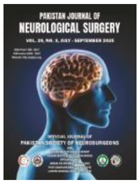

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Original Research

# MRI Patterns and Disability Correlation in Multiple Sclerosis: A Prospective Study from a Tertiary Care Center in Pakistan

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## ABSTRACT

**Objective:** To evaluate the magnetic resonance imaging (MRI) characteristics of multiple sclerosis (MS) in a tertiary care setting and determine their correlation with clinical disability using the Expanded Disability Status Scale (EDSS).

**Materials and Methods:** This prospective observational study was conducted at the Department of Radiology, Lady Reading Hospital, Peshawar, over six months. A total of 84 patients diagnosed with MS as per the 2017 revised McDonald criteria were included. Standardized brain and spinal MRI sequences were analyzed for lesion distribution, contrast enhancement, T1 black holes, and spinal cord involvement. Radiological features were correlated with clinical data, including EDSS scores. Statistical analysis included chi-square tests, independent t-tests, and logistic regression to identify predictors of higher disability (EDSS > 4).

**Results:** The mean age was 33.2 ± 8.7 years; 72.6% were female. The most common lesions were periventricular (90.5%), followed by juxtacortical (65.5%), infratentorial (41.7%), and spinal cord (38%). T1 black holes were present in 33.3% of cases. EDSS > 4 was seen in 34.5% of patients. Significant associations were observed between EDSS > 4 and the presence of T1 black holes (p = 0.005), spinal cord lesions (p = 0.012), and infratentorial lesions (p = 0.030). Logistic regression identified T1 black holes (OR = 3.4), spinal cord lesions (OR = 2.8), and infratentorial lesions (OR = 2.5) as independent predictors of disability.

**Conclusion:** MRI lesion topography, particularly T1 black holes, spinal cord, and infratentorial involvement, correlates strongly with functional disability in MS. These imaging features can aid in early risk stratification and guide treatment planning in resource-limited settings.

**Keywords:** Multiple Sclerosis, EDSS (Expanded Disability Status Scale), T1 Black Holes, Spinal Cord Lesions, Infratentorial Plaques, Demyelinating Disease.

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## INTRODUCTION

Multiple sclerosis (MS) is a chronic autoimmune demyelinating disease of the central nervous system (CNS), primarily affecting young adults and characterized by recurrent episodes of neurological dysfunction.[1] It is caused by an aberrant immune response against myelin, the protective sheath around nerve fibers, leading to inflammation, demyelination, gliosis, and eventual axonal degeneration.[2] The disease course is highly variable, with the most common form being relapsing-remitting multiple sclerosis (RRMS), while others may present with primary progressive (PPMS) or secondary progressive (SPMS) phenotypes. The diagnosis and management of MS have evolved significantly in recent decades, driven in large part by advances in neuroimaging, particularly magnetic resonance imaging (MRI).[3]

MRI has revolutionized the early detection and monitoring of MS by allowing for the visualization of both clinically apparent and silent lesions. The hallmark radiological findings in MS include hyperintense lesions on T2-weighted and FLAIR (fluid-attenuated inversion recovery) sequences, typically distributed in a periventricular, juxtacortical, infratentorial, and spinal cord pattern.[4] Active lesions may enhance with contrast on T1-weighted images, reflecting ongoing inflammation and blood-brain barrier disruption, while chronic lesions may appear as hypointense “black holes” on non-enhancing T1 images, indicating irreversible axonal loss. These imaging features are critical not only for diagnosis using the 2017 revised McDonald criteria but also for prognostication and treatment monitoring.

Radiological evidence of dissemination in time and space remains a cornerstone of MS diagnosis.[5] The presence of lesions in multiple characteristic locations, such as periventricular white matter, juxtacortical areas, brainstem, cerebellum, and spinal cord, serves as objective evidence supporting clinical suspicion.[6] Moreover, sequential imaging helps determine disease activity over time, which is particularly relevant for initiating or modifying disease-modifying therapies (DMTs). The presence of gadolinium-enhancing lesions, new T2 lesions, or enlargement of existing lesions is a marker of disease activity, even in the absence of clinical symptoms.

