



Original Research

## Comparative Analysis of MRI DWI/ADC Changes with Clinical Recovery in Stroke Patients

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### ABSTRACT

**Objective:** To determine the relationship between MRI diffusion weighted imaging (DWI), apparent diffusion coefficient (ADC) changes, and clinical recovery in acute ischemic stroke patients.

**Materials and Methods:** This prospective observational study was conducted at the Radiology Department of Lady Reading Hospital, Peshawar, from January 2025 to June 2025. A total of 234 patients with acute ischemic stroke were included. All patients underwent MRI with DWI and ADC sequences within 24 hours of symptom onset. Clinical severity was assessed using the National Institutes of Health Stroke Scale (NIHSS), and functional recovery was evaluated using the Modified Rankin Scale (mRS) and Barthel Index at discharge and 30-day follow-up. Statistical analysis included Pearson correlation and multivariate regression to assess the association between imaging parameters and clinical outcomes.

**Results:** Acute infarcts on DWI/ADC were identified in 205 (87.6%) patients. Favorable clinical recovery (mRS  $\leq 2$  at 30 days) was seen in 56.4% of patients and was significantly associated with smaller baseline DWI lesion volumes ( $p < 0.001$ ), higher ADC values ( $p < 0.001$ ), and lower baseline NIHSS scores ( $p < 0.001$ ). DWI reversal on follow-up imaging was observed in 38.6% of patients and was strongly associated with improved functional outcomes ( $p = 0.002$ ). Multivariate analysis confirmed baseline DWI volume, mean ADC value, and NIHSS score as independent predictors of recovery.

**Conclusion:** DWI lesion size, ADC value, and initial NIHSS score are significant predictors of clinical recovery in acute ischemic stroke patients. Incorporation of MRI-based diffusion imaging in routine stroke assessment improves early prognostication and guides management decisions.

**Keywords:** Stroke, Diffusion Weighted Imaging, Apparent Diffusion Coefficient, Clinical Recovery, MRI, Functional Outcome.

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## INTRODUCTION

Stroke has been considered a serious global health challenge, and it has been identified as a major reason for both disability and death in adult populations across the world.<sup>1</sup> The condition of acute ischemic stroke, which results from a sudden blockage within cerebral arteries, has been found to account for the majority of stroke cases.<sup>2</sup> It has been observed that the rapid identification of this condition, followed by timely medical intervention, has played an essential role in improving patient recovery.<sup>3</sup> Immediate diagnosis, together with the application of therapeutic techniques such as clot-dissolving medications or endovascular treatment, has been regarded as necessary to reduce the risk of long-term disability. In this process, the use of brain imaging has been regarded as extremely important since it allows early identification of brain tissue damage.

Magnetic resonance imaging has been acknowledged as a crucial advancement in the examination of acute ischemic stroke because it has provided detailed information about the condition of brain tissues.<sup>4</sup> Among several imaging sequences, diffusion-weighted imaging together with apparent diffusion coefficient mapping has been described as the most important in identifying areas of restricted blood flow within the brain. Diffusion-weighted imaging has been considered very effective for identifying cytotoxic swelling that happens soon after the blood supply is cut off. This technique has been used to highlight restricted diffusion areas where brain cells have been damaged.<sup>5</sup> In parallel, apparent diffusion coefficient maps have been employed to measure the extent of reduced water movement in the brain, which has been linked to the severity of cell injury.

It has been observed in many published studies that diffusion-weighted imaging has demonstrated high sensitivity in detecting

ischemic changes during the very early period after stroke onset.<sup>6</sup> Previous research has shown that this method can reveal changes within minutes of symptom appearance, while traditional imaging methods have often failed to do so. This increased sensitivity has been noted especially in strokes affecting the posterior part of the brain, where computed tomography has usually provided limited details due to poor visibility in that region. Consequently, diffusion-weighted imaging has been trusted as the best option for confirming early brain injury in stroke cases.

Additionally, apparent diffusion coefficient mapping has been used to provide valuable measurements of the degree of damage to brain cells. Researchers have consistently documented that lower apparent diffusion coefficient values have reflected more severe injury, while higher values have been associated with tissue that might still recover. This relationship between reduced apparent diffusion coefficient values and unfavorable patient outcomes has been mentioned in multiple investigations.<sup>7</sup> These findings have supported the inclusion of apparent diffusion coefficient maps in routine stroke assessments since they offer more precise insights about the condition of the brain.

