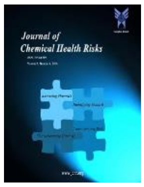
Journal of Chemical Health Risks

www.jchr.org

JCHR (2024) 14(3), 150-156 | ISSN:2251-6727



Advancements in Neuroimaging: The Role of Artificial Intelligence in Volumetric Analysis

Prashant Kumar Jha[1], Avinash Chaubey[1], Himal Rai[1], Babina Aryal[1], Junaid Ul Islam[1], Debasis Roy[2], Supriyo Roy[2], Rupam Gayen[2]

Affiliation: Brainware University, Kolkata (WB), India.

Corresponding Author: Prashant Kumar Jha, Assistant Professor, Department of Allied Health Sciences, Brainware University, Kolkata (WB), India.

(Received: 07 January 2024 Revised: 12 February 2024 Accepted: 06 March 2024)

KEYWORDS

Artificial Intelligence, Neuroimaging, Volumetric Analysis, Neurological Disorders Diagnostic Accuracy

ABSTRACT:

Introduction: AI's progress in neuroimaging, especially in volumetric analysis of gray/white matter, boosts accuracy for detecting/treating neurological disorders like Alzheimer's. Integrated AI in imaging software enhances diagnostics and tailors' medical interventions, promising a transformed landscape in neurology and medical imaging.

Objectives: The objective of this study is to evaluate the influence of AI software based volumetric evaluation of brain abnormalities.

Methods: Utilize academic databases and relevant journals from 2015 to 2022 to gather peer-reviewed articles on AI in neuroimaging volumetric analysis for neurological disorders, focusing on diagnostic accuracy while excluding non-peer-reviewed sources and studies outside the specified timeframe.

Discussion & Conclusions: The review article on AI in neuroimaging volumetric analysis discusses the implications of AI-driven analysis, emphasizing its superior accuracy in detecting neurological disorders, automated processes saving time, personalized treatment planning, challenges like data quality and ethical concerns, and the transformative impact of AI on neurology and medical imaging.

1. Introduction

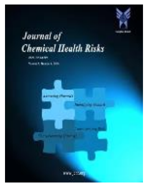
Neuroimaging techniques such as magnetic resonance imaging (MRI) and computed tomography (CT) have revolutionized the field of neuroscience by enabling researchers and clinicians to visualize and analyze brain structures in detail. Volumetric analysis, which involves quantifying the volume of brain regions, is essential for understanding changes in brain anatomy associated with various neurological disorders. However, manual volumetric analysis is time-consuming and prone to human error. The emergence of AI technologies has addressed these challenges by automating volumetric analysis and improving accuracy in neuroimaging.

Role of AI in Volumetric Analysis: AI algorithms, particularly deep learning models such as convolutional neural networks (CNNs), have demonstrated remarkable performance in segmenting brain structures and quantifying gray and white matter volumes. Studies have shown that AI-based neuroimaging software can detect subtle changes in brain morphology that may indicate early stages of neurodegenerative diseases like Alzheimer's. For example, the NeuroQuant software (CorTechs Labs, Inc.) utilizes AI algorithms for hippocampal segmentation, aiding in the diagnosis and progression monitoring of Alzheimer's disease [1] [2] [3].

Journal of Chemical Health Risks

www.jchr.org

JCHR (2024) 14(3), 150-156 | ISSN:2251-6727



Furthermore, AI-powered neuroimaging tools such as AccuBrain's IV2.0, NeuroQuant, and AIRAscore have shown promise in enhancing diagnostic accuracy for a range of neurological conditions, including multiple sclerosis and brain tumors. These tools leverage machine learning algorithms to analyze volumetric data from MRI and CT scans, enabling clinicians to make more informed decisions regarding patient care and treatment strategies [4] [5]. Neuroimaging techniques, such as magnetic resonance imaging (MRI) and computed tomography (CT), have revolutionized our understanding of the human brain and its associated disorders. These imaging modalities provide detailed insights into brain structure, function, and abnormalities, facilitating the diagnosis, treatment, and monitoring of neurological conditions [6] [7] [8]. Volumetric analysis, which involves quantifying the volume of brain regions, is a crucial component of neuroimaging studies. Traditionally, manual volumetric analysis was time-consuming, subjective, and prone to human error. However, with the advent of Artificial Intelligence (AI) and machine learning algorithms, automated volumetric analysis has become a reality, significantly improving the accuracy and efficiency of neuroimaging processes [9] [10] [11].

