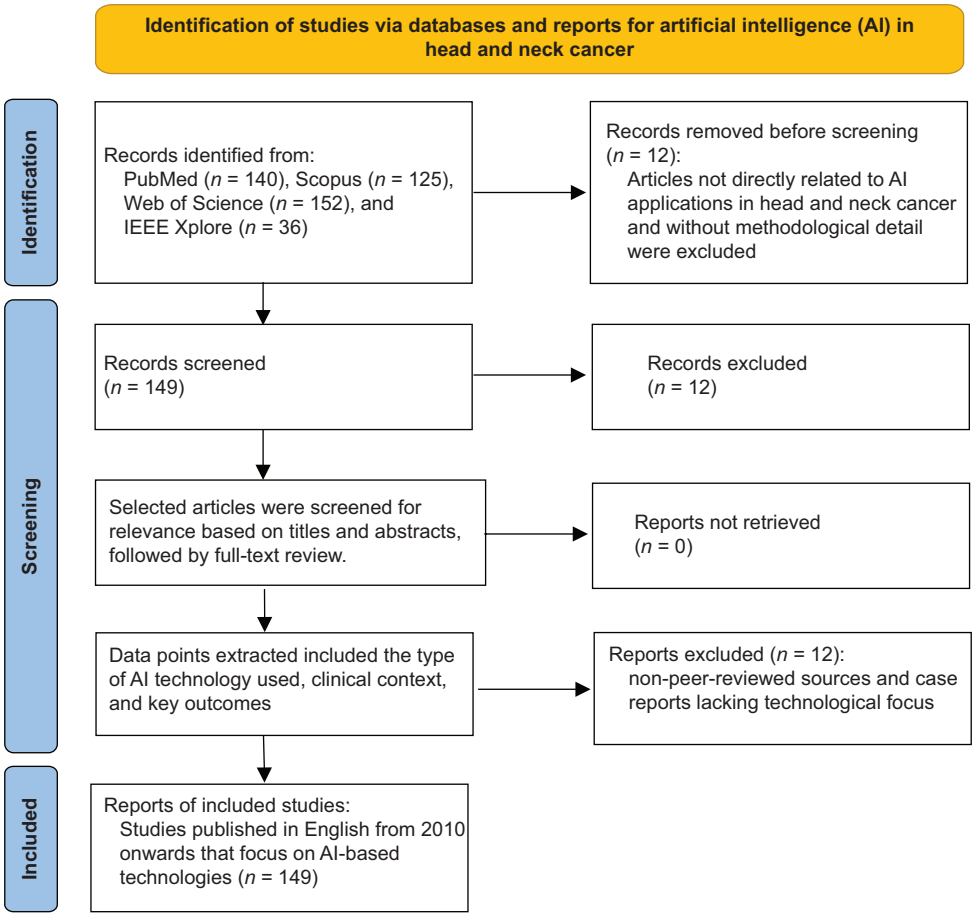

Figure 2. Workflow of the review

The deployment of surgical robots in this domain is steadily increasing as their capabilities advance. Designed to complement highly skilled surgeons, these systems elevate the standard of care by performing intricate procedures with a level of precision unattainable by manual techniques alone. Advanced AI-driven algorithms allow robotic systems to execute complex movements with unprecedented accuracy, ensuring optimal resection margins and preservation of critical structures. This synergy enhances surgical success rates and minimizes damage to adjacent tissues.

One of the key advantages of integrating robotics into head-and-neck cancer surgery is the provision of continuous, real-time guidance. Equipped with sophisticated sensors and high-definition imaging technology, these systems analyze the patient's anatomy dynamically during procedures, offering detailed feedback to surgeons. For example, in cases of sinonasal carcinoma, robotic systems can help navigate the sinus cavities and skull base, reducing the likelihood of accidental injury and ensuring complete tumor removal.[23] Such real-time analysis and guidance empower surgeons to make informed decisions during complex operations.

Furthermore, surgical robots excel at analyzing preoperative and intraoperative imaging data to identify anomalies or subtle tumor boundaries that might be missed using conventional methods. This capability allows for more precise excisions, decreasing residual disease and recurrence rates. AI algorithms facilitate rapid data processing, streamlining decision-making and making surgeries more efficient and effective.

The benefits of robotic assistance extend beyond improved surgical outcomes. Patients often experience shorter operative times, reduced intraoperative blood loss, and lower rates of postoperative complications, such as infections and nerve damage. These advantages translate into faster recovery periods and better quality of life post-surgery. For example, in cases of advanced skull base cancers, robotic-assisted approaches have resulted in decreased hospitalization durations and minimized tissue trauma.[24]

For surgeons, robotic systems provide enhanced dexterity and stability, enabling the performance of highly complex maneuvers with ease. This technology allows surgical teams to overcome anatomical challenges inherent in head-and-neck cancer surgeries, thereby expanding the scope of minimally invasive options. In addition, working alongside robotic systems offers opportunities for surgeons to refine their skills, leading to continuous improvement in surgical techniques and patient care.