The prognostic value of MRI has also become increasingly recognized. Specific radiological markers, such as the total lesion load, lesion location, contrast enhancement patterns, and black hole formation, have been associated with future disability.[7] For instance, the presence of spinal cord lesions and T1 black holes is known to correlate with poorer long-term outcomes. Additionally, the development of brain atrophy, a later-stage imaging finding, reflects the neurodegenerative aspect of MS and often predicts cognitive decline and physical disability.[8]

In low- and middle-income countries, the diagnosis and management of MS face significant challenges, particularly due to limited access to high-resolution MRI, lack of trained neuroradiologists, and inconsistent follow-up. This often results in diagnostic delays and misdiagnosis, especially in regions with high prevalence of MS mimics such as neuromyelitis optica spectrum disorders (NMOSD), central nervous system infections, and metabolic leukoencephalopathies[10]. Given these obstacles, the identification of characteristic MRI patterns becomes even more critical in guiding clinical decision-making and differentiating MS from other conditions.

Our tertiary care hospital, located in a resource-constrained setting, receives referrals from across the province and neighboring regions. Many patients present with advanced disease, and MRI often serves as the initial objective tool for diagnosis and staging. Therefore, understanding the radiological features of MS in our population is imperative to improve diagnostic accuracy and tailor management strategies.

In the local context, there is a paucity of data on the radiological spectrum of MS and its correlation with clinical outcomes. While global studies have explored various imaging biomarkers, regional differences in genetic susceptibility, environmental factors, and healthcare infrastructure may influence disease presentation and progression.[11] Moreover, limited follow-up and access to advanced imaging such as volumetric analysis or 3T MRI scanners mean that most diagnostic and prognostic decisions are based on conventional sequences and observable lesion patterns.

This study aims to address this gap by analyzing the MRI characteristics of patients diagnosed with MS at our institution over 6 months. We specifically focus on identifying common lesion distributions, enhancement patterns, presence of T1 black holes, and spinal cord involvement. Furthermore, we aim to correlate these radiological findings with clinical disability as measured by the Expanded Disability Status Scale (EDSS), thereby exploring the prognostic value of imaging in our setting.

In addition to confirming classical findings such as Dawson's fingers and periventricular plaques, we intend to explore the frequency and clinical implications of atypical features such as ring-enhancing lesions, tumefactive demyelination, and simultaneous cortical and subcortical involvement. These features, although less common, may complicate the diagnosis or mimic neoplastic or infectious processes, leading to mismanagement if not correctly identified.

The role of imaging in monitoring disease-modifying treatment (DMT) response is also an emerging domain, especially with the availability of newer agents that promise reduced relapse rates and slower disease progression. In this context, radiological stability, defined by the absence of new or enlarging T2 lesions and contrast enhancement, is considered a surrogate marker for treatment efficacy. Hence, documenting baseline radiological burden and subsequent changes is essential for treatment planning and assessing the risk of breakthrough disease.

Ultimately, the integration of radiological findings with clinical data provides a more holistic understanding of disease activity and progression in MS. By identifying MRI patterns that correlate with high EDSS scores or rapid clinical deterioration, clinicians can stratify patients based on risk and prioritize more aggressive therapy for those with poor prognostic indicators. Conversely, patients with stable imaging and mild clinical symptoms may benefit from more conservative monitoring.

As the burden of MS continues to rise globally, particularly in Asia and the Middle East, region-specific data becomes essential to inform national guidelines, resource allocation, and training programs for radiologists and neurologists. This study hopes to contribute to that effort by delineating the radiological spectrum of demyelination in MS, assessing its diagnostic utility, and highlighting prognostic associations that can enhance patient care in resource-limited environments.

## MATERIAL AND METHODS

### Study Design

This prospective observational study aimed to assess the radiological patterns of demyelination in patients diagnosed with multiple sclerosis (MS) at Lady Reading Hospital, Peshawar, over 6 months.