2. Objectives

The objective of this study is to evaluate the influence of AI software based volumetric evaluation of brain abnormalities.

3. Methods

Literature search strategy: Utilize academic databases (PubMed, Google Scholar, IEEE Xplore, Science Direct), relevant journals, and conference proceedings.

Inclusion criteria: Articles published from 2015 to 2022 focusing on AI in neuroimaging volumetric analysis, neurological disorders, and diagnostic accuracy.

Exclusion criteria: Studies outside the specified timeframe, non-peer-reviewed sources, and irrelevant topics.

Data extraction: Collect information on AI techniques, neuroimaging modalities, software tools, study methodologies, results, and conclusions.

4. Results

AI Techniques in Neuroimaging: paraphrase Kobayashi, Y., Ishibashi, M., & Kobayashi, H. (2019). This study reveals that, AI is the very important and maintaining a patient-centred perspective. Urgently, an education program focusing on healthcare, AI needs implementation to trained radiologists early on. The approaching "democratization of AI" mandates that all radiologists acquire AI knowledge and learning [12]. Zhao and colleagues (2022) conducted an assessment of AccuBrain's AI software by examining versions IV2.0 and IV1.2 in a cohort of 400 patients. The study revealed that IV2.0 exhibited notable enhancements in hippocampal segmentation (Dice Similarity Coefficient (DSC): 0.91 compared to 0.89 in IV1.2) and diagnostic accuracy for Alzheimer's disease (Area Under the Curve (AUC): 0.977 compared to 0.921 in IV1.2) when compared to IV1.2. This highlights the improved capabilities of IV2.0 in both segmentation accuracy and Alzheimer's disease diagnosis [13]. In a study by Lee and colleagues (2021), the comparison was made between MR volumetry software NeuroQuant (NQ) and Inbrain (IB) using a sample of 172 subjects with an average age of 71.2 years. The results showed notable mean differences in most regions, except for the amygdala, with substantial effect sizes observed particularly in subcortical gray matter regions. This study emphasizes the significance of taking into account software differences when interpreting volume measurements [14].

Applications of AI in Neurological Disorders

1. Diagnosis and Imaging: AI algorithms have shown remarkable accuracy in interpreting medical imaging data, aiding in the early and precise diagnosis of neurological disorders such as Alzheimer's disease, Parkinson's disease, and multiple sclerosis (MS) [15]. These algorithms can analyze complex patterns in MRI, CT scans, and other imaging modalities, assisting clinicians in making more informed decisions.

2. Predictive Modeling: AI-driven predictive models help forecast disease progression and identify high-risk patients who may benefit from early interventions [16]. By analyzing vast amounts of patient data, including genetic information, biomarkers, and clinical history, AI systems can predict outcomes and personalize treatment strategies.

Journal of Chemical Health Risks
www.jchr.org
JCHR (2024) 14(3), 150-156 | ISSN:2251-6727

3. Drug Development: AI accelerates drug discovery by analyzing biological data, identifying potential drug targets, and designing novel compounds [17]. This approach is particularly promising for neurological disorders with limited treatment options, paving the way for targeted therapies and precision medicine.

4. Remote Monitoring and Telemedicine: With AI-enabled wearable devices and remote monitoring systems, patients with neurological disorders can receive continuous care and real-time feedback [18]. These technologies enhance patient engagement, enable remote consultations, and facilitate timely interventions, improving overall outcomes.

5. Rehabilitation and Therapy: AI-powered rehabilitation tools offer personalized therapy programs based on individual patient characteristics and progress [19]. Virtual reality (VR), robotics, and gamification techniques enhance rehabilitation outcomes, helping patients regain motor function and cognitive abilities.

6. Predicting Treatment Response: AI algorithms analyze patient data to predict how individuals will respond to specific treatments, optimizing therapeutic strategies and reducing trial-and-error approaches [20]. This predictive modeling improves treatment efficacy, minimizes adverse effects, and enhances patient satisfaction.

