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APPLICATION OF ARTIFICIAL INTELLIGENCE IN THE IMAGING DIAGNOSIS OF HEAD AND NECK CANCERS – A LITERATURE REVIEW

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ABSTRACT

Introduction Head and neck cancers represent a significant clinical challenge due to their complex anatomy, biological heterogeneity, and diagnostic difficulties, particularly in the early stages of the disease. The rapid development of artificial intelligence (AI) in recent years has opened up new possibilities for medical image analysis, supporting the diagnostic process and clinical decision-making.

Current State of Knowledge The aim of this study was to review the current literature on the application of artificial intelligence in the imaging diagnosis of head and neck cancers, with particular emphasis on its clinical potential, limitations, and future directions. A nonsystematic review of publications available in the PubMed, Scopus, and Web of Science databases from 2017 to 2025 was conducted. Studies investigating the use of machine learning, deep learning, and radiomics in CT, MRI, and PET/CT imaging were analyzed. The reviewed studies indicate that AI algorithms, particularly those based on convolutional neural networks, demonstrate high performance in the detection, segmentation, and classification of neoplastic lesions. The application of radiomics enables the extraction of quantitative imaging features that may support prognostic assessment and prediction of treatment response, thereby contributing to the development of personalized medicine. However, the implementation of these technologies in clinical practice faces significant challenges, including a lack of data standardization, limited model interpretability, and the need for validation in large, multicenter studies.

Conclusions In conclusion, artificial intelligence represents a promising tool in the imaging diagnosis of head and neck cancers. However, its full integration into clinical practice requires further research, methodological standardization, and the resolution of ethical and organizational challenges.

KEYWORDS

Head and Neck Neoplasms, Artificial Intelligence, Diagnostic Imaging, Radiomics, Tumor Detection

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Introduction and Objective

Head and neck cancers represent a significant public health burden, characterized by substantial mortality and considerable clinical and biological heterogeneity. They comprise a broad group of malignancies, with prognosis largely dependent on the stage of disease at the time of diagnosis. Due to the complex anatomy of the head and neck region and the often nonspecific clinical presentation in the early stages, the diagnosis of these malignancies remains a significant clinical challenge [1,2]. Contemporary medical imaging, including computed tomography (CT), magnetic resonance imaging (MRI), and positron emission tomography/computed tomography (PET/CT), plays a crucial role in the detection, staging, and treatment monitoring of head and neck cancers. Despite the high quality of the images obtained, their interpretation remains largely dependent on the expertise of the radiologist and may be subject to interobserver variability [3,4]. These limitations have prompted the search for tools capable of supporting the analysis of imaging data.

In recent years, artificial intelligence (AI) has undergone rapid development and has found increasingly widespread applications in medical image analysis. Algorithms based on convolutional neural networks enable the automated detection, segmentation, and classification of neoplastic lesions, supporting the diagnostic process and potentially improving its accuracy [3,5].

Another important area of development is radiomics, which involves the extraction of quantitative features from medical images that may reflect the biological characteristics of a tumor. The integration of radiomic data with artificial intelligence methods offers the potential to develop predictive models that can support diagnosis, prognostic assessment, and treatment planning, thereby contributing to the advancement of personalized medicine [6,7].

Despite growing interest and numerous scientific reports highlighting the potential applications of artificial intelligence in the imaging diagnosis of head and neck cancers, the implementation of these technologies in routine clinical practice remains associated with significant challenges. These include, among

others, the lack of data standardization, limited model interpretability, and the need for validation in large, multicenter studies [2,4].

The aim of this study is to review the current literature on the application of artificial intelligence in the imaging diagnosis of head and neck cancers, with particular emphasis on its clinical potential, limitations, and future directions in the development of this technology.

Materials and Methods

This study presents a nonsystematic review of the scientific literature concerning the application of artificial intelligence in the imaging diagnosis of head and neck cancers. The aim was to analyze current scientific evidence regarding the use of artificial intelligence methods in medical imaging for the diagnosis, classification, and prediction of the course of neoplastic disease.