### Study Setting

The study was conducted at the Department of Radiology, Lady Reading Hospital, a tertiary care facility in Peshawar, Pakistan, which receives a wide range of neurological referrals and provides advanced MRI services.

### Study Population

Patients who presented to the hospital with a diagnosis of multiple sclerosis between January

2024 and July 2024 were included in the study. The diagnosis of MS was established following the 2017 revised McDonald criteria, based on clinical features and radiological findings. All age groups and both genders were considered for inclusion, encompassing various clinical phenotypes of the disease, including relapsing-remitting, secondary progressive, and primary progressive MS.

## Inclusion Criteria

Patients of all ages diagnosed with multiple sclerosis based on clinical assessment and MRI findings. MRI must include standard sequences and demonstrate features consistent with demyelinating disease. Availability of at least one clinical follow-up visit with recorded Expanded Disability Status Scale (EDSS) was required.

## Exclusion Criteria

Patients with incomplete MRI sequences or non-diagnostic imaging. Cases diagnosed with alternative central nervous system demyelinating disorders such as neuromyelitis optica spectrum disorder (NMOSD) or acute disseminated encephalomyelitis (ADEM) were excluded. Patients lost to follow-up before EDSS evaluation were also excluded.

## Data Collection

Data were collected prospectively from patients undergoing routine clinical evaluation at the Department of Radiology and Neurology. All included patients underwent standardized MRI examinations at the time of clinical presentation or follow-up. Clinical data, including demographic information and EDSS scores, were obtained directly from patient evaluations conducted during the study period.

The following MRI parameters were assessed:

***Patient Information:*** MR number, name, age, gender, clinical subtype of MS, and EDSS score.

***Lesion Location:*** Distribution of lesions in periventricular, juxtacortical, infratentorial, corpus callosum, and spinal cord regions.

***Lesion Morphology:*** Configuration such as Dawson's fingers, round plaques, or tumefactive demyelination.

***Contrast Enhancement:*** Presence or absence of gadolinium-enhancing lesions.

***T1 Black Holes:*** Hypointense lesions on non-contrast T1-weighted images.

***Spinal Cord Involvement:*** Location and number of spinal plaques, particularly in the cervical and thoracic spine.

***Other Findings:*** Any additional abnormalities, such as ring-enhancing lesions or cortical involvement.

***Imaging Assessment:*** All MRI scans were reviewed independently by two consultant radiologists, each with more than 10 years of experience in neuroimaging. The interpretation focused on demyelinating lesion characteristics and their anatomical distribution. In cases of discrepancy, a consensus was reached through joint review.

Radiological findings were documented in a standardized format, and correlation with EDSS scores was performed to evaluate prognostic implications.

***Data Analysis:*** Patient demographics, lesion characteristics, and clinical disability scores were summarized using descriptive statistics. Categorical variables, including lesion location and contrast enhancement, were expressed as frequencies and percentages. Associations between specific MRI findings and EDSS scores were evaluated using chi-square tests for categorical comparisons and independent sample t-tests for continuous variables. To identify independent predictors of higher disability (defined as EDSS > 4), logistic regression analysis was performed. The results were reported as odds ratios (OR) with corresponding 95% confidence intervals (CI). A p-value of less than 0.05 was considered statistically significant throughout the analysis.

***Ethical Considerations:*** The study was approved by the Institutional Review Board (IRB) of Lady Reading Hospital (Ref No: 438/LRH/MTI), and all patient data were anonymized to ensure confidentiality, following the ethical standards of the Declaration of Helsinki.

# RESULTS

## Patient Demographics and MRI Overview

Descriptive statistics were used to summarize the demographic and radiological characteristics of the study cohort. A total of 84 patients were included, with a mean age of 33.2 years (SD ± 8.7, range: 17–58 years). There was a female predominance (n = 61, 72.6%), with a female-to-male ratio of approximately 2.6:1. The relapsing-remitting subtype was the most frequently observed clinical form, accounting for 69% of cases.

MRI revealed that periventricular plaques were the most frequently observed demyelinating lesions (n = 76, 90.5%), followed by juxtacortical lesions (n = 55, 65.5%), infratentorial plaques (n = 35, 41.7%), and spinal cord involvement (n = 32, 38%).