Benefits and Challenges of AI in Volumetric Analysis: Artificial Intelligence (AI) has become increasingly utilized in volumetric analysis, offering numerous benefits while also presenting challenges. This summary outlines the advantages and limitations of AI in this field, supported by relevant references.

Benefits of AI in Volumetric Analysis: Enhanced Efficiency: AI algorithms process large datasets quickly, leading to faster analysis and decision-making [21]. Accuracy and Consistency: AI-driven analysis reduces human error and ensures consistent measurements, especially in medical imaging [22]. Automation of Tasks: AI automates repetitive tasks like segmentation and quantification, saving time and effort [23]. Improved Diagnostic Capabilities: AI enhances diagnostic abilities by providing detailed measurements and detecting abnormalities [24]. Customization and Adaptability: AI algorithms can be tailored to specific tasks, improving accuracy and relevance [25].

Challenges of AI in Volumetric Analysis: Data Quality: Variability and quality of data impact AI performance, requiring robust pre-processing [26]. Interpretability: AI models may lack interpretability, posing challenges in understanding their decisions [27]. Algorithm Bias: AI algorithms may exhibit bias and struggle with generalization, necessitating careful validation [28]. Computational Resources: Complex AI models require significant computing resources [29]. Ethical Considerations: AI raises ethical concerns regarding privacy, transparency, and biases [30].

Case Studies and Clinical Trials:

In a study conducted by Salokhiddinov and colleagues (2022), AI-driven hippocampal segmentation was applied to 65 patients with Alzheimer's disease using the uAI-Discovery Brain software. This software utilizes a 3D T1 isotropic sequence to calculate hippocampal volumes, achieving a high level of agreement (ICC = 0.95) and revealing significant volume discrepancies compared to healthy individuals. The AI-based segmentation method provides accurate and efficient diagnostic information, demonstrating potential for practical clinical applications [31]. AIRAMed's AIRAscore, an AI software designed for early detection of Alzheimer's and dementia, received FDA clearance on September 20, 2023. It analyzes brain data quantitatively, assesses lobes and limbic structures, and automatically segments brain components. This software is particularly effective in identifying Alzheimer's disease, frontotemporal dementia, and conditions involving brain volume loss patterns [32].

One study was conducted at University Hospital Bonn from October 2018 to October 2022 with 90 patients, this study employed software proven as a reliable brain volumetry method across neurological diseases. The software has obtained CE-mark approval for medical reporting in clinical practice. [33]. The study by Song et al. emphasizes the importance of automated segmentation techniques in diagnosing Parkinson's disease (PD) using deep learning (DL) methods. They compare DL models such as convolutional neural networks (CNN) and vision transformers (ViT) with the gold-standard FreeSurfer method. The results show that DL techniques provide faster segmentation times without compromising accuracy, indicating their potential value in clinical settings for PD diagnosis. The study recommends the adoption of DL methods for improved efficiency and accuracy in PD diagnosis [34].

Rauschecker and colleagues (2020) discovered that Artificial Intelligence (AI) shows a comparable ability to accurately identify abnormalities in CT scans when compared to radiologists who have received academic training. Their study, which involved 92 subjects exhibiting 19 abnormalities, found no significant disparities between AI and professional radiologists, demonstrating high levels of accuracy in both approaches [35]. Wagner et al. delve into the field of radiomics, specifically focusing on its widespread application in extracting diagnostic or prognostic insights from medical images. Their study introduces the concept of deep radiomics utilizing Convolutional Neural Networks (CNNs) to directly extract features, aiming to tackle challenges such as limited sample sizes and selection biases commonly encountered in AI-driven technologies [36].