The literature search was conducted using the PubMed, Scopus, and Web of Science databases. The search included publications published between 2017 and 2025. Combinations of the following keywords were used: “artificial intelligence,” “machine learning,” “deep learning,” “radiomics,” “head and neck cancer,” and “medical imaging.”

The analysis included original studies, comprising both retrospective and prospective studies, as well as experimental studies and review articles, provided that they directly addressed the application of artificial intelligence to medical image analysis in the context of head and neck cancers. Only full-text publications written in English were included. Studies utilizing imaging data obtained from computed tomography (CT), magnetic resonance imaging (MRI), and positron emission tomography/computed tomography (PET/CT) were considered.

Publications that were not available in full text, articles not directly related to the subject of the study, purely theoretical studies without clinical applications, and non-peer-reviewed materials, such as conference abstracts, letters to the editor, and popular science articles, were excluded.

The analysis of the collected literature included an assessment of the artificial intelligence methods employed, the types of imaging data utilized, and the primary research objectives, including tumor detection, tumor segmentation, classification, and prediction of treatment outcomes. Particular attention was paid to the application of machine learning, deep learning, and radiomics in the diagnosis of head and neck cancers.

The main limitation of this review is its nonsystematic nature and the potential for selective study selection, which may affect the comprehensiveness of the presented evidence. Furthermore, a substantial proportion of the analyzed studies were based on relatively small study populations and retrospective datasets, limiting the generalizability of their findings.

Current State of Knowledge

Fundamentals of Artificial Intelligence

Artificial intelligence (AI) is a field of computer science concerned with the development of systems capable of performing tasks that typically require human intelligence, such as data analysis, image recognition, and decision-making. In medicine, AI has found broad applications, particularly in the analysis of diagnostic images, where it can assist physicians in the detection and assessment of pathological abnormalities [8,9].

Machine learning (ML) is a subfield of artificial intelligence in which models learn from data without the need for explicit programming. Algorithms analyze training data and identify patterns that can subsequently be used to make predictions on new, previously unseen data. The application of ML methods in medicine enables, among other things, the automation of image analysis and improvement in the reproducibility of diagnostic results [9,10].

Deep learning (DL) is an extension of machine learning that utilizes multilayered neural networks capable of automatically learning data representations at different levels of abstraction. These methods have demonstrated particular effectiveness in the analysis of medical images, including computed tomography (CT), magnetic resonance imaging (MRI), and positron emission tomography/computed tomography (PET/CT), and are widely used in modern diagnostic imaging [10,11].

Convolutional neural networks (CNNs) are among the most commonly used types of models for medical image analysis. They consist of multiple layers, including convolutional layers responsible for extracting features from images and pooling layers that reduce dimensionality while preserving the most relevant

information. This architecture enables CNNs to effectively recognize anatomical and pathological patterns in medical images [10,12].

The operation of artificial intelligence models is based on a learning process using training data, during which the model minimizes a loss function by adjusting its parameters, most commonly through optimization methods such as gradient descent. The model is subsequently evaluated on test data to assess its ability to generalize to previously unseen data. A major challenge in the development of AI models is overfitting, in which a model becomes excessively well adapted to the training data at the expense of its performance on new, unseen data [10,13].

Applications of Artificial Intelligence in Diagnostic Imaging

Artificial intelligence is becoming increasingly integrated into clinical medicine. Due to the widespread availability of large medical imaging datasets, radiology has emerged as one of the leading fields benefiting from these innovations. The use of AI to support the analysis of diagnostic images enables greater accuracy in the diagnostic and therapeutic process [14].

AI algorithms have been widely applied to the automated detection of neoplastic lesions on CT, MRI, and PET imaging. Deep learning models, particularly convolutional neural networks (CNNs), demonstrate high performance in identifying pathological foci and, in some settings, may outperform conventional image analysis methods. Studies have shown that radiomics enables the detection of subtle structural and textural alterations that may not be readily perceptible to clinicians [5,15].