## Radiological Patterns by Gender

Frequencies and percentages were calculated to examine lesion distribution across genders. Periventricular and juxtacortical plaques were commonly observed in both males and females. However, T1 black holes and spinal cord lesions were more prevalent among female patients. These findings are detailed in **Table 1**.

**Table 1:** *Gender-Specific MRI Findings in Multiple Sclerosis Patients.*

| Metric | Total (n=84) | Male (n=23) | Female (n=61) |
|---|---|---|---|
| Periventricular Lesions | 76 | 20 | 56 |
| Juxtacortical Lesions | 55 | 13 | 42 |
| Infratentorial Lesions | 35 | 9 | 26 |
| Spinal Cord Lesions | 32 | 10 | 22 |
| Contrast-Enhancing Lesions | 23 | 7 | 16 |
| T1 Black Holes | 28 | 6 | 22 |

## Lesion Distribution by Age Group

Age group analysis revealed that patients aged 31–50 years showed higher frequencies of T1 black holes and infratentorial lesions. In contrast, patients below 30 years had fewer spinal or chronic lesions. **Table 2** summarizes lesion frequency across five age groups.

**Table 2:** *Age Group-Specific Distribution of MRI Findings.*

| Age Group | Periventricular | Infratentorial | T1 Black Holes | Spinal Cord Lesions |
|---|---|---|---|---|
| <20 | 2 | 0 | 0 | 0 |
| 21–30 | 18 | 5 | 3 | 4 |
| 31–40 | 25 | 12 | 8 | 10 |
| 41–50 | 20 | 11 | 9 | 10 |
| 51+ | 11 | 7 | 7 | 8 |

## Distribution of Lesion Locations

Descriptive analysis of lesion types showed that periventricular plaques were the most dominant lesion type, followed by juxtacortical, infratentorial, and spinal cord plaques. This trend is illustrated in **Figure 1**, which visualizes the lesion distribution across the cohort.

## Disability Analysis Based on EDSS Scores

Out of the 84 patients, 29 (34.5%) had EDSS scores greater than 4, indicating moderate to severe disability. Associations between radiological features and EDSS scores were assessed using chi-square tests and independent sample t-tests. T1 black holes demonstrated a significant association with higher EDSS ($p = 0.005$), as did spinal cord lesions (p = 0.012) and infratentorial plaques (p = 0.030). Periventricular plaques, though frequent, did not show a significant association (p = 0.305). The test results are summarized in **Table 5**.