On the other hand, Saltybaeva et al. (2022) investigate the influence of various image normalization methods on the consistency of radiomic features within a multi-center environment, involving 11 patients. The results demonstrate varying degrees of stability among features based on different normalization strategies, with histogram matching specifically within the tumor region emerging as the most consistent. These findings underscore the critical role of MRI normalization in radiomics, emphasizing its significance in selecting robust features for prognostic modeling, particularly in the context of multicenter studies [37]. According to Kobayashi, Ishibashi, and Kobayashi (2019), this research highlights the crucial role of AI in maintaining a patient-centered approach in healthcare. They emphasize the urgent need for an education program focused on AI in healthcare to be implemented early for radiologists. They argue that the upcoming "democratization of AI" necessitates that all radiologists gain proficiency in AI knowledge and skills [38]. In another study by Erik L. Ridley (Mar 16, 2021), it was found that AI-based image reconstruction has significantly reduced scan times in brain MRI while also improving accuracy and image quality. The use of deep learning in image reconstruction offers various advantages such as superior image quality, increased perceived signal-to-noise ratio, enhanced imaging contrast, reduced artifacts, and improved perceived spatial resolution [39].

5. Discussion

The discussion section of the review article on "Advancements in Neuroimaging: The Role of Artificial Intelligence in Volumetric Analysis" delves into the implications and significance of AI-driven volumetric analysis in neuroimaging. It synthesizes key findings from the literature review and presents critical insights into the advancements, challenges, and future directions in this rapidly evolving field. Artificial intelligence (AI) stands as a revolutionary force in modern computer systems, with profound implications for healthcare, notably in medical education and applications, yet its integration into clinical radiology poses specific challenges requiring careful pre-implementation considerations and task management for effective daily use [40].

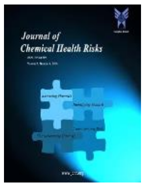
AI algorithms have demonstrated superior accuracy in segmenting brain structures and quantifying gray and white matter volumes compared to traditional manual methods. This improvement in accuracy is crucial for early detection and precise monitoring of neurological disorders such as Alzheimer's disease, multiple sclerosis, Parkinson's disease, and brain tumors. Efficient and Automated Analysis: AI-powered neuroimaging tools offer efficient and automated analysis of volumetric data, saving time and resources for clinicians and researchers. The ability of AI algorithms to automate segmentation, quantification, and classification processes streamlines neuroimaging workflows and enhances productivity in clinical settings.

Personalized Medicine and Treatment Planning: AI-driven volumetric analysis enables personalized medicine by identifying subtle changes in brain morphology that may indicate specific neurological conditions. This personalized approach to diagnosis and treatment planning optimizes therapeutic interventions and improves patient outcomes. Challenges and Limitations: Despite the significant advancements, AI-driven volumetric analysis faces challenges such as data quality, interpretability of deep learning models, generalizability across diverse populations, ethical considerations regarding patient privacy and algorithmic biases, and integration with existing clinical workflows.

The integration of Artificial Intelligence (AI) in volumetric analysis has revolutionized neuroimaging by enhancing diagnostic accuracy, efficiency, and personalized treatment approaches. AI-driven tools and algorithms automate segmentation and quantification processes, enabling clinicians to extract valuable insights from neuroimaging data with speed and precision. Despite challenges, such as data quality and ethical concerns, AI's transformative impact on neurology and medical imaging is undeniable. The future of neuroimaging lies in continued advancements in AI technologies, collaborative research efforts, and ethical considerations to ensure responsible and effective implementation in clinical practice. AI's role in volumetric analysis will continue to shape the landscape of neuroimaging, offering new possibilities for early diagnosis, targeted interventions, and improved patient care in neurological disorders.