As a result, the integration of surgical robotics into head-and-neck cancer treatment signifies a groundbreaking advance in healthcare. Their ability to deliver precise, real-time guidance, analyze complex imaging data, and perform delicate maneuvers has revolutionized surgical methodology. As these technologies evolve, their role is expected to grow, promising further enhancements in surgical outcomes, reduced patient morbidity, and higher standards of care. The ongoing development of surgical robots will undoubtedly shape the future landscape of head-and-neck cancer surgeries, making procedures safer, more effective, and more accessible.[25]

4. Remote monitoring for head-and-neck cancer

The application of remote monitoring technologies has become a pivotal element in the contemporary management of head-and-neck cancers. In particular, the integration of AI has revolutionized how clinicians track disease progression, assess treatment adherence, and deliver personalized care without requiring frequent in-person visits.[24-28] AI-enhanced remote monitoring systems enable healthcare professionals to continuously gather and analyze a vast array of patient data—such as imaging results, vital signs, symptom reports, and genetic profiles—facilitating early detection of changes indicative of disease progression or complications. This proactive approach not only allows for timely interventions but also supports tailored treatment strategies based on individual patient profiles, including genetic predispositions, lifestyle factors, and previous treatment responses.[29]

Real-world examples and case studies highlight the transformative impact of AI-driven remote monitoring in head-and-neck cancer care. For example, a pilot study at a tertiary care center implemented an AI-driven platform to analyze weekly magnetic resonance imaging scans and symptom questionnaires submitted remotely by patients with sinonasal carcinoma. This system successfully identified early signs of tumor recurrence, prompting preemptive treatment adjustments that improved overall survival rates.[29,30] Similarly, in cases of nasopharyngeal carcinoma, AI algorithms have been employed to interpret serial imaging data and predict disease trajectory, enabling clinicians to customize radiotherapy schedules and reduce unnecessary exposure.[29]

Remote monitoring also enhances patient engagement and adherence. For example, wearable devices integrated with AI algorithms can track patients' activity levels, sleep patterns, and symptoms in real time. Patients with head-and-neck cancers have used smart devices that alert healthcare teams to potential issues such as weight loss,

pain escalation, or wound infections, prompting swift clinical responses.[31] In addition, AI-enabled telehealth platforms facilitate seamless communication among multidisciplinary teams—oncologists, radiologists, speech therapists, and nutritionists—ensuring coordinated and comprehensive care.[31,32]

Furthermore, AI's predictive analytics capabilities enable clinicians to forecast disease progression with higher accuracy. By analyzing longitudinal data from electronic health records, imaging, and genomic testing, AI models can estimate the likelihood of recurrence or metastasis, influencing decisions on surveillance intensity or adjuvant therapy.[32] This predictive capacity is particularly valuable in head-and-neck cancers, where early detection of recurrence can significantly improve prognosis and quality of life.

From an operational perspective, AI-driven remote monitoring streamlines workflows, reduces administrative burdens, and optimizes resource allocation. Automated data collection and analysis lessen the need for frequent hospital visits, decreasing healthcare costs and improving patient convenience.[33] Moreover, real-time data access supports evidence-based clinical decision-making, ensuring that treatment plans reflect the latest developments and research findings.[34]

As a result, the integration of AI-driven remote monitoring systems in head-and-neck cancer care offers a multifaceted enhancement—personalized treatment, early detection, patient engagement, and efficient resource use. As technology advances, future innovations may include sophisticated wearable sensors capable of detecting biochemical markers of tumor activity or AI platforms that integrate virtual reality for remote rehabilitation. These developments promise to further transform head-and-neck cancer management, ultimately leading to improved patient outcomes and quality of life.[35]

5. Challenges of implementing AI in head-and-neck cancer care

Despite the promising advancements of AI in head-and-neck cancer diagnosis and treatment, several significant challenges hinder its widespread clinical adoption and effectiveness. One primary concern revolves around data privacy and security.[36,37] AI systems rely heavily on large-scale datasets comprising sensitive patient information, including medical images, genetic profiles, and electronic health records. Ensuring the confidentiality and integrity of this data is paramount, yet the risk of data breaches and unauthorized access remains a persistent issue. Protecting patient privacy while enabling data sharing for AI development necessitates robust security protocols and compliance with stringent regulations, which can be complex and resource-intensive to implement.[38,39]

Algorithm bias and fairness constitute another critical challenge. AI models are trained on available datasets, which may not be fully representative of diverse populations. If the training data lack sufficient variability across demographics, such as age, ethnicity, and socioeconomic status, the resulting algorithms may perform unevenly, leading to disparities in diagnosis accuracy and treatment recommendations. This bias can exacerbate existing healthcare inequalities, particularly affecting underserved or minority groups that are underrepresented in training datasets.[40,41]

The quality and variability of data used for training AI algorithms also pose significant hurdles. Medical imaging data can differ due to variations in imaging equipment, protocols, and operators across institutions. Such heterogeneity can impact the robustness and generalizability of AI models, potentially leading to inconsistent performance when applied in different clinical settings. In addition, issues related to incomplete, noisy, or mislabeled data can diminish the reliability of AI outputs, raising concerns about diagnostic accuracy and patient safety.[42,43]