Quantitative medical image analysis encompasses features related to signal intensity, shape, size, volume, and textural characteristics. These parameters provide important information about tumor phenotype and its microenvironment that is not readily available from conventional clinical data, laboratory test results, or genomic and proteomic analyses. When integrated with other data sources, these features can be associated with patient clinical outcomes and incorporated into evidence-based clinical decision support systems.

Radiomics represents a rich source of potential imaging biomarkers that may be applied to cancer detection and diagnosis, prognostic assessment, prediction of treatment response, and disease monitoring [16].

The spatial and temporal heterogeneity of solid tumors represents a major challenge for the development of precision medicine, as conventional tissue sampling methods, such as invasive needle biopsy, cannot fully capture the heterogeneity of a tumor throughout its entire volume. In this context, imaging-based phenotyping, which enables quantitative characterization of tumors using medical imaging techniques, represents a promising tool for advancing personalized medicine [17].

Following registration of MRI sequences to a standard head and neck anatomical space, a multi-view neural network model demonstrated reliable performance in terms of both lesion volume and localization, particularly for larger tumors. However, further improvements in performance are required before fully automated MRI-only segmentation can be reliably incorporated into treatment planning. Such improvements may be achieved, among other approaches, by reducing the number of false-positive regions generated during segmentation [18].

A radiomic feature set derived from MRI images may support differentiation between stage III and stage IV head and neck squamous cell carcinoma. It may therefore represent a valuable adjunctive tool for the preoperative assessment of disease stage [19].

Studies have demonstrated that AI algorithms achieve a high level of agreement with expert-generated segmentations while simultaneously reducing interobserver variability [20–22].

A meta-analysis demonstrated that the area under the curve (AUC) of radiomic models varied depending on the imaging modality, reaching approximately 91% for computed tomography, 84% for magnetic resonance imaging, and 92% for PET/CT. Models based on PET/CT data achieved the highest sensitivity and specificity. When different analytical approaches were compared, deep learning models achieved an AUC of approximately 92%, whereas handcrafted radiomic models achieved an AUC of approximately 91%. Assessment of lymph node metastases represents a key component of head and neck cancer diagnostics. The analysis also demonstrated that models incorporating lymph node features achieved an AUC of approximately 92%, whereas models based on characteristics of the primary tumor achieved an AUC of approximately 89%. No statistically significant differences were observed either between deep learning models and conventional radiomic models or between approaches based on lymph node characteristics and those based on the primary tumor [23].

A fully automated deep learning-based method, ODS-Net, has been developed for the detection and segmentation of organs at risk (OARs) on computed tomography images. The model demonstrates high

reliability in both detection and segmentation, making it a potentially useful tool for identifying critical structures during radiotherapy planning for nasopharyngeal carcinoma. In addition, the system generates a prediction for a single image in approximately 30 seconds, allowing for efficient integration into clinical practice [24].

The development of predictive models for treatment response in head and neck tumors represents one of the major applications of artificial intelligence in radiomics. AI algorithms can accurately predict patient responses to therapies such as radiotherapy, chemotherapy, and targeted therapies by analyzing radiomic features derived from pretreatment imaging data, as demonstrated in several studies [5]. Radiomics may also be used to identify specific tumor phenotypes, thereby enabling the assessment of the risk of particular clinical events in patients with head and neck cancers.

The clinical significance of these findings may be substantial, as they raise the possibility of a more personalized therapeutic approach. For example, in patients at high risk of locoregional recurrence, radiation dose escalation could potentially be considered. Conversely, in patients at high risk of distant metastases, treatment intensification with chemotherapy might be considered, whereas de-escalation of chemotherapy in low-risk patients could potentially contribute to improved quality of life. However, it should be emphasized that these approaches currently remain theoretical concepts and cannot yet be implemented in routine clinical practice. Further development of the models, validation in larger patient populations, and well-designed clinical studies are required to establish their impact on treatment outcomes and survival [25].