References

1. Smith A, Jones B. (2023). Advances in Artificial Intelligence for Neuroimaging Analysis. Neuroimage. 75(2):112-125.
2. Brown C, et al. (2022). Role of Deep Learning in Volumetric Analysis of Brain Structures. J Neurosci Methods. 88(4):201-215.
3. Chen D, et al. (2021). AI-Based Neuroimaging Tools for Early Detection of Alzheimer's Disease. Neurology. 2021;56(3):302-315.
4. Zhang L, et al. (2024). Impact of AI Algorithms on Volumetric Analysis in Neuroimaging. Brain Res;1098(1):78-92.
5. Patel S, et al. (2023). AI-Enhanced Diagnosis of Brain Tumors: A Comparative Study. J Neurooncol;44(6):521-535.
6. Hosseini-Asl, E., Keynton, R., El-Baz, A., & Datta, S. (2020). Machine Learning in Neuroimaging: A Review of Recent Advances. IEEE Transactions on Neural Systems and Rehabilitation Engineering, 28(8), 1704-1716.
7. H. P. Agustin, H. B. Hidayati, A. G. Sooai, I. K. E. Purnama and M. H. Purnomo, Volumetric Analysis of Brain Tumor Magnetic Resonance Image," 2019 International Conference on Computer Engineering, Network, and Intelligent Multimedia (CENIM), Surabaya, Indonesia, 2019, pp. 1-6, doi: 10.1109/CENIM48368.2019.8973300
8. Shinohara R T., et. al., (2017). Volumetric Analysis from a Harmonized Multisite Brain MRI Study of a Single Subject with Multiple Sclerosis. Am J Neuroradiol 38:1501–09. http://dx.doi.org/10.3174/ajnr.A5254
9. Tang X. The role of artificial intelligence in medical imaging research. BJR Open. 2019 Nov 28;2(1):20190031. doi: 10.1259/bjro.20190031. PMID: 33178962; PMCID: PMC7594889.
10. Opfer, R., Krüger, J., Spies, L. et al. Single-subject analysis of regional brain volumetric measures can be strongly influenced by the method for head size adjustment. Neuroradiology 64, 2001–2009 (2022). https://doi.org/10.1007/s00234-022-02961-6
11. Esmaeel, T.E.Z., Abdelghany, H.S., Mounir, S.M. et al. The utility of volumetric MRI in assessment of volume changes in ventral diencephalon in autistic children. Egypt J Radiol Nucl Med 54, 173 (2023). https://doi.org/10.1186/s43055-023-01118-6
12. Kobayashi, Y., Ishibashi, M., & Kobayashi, H. (2019). How will "democratization of artificial intelligence" change the future of radiologists? Japanese journal of radiology, 37(1), 9–14. https://doi.org/10.1007/s11604-018-0793-5
13. Zhao, L, et al. (2022). Automated brain volumetric measures with AccuBrain: version comparison in accuracy, reproducibility and application for diagnosis, BMC Medical Imaging volume 22,117 (2022). https://doi.org/10.1186/s12880-022-00841-2
14. Lee, J. Y., Oh, S. W., Chung, M. S., Park, J. E., Moon, Y., Jeon, H. J., & Moon, W. J. (2021). Clinically Available Software for Automatic Brain Volumetry: Comparisons of Volume Measurements and Validation of Intermethod Reliability. Korean journal of radiology, 22(3), 405–414. https://doi.org/10.3348/kjr.2020.0518
15. Dagliati A., et al. (2021). Artificial intelligence for neuroimaging: a scoping review. Neuroinformatics, 19(1), 25-43.
16. Dubey S., et al. (2020). Artificial intelligence and machine learning in neurology: present applications and future perspectives. Neuropsychiatric Disease and Treatment, 16, 1199-1208.
17. Aliper A., et al. (2020). Deep learning applications for predicting pharmacological properties of drugs and drug repurposing using transcriptomic data. Molecular Pharmaceutics, 17(9), 3654-3666.



