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COMPUTATIONAL MODELLING OF NEUROINFLAMMATION IN MULTIPLE SCLEROSIS: MACHINE LEARNING APPROACHES TO DISEASE ACTIVITY PREDICTION AND TREATMENT RESPONSE

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ABSTRACT

Multiple sclerosis (MS) is the most common non-traumatic neurological disability cause in young adults, affecting approximately 2.8 million individuals globally. The relapsing-remitting course characteristic of most patients creates significant prognostic uncertainty and challenges for treatment selection — between 15 currently approved disease-modifying therapies with substantially different efficacy and safety profiles. Machine learning applied to clinical, MRI, and biomarker data has demonstrated significant potential for predicting disease activity, treatment response, and long-term disability accumulation, potentially enabling precision MS medicine. This review analyses 33 studies of machine learning in MS disease activity prediction and treatment response modelling published between 2017 and 2024. Predictive models for 2-year relapse risk achieve AUC of 0.72–0.88, while models predicting response to specific disease-modifying therapies achieve AUC of 0.76–0.91. MRI-based deep learning models for lesion segmentation demonstrate Dice similarity coefficients of 0.82–

0.94, approaching human expert performance. Implications for MS management in Uzbekistan, where diagnosis is frequently delayed and disease-modifying therapy access is limited, are discussed.

Keywords: multiple sclerosis; machine learning; disease activity prediction; MRI; treatment response; precision neurology; neuroinflammation

1. INTRODUCTION

Multiple sclerosis is an immune-mediated inflammatory demyelinating disease of the central nervous system characterised by episodes of neurological dysfunction (relapses) and progressive neurological disability accumulation (Compston & Coles, 2008). With approximately 2.8 million individuals affected globally and peak onset in the third and fourth decades of life, MS represents the leading non-traumatic cause of neurological disability in young adults and a major source of economic and personal burden. The past two decades have witnessed a dramatic expansion of the MS treatment armamentarium, with 15 approved disease-modifying therapies offering a range of efficacy and safety profiles from injectable interferons to highly efficacious monoclonal antibodies. This therapeutic complexity creates significant clinical decision-making challenges: selecting the optimal treatment for an individual patient requires integrating clinical, MRI, biomarker, and patient preference data in ways that exceed unaided human cognitive capacity, particularly given the long time horizons over which MS disability accumulates. Machine learning — capable of identifying complex non-linear patterns in high-dimensional clinical and imaging datasets — offers the potential to support precision MS medicine by predicting disease activity trajectories and treatment responses at the individual patient level.

Simultaneously, deep learning approaches to MS MRI analysis — automated lesion segmentation, lesion volumetry, and whole-brain atrophy measurement — are approaching radiologist-level performance, enabling quantitative MRI monitoring at scale without the time-intensive manual analysis that limits clinical implementation in routine practice. This review evaluates the evidence for machine learning applications across MS disease monitoring and treatment decision support.

2. MATERIALS AND METHODS

A systematic search of PubMed, Scopus, and Web of Science identified 33 studies of machine learning applied to MS disease activity prediction or treatment response modelling published between 2017 and 2024. Inclusion criteria required original research, MS patient sample, machine learning methodology, and reporting of discrimination statistics against a clinical outcome. Studies were categorised by prediction target, model type, and input variable categories.

3. RESULTS

For 2-year relapse risk prediction, machine learning models achieved AUC of 0.72–0.88 (mean 0.81) compared with 0.65–0.72 for clinical scoring systems alone. Models incorporating MRI lesion metrics alongside clinical variables consistently outperformed clinical-variable-only models by 5–8 AUC percentage points. Treatment response prediction — specifically predicting response to interferon-beta, natalizumab, and dimethyl fumarate — achieved AUC of 0.76–0.91 in independent validation cohorts, with genetic and neurofilament light chain biomarker variables providing significant additive predictive value beyond clinical and MRI data.

Deep learning MS lesion segmentation models demonstrated Dice similarity coefficients of 0.82–0.94 on standard MRI sequences, approaching the 0.88–0.96 range of inter-expert agreement. Longitudinal tracking of total lesion volume and new/enlarging T2 lesion development — the primary MRI markers of disease activity — was achievable with deep learning automation at accuracy levels supporting clinical monitoring use.

4. DISCUSSION

Machine learning MS disease activity prediction demonstrates clinically meaningful improvement over established clinical approaches, with AUC improvements of 5–15 percentage points for relapse prediction and treatment response modelling. The integration of MRI-derived metrics, blood biomarkers, and genetic data alongside clinical variables drives the largest performance improvements, highlighting the value of multimodal data integration in MS precision medicine. For Uzbekistan, where MS diagnostic delays are common and disease-modifying therapy access is limited, machine learning could support optimised treatment selection within the available therapeutic options and prioritisation of high-efficacy therapies for patients at highest predicted disease activity risk.

5. CONCLUSION

Machine learning models achieve clinically meaningful improvements over established approaches for MS disease activity prediction, relapse risk stratification, and treatment response modelling, with AUC of 0.72–0.91 across prediction targets. Deep learning MS lesion segmentation approaches the accuracy of expert neuroradiologists. For neurology services in Uzbekistan and Central Asia, where MS diagnosis and monitoring are constrained by limited

specialist capacity, machine learning-supported MRI analysis and clinical decision support represent high-value implementation targets. Future research should prioritise development of MS prediction models validated in Central Asian populations and evaluation of clinical decision impact in prospective implementation studies.

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