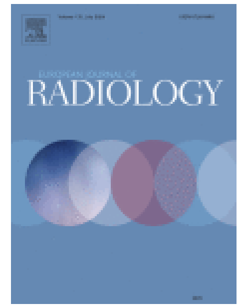
European Journal of Radiology
Volume 176, July 2024, 111509



Role of artificial intelligence in brain tumour imaging

Author links open overlay panelEzekiel Chukwujindu [a], Hafsa Faiz [a], Sara Al-Douri [b], Khunsa Faiz [c], Alexandra De Sequeira [d]

https://doi.org/10.1016/j.ejrad.2024.111509Get rights and content

Abstract

Artificial intelligence (AI) is a rapidly evolving field with many neuro-oncology applications. In this review, we discuss how AI can assist in brain tumour imaging, focusing on machine learning (ML) and deep learning (DL) techniques. We describe how AI can help in lesion detection, differential diagnosis, anatomic segmentation, molecular marker identification, prognostication, and pseudo-progression evaluation. We also cover AI applications in non-glioma brain tumours, such as brain metastasis, posterior fossa, and pituitary tumours. We highlight the challenges and limitations of AI implementation in radiology, such as data quality, standardization, and integration. Based on the findings in the aforementioned areas, we conclude that AI can potentially improve the diagnosis and treatment of brain tumours and provide a path towards personalized medicine and better patient outcomes.

Introduction

Central nervous system cancer is the tenth leading cause of death in men and women [1]. Brain tumour is not the primary cause of mortality, yet 40 % of all other cancer types can develop into brain cancer due to metastasis [1]. The diagnosis of brain tumors is predominantly based on neuroimaging findings, using techniques such as contrast-enhanced computed tomography (CT) or magnetic resonance imaging (MRI).
Among the central nervous system (CNS) neoplasms, the most common type is Glioma originating from glial cells [2].
Gliomas are heterogeneous groups of disease, with many different histotypes and molecular subtypes ranging from slow growing pilocytic astrocytoma to the aggressive glioblastoma multiforme (GBM). Given poor prognosis of patients with brain cancer at a higher stage, accurate grading is crucial for treatment and prognosis.
Common tests used for tumour diagnosis and grade estimation include neurological examination, imaging, biopsies, and biomarkers. Biopsies are the gold standard, but invasive and risky.
Techniques such as contrast-enhanced computed tomography (CT) or magnetic resonance imaging (MRI) are used for diagnosis of brain tumours. As they are non-invasive and accessible, many efforts have been made to increase the information from brain imaging.
Conventional MRI sequences, which include pre- and postcontrast T1-weighted imaging, T2-weighted imaging, and T2-weighted fluid-attenuated inversion recovery (FLAIR) sequences, help delineate tumour volume and morphologic characteristics. Unfortunately, contrast enhancement is nonspecific, and the detection of foci of tumour infiltration within the T2-weighted FLAIR signal intensity abnormality is nearly impossible with conventional sequences [3].
Advanced MRI methods, including diffusion-weighted imaging, diffusion tensor imaging, perfusion MRI and MR spectroscopy, are used clinically for grading gliomas and identifying regions of tumour infiltration. They are usually qualitative and vary across sites, units, and methods. With increasing incidence of brain tumours, [4] a non-invasive, automatic computer-aided tool that can diagnose and grade a tumour quickly is needed.

One of the ways in which tumours can be swiftly diagnosed is through artificial intelligence. Artificial intelligence (AI) is defined as machines performing tasks characteristic of human intelligence [5]. AI-based algorithms have been used in the healthcare field to improve diagnosis, predict outcomes, guide efforts in drug discovery and for rapid data processing in clinical research. Moreover, neuroimaging research in AI has grown exponentially. There have been several articles published on the use of AI in brain tumour imaging. Ce et al [6] provided a description of AI-based models and a narrative review of their applications in various studies concerning brain imaging. Zhu et al [7] reviewed the latest machine learning-based AI applications in the radiomic analysis of brain tumours, providing a perspective on challenges and future avenues. However, other aspects of AI, such as its usage in non-glioma evaluations, as well as a discussion on the promise of the use of transformers in neuro-oncology imaging, is an important area of research. Thus, this article aims to evaluate the various uses of AI-assisted tools in the diagnosis and treatment of brain tumours, with a unique focus on brain gliomas as well as non-glioma evaluations, and transformer-based networks in brain tumour imaging.

Section snippets

Machine learning

Machine learning (ML), falling under the umbrella of AI, incorporates algorithms and statistical models to make predictions about new data points [8], [9]. In ML, computers learn automatically from data accumulation and improve with experience.
Deep learning (DL) is a subclass of ML that processes raw unstructured data using multi-layered artificial neural networks (ANN) [8], [9]. It is currently the basis of most of the AI tools used for image interpretation.. It can extract features, analyze

Artificial intelligence in image analysis

One of the most common applications of AI is in the analysis of diagnostic imaging. The process (Fig. 6) often commences with transforming the raw visual data into a format comprehensible to various deep learning models. This transformation is critical, whether the model in use is a Convolutional Neural Network (CNN), Vision Transformer

(ViT), or another advanced architecture [11], [12]. The core essence of these models lies in their ability to interpret the visual content of images through a

Lesion detection and grade Prediction

AI can improve diagnosis of small lesions [17] by using MRI, CT and PET scan data. (Table 3). Small lesions affect treatment choices and are very relevant for DL algorithms [18]. CAD tools need to be tuned to ensure accuracy and reduce overdiagnosis and overtreatment (Fig. 1).