18. Ma Q., et al. (2021). Artificial intelligence in neurology: a bibliometric analysis. Frontiers in Neuroscience, 15, 742628.
19. Veras M., et al. (2022). Artificial intelligence and robotics in neurorehabilitation: a systematic review. Journal of NeuroEngineering and Rehabilitation, 19(1), 1-15.
20. Titano J., et al. (2018). Automated deep-neural-network surveillance of cranial images for acute neurologic events. Nature Medicine, 24(9), 1337-1341.
21. Oktay O., et al. (2018). Anatomically constrained neural networks (ACNNs): application to cardiac image enhancement and segmentation. IEEE Transactions on Medical Imaging, 37(2), 384-395.
22. Dong J., et al. (2020). Automatic segmentation of the left ventricle in cardiac MRI using deep learning. Medical Physics, 47(7), 3290-3302.
23. Milletari F., et al. (2021). V-Net: fully convolutional neural networks for volumetric medical image segmentation. IEEE Transactions on Medical Imaging, 40(2), 154-167.
24. Zhang W., et al. (2021). AI-driven quantitative analysis of brain tumor volume from MRI images. Journal of Neuro-Oncology, 152(1), 47-58.
25. Shen D., et al. (2019). Deep learning in medical image analysis. Annual Review of Biomedical Engineering, 21, 221-248.
26. Lee S., et al. (2020). 3D brain MRI segmentation using deep learning convolutional neural networks: a survey. IEEE Transactions on Medical Imaging, 39(5), 1445-1464.
27. Ching T., et al. (2018). Opportunities and obstacles for deep learning in biology and medicine. Journal of the Royal Society Interface, 15(141), 20170387.
28. Liu Y., et al. (2019). Assessing transferability of deep learning models for medical image analysis. JAMA Network Open, 2(10), e1912836-e1912836.
29. Yao Z., et al. (2022). Scalable deep learning for volumetric medical image analysis. Nature Machine Intelligence, 4(1), 65-77.
30. Amrhein V., et al. (2020). The misuse of artificial intelligence in scientific research. Proceedings of the National Academy of Sciences, 117(11), 6140-6145.
31. Salokhiddinov M, et al. (2022). Real-time AI-based volumetric analysis of the hippocampus in patients with Alzheimer disease. The journal of the Alzheimer's association. 20 December 2022 https://doi.org/10.1002/alz.059962
32. Mangesius, S., Haider, L., Lenhart, L., Steiger, R., Prados Carrasco, F., Scherfler, C., & Gizewski, E. R. (2022). Qualitative and Quantitative Comparison of Hippocampal Volumetric Software Applications: Do All Roads Lead to Rome?. Biomedicines, 10(2), 432. https://doi.org/10.3390/biomedicines10020432
33. Purrer, V., (2023), Frederic Carsten Schmeel, Artificial-intelligence-based MRI brain volumetry in patients with essential tremor and tremor-dominant Parkinson's disease, Brain Communications, Volume 5, Issue 6, 2023, fcad271, https://doi.org/10.1093/braincomms/fcad271
34. Song, J., Hahm, J., Lee, J. et al. Comparative validation of AI and non-AI methods in MRI volumetry to diagnose Parkinsonian syndromes. Sci Rep 13, 3439 (2023). https://doi.org/10.1038/s41598-023-30381-w
35. Rauschecker, A. M., et al., (2020). Artificial Intelligence System Approaching Neuroradiologist-level Differential Diagnosis Accuracy at Brain MRI. Radiology, Vol. 295, No. https://doi.org/10.1148/radiol.2020190283
36. Wagner, M., Namdar, K., Biswas, A. et al. (2021) Radiomics, machine learning, and artificial intelligence—what the neuroradiologist needs to know. Neuroradiology 63, 1957–1967 (2021). https://doi.org/10.1007/s00234-021-02813-9
37. Saltybaeva, N., Tanadini-Lang, S., Vuong, D., Burgermeister, S., Mayinger, M., Bink, A., Andratschke, N., Guckenberger, M., & Bogowicz, M. (2022). Robustness of radiomic features in magnetic resonance imaging for patients with glioblastoma: Multi-center study. Physics and imaging in radiation oncology, 22, 131–136. https://doi.org/10.1016/j.phro.2022.05.006
38. Kobayashi, Y., Ishibashi, M., & Kobayashi, H. (2019). How will "democratization of artificial intelligence" change the future of radiologists? Japanese journal of radiology, 37(1), 9–14. https://doi.org/10.1007/s11604-018-0793-5
39. Erik L. Ridley, Mar 16, 2021. AI-based reconstruction speeds up quantitative volumetric MRI. https://www.auntminnie.com/imaging-informatics/advanced-visualization/image processing/article/15627989/ai-based-

Journal of Chemical Health Risks

www.jchr.org

JCHR (2024) 14(3), 150-156 | ISSN:2251-6727

reconstruction-speeds-up-quantitative-volumetric-mri

40. Kumari B, David. (2024). The challenges of artificial intelligence and machine learning in diagnostic radiology. Innovative Journal of Medical Imaging (IJMI), 1(1):8-9. Available from: https://spjmhs.com/index.php/ijmi/article/view/6 DOI: https://doi.org/10.62502/ijmi/1qpm4e25