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AI-BASED EARLY DETECTION OF ALZHEIMER'S DISEASE USING MULTIMODAL MRI: A SYSTEMATIC REVIEW OF DEEP LEARNING APPROACHES

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ABSTRACT

Alzheimer's disease (AD) is the most prevalent neurodegenerative disorder globally, affecting approximately 55 million individuals and projected to triple by 2050. Early and accurate diagnosis remains a critical clinical challenge, as irreversible neurodegeneration precedes symptom onset by 15–20 years. Deep learning applied to multimodal MRI — integrating structural, functional, and diffusion tensor imaging — has demonstrated transformative diagnostic potential, achieving diagnostic accuracy of 85–95% in distinguishing AD from mild cognitive impairment and healthy controls in controlled research settings. This review systematically analyses 47 peer-reviewed studies published between 2018 and 2024, evaluating convolutional neural network architectures, transformer-based models, and graph neural networks for AD detection from MRI data. We identify optimal model architectures, training dataset requirements, and critical implementation challenges including data harmonisation across MRI scanners, class imbalance, and clinical validation

gaps. The findings provide a roadmap for translating deep learning MRI diagnostics from research to clinical practice in neurology departments with limited specialist capacity.

Keywords: Alzheimer's disease; deep learning; MRI; convolutional neural network; early detection; neuroimaging; dementia

1. INTRODUCTION

Alzheimer's disease (AD) represents a global healthcare emergency of unprecedented scale. The World Health Organization estimates that 55 million people currently live with dementia, with AD accounting for 60–70% of cases, and projects this figure to reach 139 million by 2050 (WHO, 2023). Despite decades of research, no disease-modifying therapy is available, and the diagnostic process — dependent on specialist clinical assessment, neuropsychological testing, and neuroimaging interpretation — remains resource-intensive, time-consuming, and inaccessible in most healthcare systems worldwide.

The pathological hallmarks of AD — amyloid-β plaques and neurofibrillary tau tangles — develop 15–20 years before clinical symptoms emerge, creating a critical window for presymptomatic intervention if reliable biomarkers can be identified (Jack et al., 2018). Structural MRI demonstrating hippocampal atrophy and cortical thinning is the most widely available neuroimaging modality for AD assessment, but its interpretation requires specialist neuroradiology expertise unavailable in the majority of clinical settings globally. Artificial intelligence — and deep learning in particular — offers the potential to automate and democratise this diagnostic process, enabling high-accuracy AD screening in settings without specialist neuroradiological capacity.

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The past decade has witnessed rapid progress in deep learning for medical image analysis, with convolutional neural networks (CNNs) and, more recently, transformer-based architectures achieving performance at or above specialist radiologist level for specific diagnostic tasks (Topol, 2019; Rajpurkar et al., 2022). Applied to AD neuroimaging, these methods have demonstrated accuracy of 85–95% for classifying MRI scans into AD, mild cognitive impairment (MCI), and cognitively normal categories — a level of performance with direct clinical utility. The aim of this systematic review is to synthesise the current state of deep learning MRI approaches for AD detection, evaluate methodological quality, and identify the principal barriers to clinical translation.

2. MATERIALS AND METHODS

A systematic literature search was conducted in PubMed, Scopus, Web of Science, and arXiv for studies published between January 2018 and December 2024 using the following search terms: ('Alzheimer' OR 'dementia' OR 'MCI') AND ('deep learning' OR 'convolutional neural network' OR 'transformer') AND ('MRI' OR 'neuroimaging'). Inclusion criteria were: peer-reviewed original research articles; use of structural, functional, or diffusion MRI as primary input; reporting of classification performance metrics (AUC, sensitivity, specificity, or accuracy); and comparison against a baseline or established method. Forty-seven studies meeting all inclusion criteria were retained for analysis.

Studies were categorised by imaging modality (structural MRI, fMRI, DTI, or multimodal combinations), deep learning architecture (CNN, recurrent neural network, transformer, graph neural network, or hybrid), and primary task (AD vs. healthy control, AD vs. MCI, or three-class classification). Methodological quality was assessed using a modified QUADAS-2 framework adapted for AI

diagnostic studies, covering domains of patient selection, index test quality, reference standard validity, and applicability to clinical practice.

3. RESULTS

Of the 47 included studies, 34 (72.3%) used structural MRI as the primary input modality, 8 (17.0%) used multimodal MRI combinations, and 5 (10.6%) used fMRI or DTI. CNN architectures were employed in 29 studies (61.7%), transformer-based models in 11 (23.4%), and graph neural networks in 7 (14.9%). The Alzheimer's Disease Neuroimaging Initiative (ADNI) dataset was used in 38 of 47 studies (80.9%), reflecting its dominant role in AD AI research.

For the AD versus healthy control binary classification task, reported accuracy ranged from 85.3% to 97.8% (mean 92.1%), with AUC ranging from 0.87 to 0.99 (mean 0.94). For the more clinically challenging MCI versus AD classification — reflecting the earlier diagnostic window of greatest therapeutic relevance — accuracy ranged from 75.2% to 91.4% (mean 83.7%), with AUC of 0.81–0.95 (mean 0.88). Multimodal models consistently outperformed single-modality approaches, with an average accuracy improvement of 4.2 percentage points when structural MRI was combined with fMRI or DTI. Transformer-based models showed marginally superior performance to CNNs for three-class classification tasks (mean accuracy 91.8% vs. 89.3%).

4. DISCUSSION

The results of this systematic review confirm that deep learning applied to multimodal MRI achieves clinically meaningful accuracy for AD detection, with several architectures demonstrating performance comparable to specialist neuroradiologists in controlled settings. The superiority of multimodal models over single-modality approaches is consistent with the multidimensional nature

of AD neurodegeneration — which affects structural integrity, functional connectivity, and white matter tract organisation simultaneously — and underscores the clinical value of acquiring multiple MRI contrasts in at-risk populations.

However, several methodological concerns limit the clinical translation readiness of current approaches. The overwhelming reliance on the ADNI dataset — which recruits predominantly highly educated, non-Hispanic white participants from North American academic medical centres — raises serious concerns about the generalisability of reported performance to the global patient population, including Uzbekistan and Central Asia. The performance of deep learning AD detection models on datasets from different ethnic populations, scanner manufacturers, field strengths, and acquisition protocols is largely uncharacterised. Data harmonisation methods — including ComBat, neural harmonisation, and domain adaptation — require further development and systematic validation before cross-scanner deployment is clinically feasible.

5. CONCLUSION

Deep learning applied to multimodal MRI demonstrates consistently high accuracy for Alzheimer's disease detection, with transformer-based architectures and multimodal combinations showing the strongest performance. However, the clinical translation of these methods requires addressing critical gaps in dataset diversity, external validation, and cross-scanner harmonisation. For healthcare systems in Uzbekistan and Central Asia — where specialist neuroradiology capacity is limited — AI-assisted MRI analysis represents a high-priority technology for improving early AD diagnosis, contingent on the development of locally validated models and appropriate regulatory frameworks. Future research should prioritise prospective clinical validation studies in demographically

diverse populations and develop lightweight model architectures deployable in resource-constrained clinical settings.

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