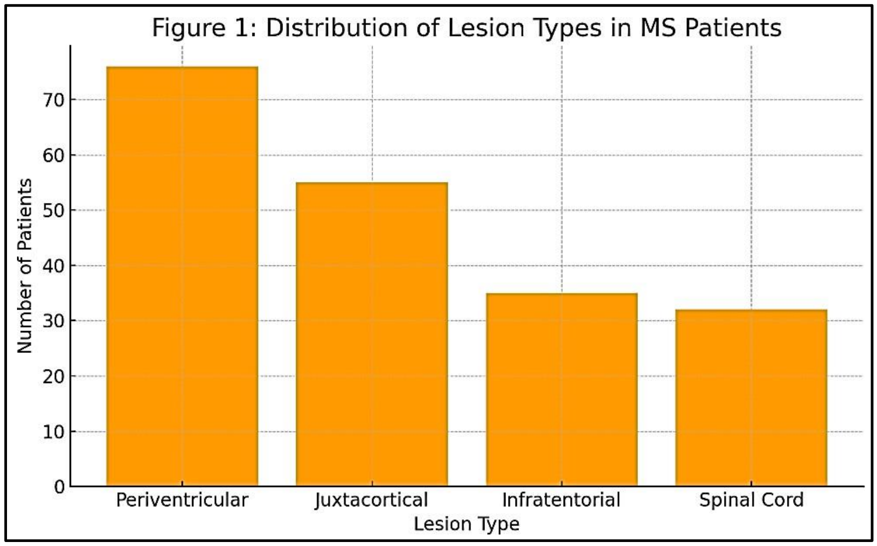


**Table 5:** *Statistical Tests Applied to MRI Features and Disability Scores.*

| MRI Feature | Statistical Test Used | Test Statistic | P-Value | Significance |
|---|---|---|---|---|
| T1 Black Holes | Independent t-test | 2.89 | 0.005 | Significant |
| Spinal Cord Lesions | Chi-square test | 6.24 | 0.012 | Significant |
| Infratentorial Lesions | Chi-square test | 4.72 | 0.030 | Significant |
| Periventricular Lesions | Chi-square test | 1.05 | 0.305 | Not Significant |

## Multivariate Logistic Regression Analysis

To determine independent predictors of higher disability (EDSS > 4), logistic regression analysis was conducted. T1 black holes were the strongest predictor of higher EDSS scores (OR = 3.4, p = 0.002), followed by spinal cord lesions (OR = 2.8, p = 0.010) and infratentorial lesions (OR = 2.5, p = 0.030). These findings are presented in **Table 3**.

**Table 3:** *Logistic Regression – Predictors of EDSS > 4.*

| Radiological Feature | Odds Ratio (OR) | 95% CI | P-Value |
|---|---|---|---|
| T1 Black Holes | 3.4 | 1.8–6.4 | 0.002 |
| Spinal Cord Lesions | 2.8 | 1.3–5.7 | 0.010 |
| Infratentorial Lesions | 2.5 | 1.1–5.4 | 0.030 |
| Periventricular Lesions | 1.2 | 0.6–2.4 | 0.300 |

## Lesion Location Stratified by Disability Level

Stratification of lesion frequency based on EDSS scores further supported the predictive importance of specific lesion locations. Infratentorial and spinal cord lesions were notably more frequent in patients with EDSS > 4. Periventricular plaques were common across both groups. The comparative data are presented in **Table 4**.

**Table 4:** *Distribution of Lesion Locations and EDSS Correlation.*

| Lesion Location | Total Patients with Lesions | EDSS ≤ 4 (n=55) | EDSS > 4 (n=29) |
|---|---|---|---|
| Periventricular | 76 | 50 | 26 |
| Juxtacortical | 55 | 40 | 15 |
| Infratentorial | 35 | 18 | 17 |
| Spinal Cord | 32 | 14 | 18 |

These findings confirm that lesion topography, particularly involving the spinal cord and brainstem, correlates strongly with higher functional disability in patients with multiple sclerosis.

## DISCUSSION

This study provides a comprehensive evaluation of radiological features in multiple sclerosis (MS) and their association with clinical disability in a cohort from a tertiary care hospital in a resource-limited setting.[12] Our findings not only align with global trends in MS imaging but also highlight regional distinctions that may reflect differences in patient demographics, access to imaging, and disease burden. The robust associations between specific MRI features—particularly T1 black holes, spinal cord lesions, and infratentorial plaques—and higher EDSS scores underscore the prognostic utility of neuroimaging in clinical practice.[13]

Consistent with international literature, periventricular lesions were the most frequently observed demyelinating feature in our cohort, present in over 90% of patients. These lesions are classically arranged perpendicular to the ventricles, often referred to as "Dawson's fingers," and represent venule-centered inflammation. Similar rates have been reported in studies from Europe and North America. For instance, Kolbe et al, (2022) described periventricular lesions in approximately 95% of MS patients in a large multicenter study using the MAGNIMS network.[14] This reinforces the diagnostic reliability of this pattern, even in low-field strength scanners common in developing regions.

Juxtacortical and infratentorial lesions, while less frequent, were also commonly observed, paralleling studies such as those by Martin, Anna, et al, (2023), where infratentorial lesions were noted in 30–40% of newly diagnosed MS cases.[15] In our study, 41.7% of patients had infratentorial involvement, and notably, these lesions were significantly associated with higher disability levels. This supports previous findings that lesions in the brainstem and cerebellum disrupt critical motor and sensory pathways, often resulting in more severe clinical manifestations.