Blanc-Durand et al [19] used dynamic 18F-FET PET images to detect brain lesions in glioma patients. They used a 3D U-Net CNN to classify lesion or non-lesion voxels from PET features. They got 0.9868 accuracy in training

Ai applications in non-glioma evaluation

Non-glioma brain tumours are a diverse group of brain tumours that can originate from different cell types and locations within the central nervous system. They include metastatic tumours, meningiomas, pituitary tumours, ependymomas, medulloblastomas, hemangioblastomas, and others. These tumours have different histopathological features, clinical manifestations, prognoses, and treatment options. Therefore, accurate and reliable methods for brain tumour classification are essential for improving

Transformer-based neural networks in brain tumour imaging

Transformers, a groundbreaking architecture initially revolutionizing natural language processing, as seen in models like ChatGPT, have expanded well beyond their original purpose. Their remarkable success in understanding and generating human language has paved the way for their application in medicine, specifically neuro-oncology imaging (Table 2), offering promising advancements in brain tumor diagnosis, classification and treatment. Transformers’ ability to efficiently process and analyze

Challenges

Implementing AI in radiology presents several challenges, including the need for high-quality, ground-truth data, seamless integration into existing user workflows, and the development of methods that are generalizable, interpretable, and robust across different settings and population groups [79].
Data Quality and Diversity: Large, well-annotated, and diverse datasets are essential to minimize measurement errors [80] and enhance algorithm performance across various sites, parameters, and

Conclusion

This review discusses the use of AI in brain tumour imaging. The development of CAD tools can improve diagnostic accuracy in detecting small metastatic brain lesions, allowing for early and accurate treatment planning, particularly for stereotactic radiosurgery.
AI-driven extraction of imaging features that are not visible to the human eye is transforming radiological image analysis and reporting from a qualitative interpretation to an objective, quantifiable, and reproducible task.
Segmentation

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work the author(s) used ChatGPT in order to Analyze reviewed articles and to retrieve results findings. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

CRediT authorship contribution statement

Ezekiel Chukwujindu: Writing – review & editing, Writing – original draft, Formal analysis, Data curation, Conceptualization. **Hafsa Faiz:** Writing – review & editing, Writing – original draft, Formal analysis, Data curation, Conceptualization. **Sara Al-Douri:** Writing – review & editing, Writing – original draft, Formal analysis, Data curation, Conceptualization. **Khunsa Faiz:** Writing – review & editing, Writing – original draft, Formal analysis, Data curation, Conceptualization. **Alexandra De**

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References (80)

- G.S. Tandel *et al.*

  Multiclass magnetic resonance imaging brain tumor classification using artificial intelligence paradigm
  Comput Biol Med
  (Jul. 2020)
- Y. Yang

  A comparative analysis of eleven neural networks architectures for small datasets of lung images of COVID-19 patients toward improved clinical decisions
  Comput Biol Med
  (Dec. 2021)
- L.F. Machado *et al.*

  MRI radiomics for the prediction of recurrence in patients with clinically non-functioning pituitary macroadenomas
  Comput Biol Med
  (Sep. 2020)
- P. Wesseling *et al.*

  WHO 2016 Classification of gliomas
  Neuropathol Appl Neurobiol
  (Feb. 2018)
- S.J. Price

Improved delineation of glioma margins and regions of infiltration with the use of diffusion tensor imaging: an image-guided biopsy study
AJNR Am J Neuroradiol
(Oct. 2006)

- N. Grech *et al.*

Rising incidence of glioblastoma multiforme in a well-defined population
Cureus
(May 2020)

- S. Aneja *et al.*

Applications of artificial intelligence in neuro-oncology
Curr Opin Neurol
(Dec. 2019)

- M. Cè

Artificial intelligence in brain tumor imaging: a step toward personalized medicine
Current Oncology
(Mar. 01, 2023.)

- M. Zhu

Artificial intelligence in the radiomic analysis of glioblastomas: A review, taxonomy, and perspective
Front Oncol
(Aug. 2022)

- M. Rowe

An introduction to machine learning for clinicians
Academic Medicine
(Oct. 2019)

View more references

Cited by (4)

- Automated segmentation in pelvic radiotherapy: A comprehensive evaluation of ATLAS-, machine learning-, and deep learning-based models
  2024, Physica Medica

  Citation Excerpt :

  Furthermore, especially in abdomen and pelvis CT scans, the scarce contrast between soft tissue organs and the high anatomical variability usually limits automated segmentation performances [9]. Lastly, images are reconstructed during acquisition to have a predefined voxel size leading to partial volume averaging [10]. In recent years, taking full advantage of Convolutional Neural Network, automated segmentation tools have migrated from the research domain to commercially available products.
  Show abstract

- Improved EfficientNet Architecture for Multi-Grade Brain Tumor Detection
  2025, Electronics (Switzerland)

- Feasibility study of GTV determination in brain metastases based on contrast-enhanced T2-FLAIR
  2025, Chinese Journal of Cancer Prevention and Treatment

- Transfer Learning Approaches for Brain Metastases Screenings
  2024, Biomedicines