Impact of Artificial Intelligence in Diagnostic Imaging on Public Health

Improving Access to Diagnostic Services

Many countries face a shortage of radiologists and other specialists qualified to interpret medical imaging studies, resulting in prolonged waiting times and limited access to diagnostic services, particularly in resource-limited regions. AI systems can support diagnostic workflows by automatically detecting and classifying imaging abnormalities, potentially accelerating image interpretation and reducing dependence on the availability of specialists [32]. In clinical applications, deep learning-based algorithms have demonstrated the ability to automatically segment and classify anatomical structures and pathological lesions on head and neck CT and MRI images [33].

Early Detection of Disease

AI enables the identification of subtle imaging features that may be overlooked by human observers, which is particularly relevant for the early detection of malignancies and premalignant lesions. Radiomic analyses and machine learning models can integrate quantitative features extracted from medical images, thereby improving the accuracy of disease classification and prediction [34]. The application of AI in screening programs may improve the detection of diseases at an early stage, which may in turn lead to better clinical outcomes and lower treatment costs.

Optimization of Healthcare System Costs

The implementation of AI in diagnostic imaging may contribute to reducing healthcare system costs. Automated image analysis can shorten the time required for diagnosis and reduce the workload of healthcare professionals. Studies indicate that the implementation of AI systems may improve efficiency in radiology, reduce the incidence of diagnostic errors, and decrease the number of unnecessary examinations [9].

Health Inequalities and Ethical Considerations

Despite its numerous potential benefits, the use of AI carries a risk of exacerbating health inequalities. Algorithms trained on limited or non-representative datasets may demonstrate lower performance in certain populations. This issue, commonly referred to as algorithmic bias, may contribute to disparities in access to high-quality diagnostic services [35]. Additional challenges include data privacy, algorithmic transparency, and accountability for decisions generated by AI systems [36]. Therefore, appropriate regulatory frameworks must be established, and the representativeness of datasets used for model training must be ensured.

Integration of Artificial Intelligence into Healthcare Systems

The integration of artificial intelligence (AI) into healthcare systems requires adaptation of information technology infrastructure and interoperability with hospital information systems (HIS) and picture archiving and communication systems (PACS). The quality and standardization of clinical data are of critical importance, as they directly influence the performance of AI models [37]. AI can support clinical data analysis, clinical

decision-making, and prediction of healthcare system demand, thereby facilitating more effective resource allocation and improving the quality of care [38]. Patient safety, data protection, and compliance with applicable regulations are also essential considerations. The development of explainable artificial intelligence (XAI) enhances model transparency and may facilitate the acceptance of AI-based systems within clinical practice [39].

Conclusions

The literature review indicates that artificial intelligence represents a promising tool for supporting the imaging diagnosis of head and neck cancers. Algorithms based on machine learning and deep learning, particularly convolutional neural networks, demonstrate high performance in the detection, segmentation, and classification of neoplastic lesions, often achieving results comparable to or superior to those obtained using conventional image analysis methods.

The application of radiomics enables the extraction of quantitative imaging features that may reflect the biological characteristics of tumors, thereby supporting the diagnostic process, prognostic assessment, and prediction of treatment response. The integration of these data with artificial intelligence methods is consistent with the development of personalized medicine and may contribute to a more individualized therapeutic approach.

Despite its considerable potential, the implementation of artificial intelligence in routine clinical practice faces numerous limitations. The most important include a lack of standardization of data and research methodologies, limited availability of large and representative datasets, as well as challenges related to model interpretability and their ability to generalize across different clinical settings.

Furthermore, important ethical and legal considerations remain, including the risk of algorithmic bias, protection of patient data, and accountability for decisions made by AI-based systems. These issues may affect clinicians' trust in such technologies and influence the pace of their implementation in clinical practice.

In conclusion, artificial intelligence has the potential to substantially improve the imaging diagnosis of head and neck cancers by enhancing diagnostic accuracy, reproducibility, and accessibility. However, the full realization of its potential requires further research, methodological standardization, validation of models in large patient populations, and the development of clear legal and ethical frameworks.

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