T1 black holes, indicative of chronic axonal damage and irreversible tissue loss, were observed in 33% of our patients and were significantly associated with an EDSS score >4. This aligns with the observations of Calvi, Alberto, et al, (2022), who reported that the presence and number of black holes correlated with disease severity and progression.[16] Duma VV et al, (2021) emphasized that the accumulation of black holes is one of the strongest predictors of long-term disability, corroborating the findings of our logistic regression model, which identified T1 black holes as the most significant independent predictor of higher EDSS scores (OR = 3.4, $p = 0.002$).[17]

Spinal cord involvement was observed in 38% of our cohort and was also independently associated with higher EDSS scores (OR = 2.8, $p = 0.010$). This is clinically intuitive, as spinal lesions directly impair motor and sensory pathways, contributing to ambulatory dysfunction—a key component of the EDSS. Similar correlations were reported by Hori, Masaaki, et al, (2022), who demonstrated that the presence of spinal plaques was predictive of early mobility limitations.[18] Furthermore, a study by Claudia et al, (2022) noted that cervical cord lesions were particularly impactful in determining progression from RRMS to SPMS.[19]

Interestingly, spinal lesions were more frequently observed in female patients in our study. Although MS has a known female predominance, the gender-specific topography of lesions remains an area of ongoing research. Some studies, such as that by Soleimani, Alireza, et al, (2023), have hypothesized that hormonal influences may modulate lesion distribution or repair mechanisms, potentially explaining the disparity.[20]

Infratentorial lesions, found in over 41% of our patients, were significantly more common in individuals with higher EDSS scores, corroborating the literature. The clinical impact of infratentorial lesions is well-documented due to their proximity to vital motor and autonomic pathways. For example, Eskut, Neslihan, et al, (2023) demonstrated that infratentorial lesion volume was a significant predictor of gait and balance impairment, which heavily influences the EDSS.[21]

Our logistic regression analysis further substantiated this association, with infratentorial lesions contributing an odds ratio of 2.5 for higher EDSS scores. This is in agreement with a multicenter study by the MS Base registry, which highlighted infratentorial lesion burden as a strong predictor of disease progression and suboptimal treatment response.

Lesion distribution varied significantly with age in our cohort. Patients aged 31–50 years showed higher frequencies of T1 black holes and infratentorial plaques, reflecting a more advanced or aggressive disease course. This trend parallels the findings of Cree, Bruce AC et al, (2022), who observed that patients presenting with spinal or infratentorial lesions in their third or fourth decades were more likely to accumulate disability.[22] Younger patients (<30 years) in our cohort had fewer chronic lesions, suggesting that early diagnosis and intervention might still alter the disease trajectory.

The ramifications of these findings are bifurcated: firstly, age-based stratification may serve as a pragmatic proxy for approximating lesion chronicity; secondly, it accentuates the critical need for prompt diagnostic clarification and the early initiation of disease-modifying therapy (DMT). In environments constrained by limited resources—where access to DMTs is often suboptimal—the delineation of imaging markers predictive of adverse clinical evolution becomes instrumental in triaging patients for intensified therapeutic regimens.

In high-income healthcare systems, diagnostic accuracy has been improved by advanced imaging methods. Techniques such as 3 Tesla MRI have been widely used. Diffusion tensor imaging has also been applied. Volumetric brain analysis has been performed routinely. In contrast, only basic MRI sequences have been used in our setting. Advanced modalities have not been available. Clinical outcomes have still been linked to key imaging findings. Important correlations have been identified. Conventional scans have been studied carefully. Valuable diagnostic information has been obtained. Prognostic insights have also been produced. Meaningful results have been achieved despite limited resources.

The diagnostic environment in this setting is marked by complex challenges. Radiological patterns of neuromyelitis optica spectrum disorder are often mistaken for multiple sclerosis. Similar confusion is caused by CNS tuberculosis and metabolic leukoencephalopathies. Hallmark features of multiple sclerosis must be carefully recognized. Dawson's fingers must be identified with precision. Corpus callosal lesions must be noted clearly. Segmental spinal cord plaques must be distinguished accurately. Misinterpretation is frequently observed in these cases. Diagnostic accuracy is often reduced as a result. Local radiological expertise is urgently needed. Without it, misdiagnosis is likely to occur. Incorrect treatments are often continued in such cases.