Regulatory and ethical considerations further complicate AI integration into head-and-neck cancer care. The development and deployment of AI tools require rigorous validation and approval by regulatory bodies, which can be a lengthy and complex process. Ethical questions regarding accountability—such as who is responsible if an AI-assisted decision leads to adverse outcomes—must be addressed. Moreover, clinicians and patients may be hesitant to trust AI recommendations, especially when transparency about how algorithms arrive at certain conclusions (the "black box" problem) is lacking.[44,45]

Implementation challenges, including integration into existing healthcare workflows and systems, also present obstacles. AI tools need to be seamlessly fit into clinical routines without causing disruptions or increasing workload. This requires interoperability with electronic health records and imaging systems, as well as adequate training for healthcare providers. Resistance to change among clinicians and institutional inertia can slow down adoption.[46,47]

Finally, cost and resource limitations can restrict access to advanced AI technologies, especially in low-resource settings. Developing, maintaining, and updating AI systems requires substantial investment, which may not

be feasible for all healthcare facilities. This disparity in resource availability risks widening the gap in the quality of head-and-neck cancer care across different regions and institutions.[48,49]

As a result, while AI offers transformative potential in head-and-neck cancer management, addressing challenges such as data privacy, algorithm bias, data quality, regulatory hurdles, ethical concerns, integration issues, and resource constraints is crucial. This is essential to fully realize AI's benefits and ensure safe, equitable, and effective patient care.

6. Conclusion

In this review, we showed that AI has a profound and transformative impact on the diagnosis and management of head-and-neck cancer, revolutionizing traditional clinical practices through innovative applications, such as surgical robotics and remote monitoring systems. The integration of AI-driven technologies facilitates earlier detection, more precise surgical interventions, and personalized treatment strategies, ultimately improving patient outcomes and quality of life. We highlighted how surgical robotics equipped with AI algorithms enable surgeons to perform minimally invasive procedures with enhanced accuracy, real-time guidance, and reduced complication rates. These advancements expand the scope of complex head-and-neck cancer surgeries, offering safer and more effective options for patients with challenging tumors. Furthermore, we demonstrated that AI-driven remote monitoring systems allow continuous, non-invasive tracking of disease progression, treatment adherence, and early signs of recurrence. Such systems foster proactive interventions, optimize resource utilization, and promote patient engagement, all of which are essential components of personalized cancer care.

We also discussed the ongoing challenges that accompany AI integration in head-and-neck cancer care. Data privacy and security concerns remain paramount, as the reliance on large-scale, sensitive datasets necessitates stringent safeguards to prevent breaches. We showed that algorithm bias and variability in data quality pose significant risks to diagnostic accuracy and equitable healthcare delivery, especially across diverse populations and clinical settings. Addressing these issues requires careful data curation, validation, and transparency to ensure AI tools are fair and reliable. Additionally, the regulatory landscape and ethical considerations—such as accountability, informed consent, and algorithm transparency—must be navigated thoughtfully to facilitate safe deployment. We emphasized that seamless integration into existing healthcare workflows and overcoming resistance among clinicians are crucial for widespread adoption. Resource limitations and high costs further hinder equitable access to advanced AI technologies, underscoring the need for scalable and cost-effective solutions.

Despite these challenges, the potential benefits of AI in head-and-neck cancer management are substantial and far-reaching. Continued research, collaborative efforts, and regulatory frameworks are essential to harness AI's full potential while safeguarding patient rights and ensuring equitable care. We believe that ongoing technological advancements will further enhance the precision, efficiency, and personalization of head-and-neck cancer treatment. As AI evolves, it is poised to become an integral component of multidisciplinary care teams, ultimately leading to better prognoses, reduced healthcare burdens, and improved quality of life for patients. Therefore, future efforts should focus on addressing current limitations, promoting ethical standards, and ensuring that AI-driven innovations are accessible to all populations, fostering a new era of intelligent, patient-centered head-and-neck cancer care.

Acknowledgments

The author would like to thank Damascus University (https://damascusuniversity.edu.sy/), International University for Science and Technology (https://iust.edu.sy/en/), Al-Andalus University for Medical Sciences (https://au.edu.sy/ar), and Cordoba University (https://www.cpu.edu.sy/index.php/en/home) for the supports in the development of this article. Specifically, Damascus University provided access to research facilities, the International University for Science and Technology offered guidance on data analysis, Al-Andalus University for Medical Sciences facilitated collaboration with medical professionals, and Cordoba University contributed resources for literature review.

Funding

The work was funded by Damascus University (grant no: 20245760), the International University for Science and Technology (grant no: I6452025), the Al-Andalus University for Medical Sciences (grant no: 20045), and Cordoba University (grant no: 45600).

Conflict of interest

The author declares no conflict of interest.

Author contributions

This is a single-authored article.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Availability of data

Not applicable.

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