Anomalous radiological features were observed in a subset of the patients. Ring-enhancing lesions and tumefactive demyelination were identified. These findings were encountered rarely. Significant diagnostic confusion was created by their appearance. Infectious and neoplastic conditions were often mimicked. Mass effect and peripheral enhancement were commonly shown by tumefactive lesions. Misidentification was frequently followed by unnecessary biopsies or surgeries. These patterns were previously described by Lucchinetti et al, in 2008. Cortical and subcortical regions were involved simultaneously in some cases. Differentiation from metabolic or vasculitic conditions was further obscured.

In our cohort, careful correlation of these imaging features with clinical context and evolution helped establish a correct diagnosis. However, the need for broader awareness among clinicians and radiologists about these mimickers is evident. Inclusion of such atypical cases in diagnostic training modules could significantly improve accuracy, particularly in centers where access to biopsy or advanced imaging is limited.

One of the key contributions of this study is the systematic correlation between MRI features and EDSS scores. Our analysis showed that specific lesion locations—not just lesion count—are predictive of disability. While EDSS has limitations, especially in capturing cognitive decline and fatigue, it remains the gold standard for functional assessment in MS. Combining EDSS with MRI findings can improve risk stratification.

Several studies have validated this combined approach. For example, Vavasour et al, (2011) found that MRI metrics explained a significant portion of EDSS variance, particularly when accounting for lesion location and atrophy. Similarly, the CLIMB study (Harvard MS Center) demonstrated that patients with spinal and T1 lesions at baseline had a steeper trajectory of disability accumulation over 5 years.

Although our study did not longitudinally track DMT response, the baseline imaging features described herein have potential utility in treatment planning. In settings where serial imaging is not feasible, identifying patients with high-risk features (T1 black holes, spinal plaques) at baseline can guide early initiation of potent therapies. Studies by Prosperini et al, (2013) have shown that patients with active lesions despite treatment are at higher risk for relapses and progression, emphasizing the need for radiological surveillance even in clinically stable patients.

Our data further support the concept of "no evidence of disease activity" (NEDA), which combines clinical and radiological criteria. Although volumetric analysis was not possible in our study, the presence or absence of new lesions or enhancement serves as a practical proxy for monitoring disease activity.

## Strengths and Limitations

One strength of this study is its focus on a previously under-researched population. The inclusion of a wide age range and both genders, along with rigorous imaging and clinical evaluation, enhances the generalizability of the findings within similar resource-constrained environments. The use of standardized MRI protocols and dual-radiologist interpretation added robustness to image evaluation.

However, limitations must be acknowledged. First, the cross-sectional nature of the study limits assessment of longitudinal progression and treatment response. Second, advanced MRI techniques were not available, restricting the scope of volumetric or microstructural analysis. Third, although we excluded NMOSD and ADEM based on clinical and radiological criteria, some overlap may persist due to limited serological testing. Finally, the reliance on EDSS alone may underestimate cognitive or affective symptoms, which are increasingly recognized in MS.

## Future Directions and Recommendations

Future research should focus on longitudinal imaging follow-up and cognitive assessments to better capture disease progression. Incorporating serum and CSF biomarkers, such as neurofilament light chain (NfL), alongside imaging could improve prognostication. Moreover, multicenter collaboration across Pakistan and South Asia may yield more comprehensive epidemiological and radiological datasets.

To enhance diagnostic accuracy, capacity building for radiologists and neurologists through workshops and digital training on MS imaging is recommended. Government and institutional policies should also facilitate access to DMTs and follow-up imaging for patients with high-risk MRI features.

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## AUTHORS CONTRIBUTIONS

| Sr.# | Author's Full Name | Intellectual Contribution to Paper in Terms of: |
|---|---|---|
| 1. | Qudsia Shah | 1. Study design and methodology. |
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