It has also been reported in previous research that smaller areas of brain damage detected by diffusion-weighted imaging have been associated with better recovery after treatment. Studies have frequently demonstrated that patients with limited diffusion-weighted imaging lesion size are more likely to regain neurological functions and achieve independence. In contrast, patients with large lesions and extremely low apparent diffusion coefficient values have often experienced poor clinical outcomes.<sup>8</sup>

The evolution of diffusion-weighted imaging findings during the days following the initial event has been studied by many researchers.<sup>9</sup> It has been observed that reversal of abnormal findings has been linked with improved patient outcomes, while persistent or expanding

abnormalities have usually indicated worse recovery.<sup>10</sup> The same has been said about apparent diffusion coefficient measurements, where the normalization of values over time has frequently been associated with improved recovery potential.

The importance of combining clinical scales such as the National Institutes of Health Stroke Scale with imaging parameters like diffusion weighted imaging lesion size and apparent diffusion coefficient values has been repeatedly highlighted in stroke research. This combined approach has been credited with improving the accuracy of prognosis and aiding in clinical decision-making.<sup>11</sup>

Therefore, this study has been designed to analyze the changes seen on diffusion-weighted imaging and apparent diffusion coefficient maps in stroke patients and to correlate these imaging changes with recovery after stroke. This work has been intended to provide a deeper understanding of how imaging markers could help predict patient outcomes and guide future treatment approaches.

## **MATERIALS AND METHODS**

### **Study Design and Setting**

A prospective observational approach was selected for the current investigation, and it was performed at the Radiology Department of Lady Reading Hospital situated in Peshawar. This medical institution has been considered a large-scale healthcare facility that has been delivering specialized neuroimaging services to the population. The research activity was performed during a continuous period of six months, starting from January two thousand twenty five and concluding in June two thousand twenty five. Formal approval for the study was granted by the official ethical review board of Lady Reading Hospital before any patient was recruited. A written consent form was signed by all participants who were included in this work.

### **Study Population**

A total of two hundred and thirty-four individuals were selected for participation through a prospective enrollment process. These patients had been admitted to the emergency department with suspected cases of acute ischemic stroke. Each patient underwent magnetic resonance imaging of the brain, which included diffusion-weighted imaging along with apparent diffusion coefficient mapping within twenty-four hours from the onset of clinical symptoms for diagnostic confirmation.

### **Inclusion Criteria**

Only adult patients who were aged eighteen years or older were eligible for inclusion in this study. There were no restrictions on gender for patient enrollment. Individuals were included if they had experienced acute focal neurological signs suggesting a stroke episode within a single day and if they had completed a brain magnetic resonance imaging examination with diffusion-weighted and apparent diffusion coefficient sequences. Participation required the availability of clinical follow-up data that documented the level of neurological recovery.

### **Exclusion Criteria**

Several patients were excluded from this research effort. Individuals were not allowed to participate if brain imaging confirmed the existence of a hemorrhagic stroke. Additional exclusion applied to patients who had clinical features resembling stroke but were ultimately diagnosed with alternative conditions such as seizure episodes, low blood sugar, or functional disturbances. Another exclusion condition was the presence of incomplete or technically poor magnetic resonance imaging data. Those with contraindications to magnetic resonance scanning, such as patients having pacemakers,

metallic devices, or severe anxiety inside closed spaces, were also excluded from participation.

### **Clinical Assessment**

All admitted patients underwent detailed clinical evaluations after arrival. The severity of neurological impairment was quantified with the use of the National Institutes of Health Stroke Scale, which was recorded at the time of admission. Functional recovery was examined at two stages, which included the hospital discharge point as well as a follow-up examination performed thirty days after admission. The Modified Rankin Scale, together with the Barthel Index, was used to assess functional outcomes. Evaluations were conducted by trained neurologists who were not aware of the imaging outcomes to avoid any form of bias.

### **MRI Protocol**

All imaging procedures were carried out with the use of a one point five Tesla magnetic resonance imaging system. A specific acute stroke protocol was followed during the examination. Each patient underwent diffusion-weighted imaging with two b values, zero and one thousand seconds per second per square second, and corresponding apparent diffusion coefficient maps were automatically generated. Additional sequences included fluid attenuated inversion recovery, T-1 weighted fast spin echo, T2-weighted fast spin echo, and susceptibility weighted imaging, which was intended to evaluate any signs of hemorrhagic change. The slice thickness was maintained at five millimeters with appropriate coverage of the brain volume. Each imaging session was completed within approximately twenty minutes. Follow-up imaging with diffusion-weighted imaging and apparent diffusion coefficient mapping was performed selectively after five to seven days based on clinical necessity.

### **Image Interpretation**

All imaging results were reviewed independently by two consultant radiologists who had more than seven years of professional experience in brain imaging. Neither the radiologists nor the patients were informed about the clinical status of the patients during image interpretation. Hyperintense lesions on diffusion-weighted imaging and hypointense areas on apparent diffusion coefficient maps were carefully documented. The lesion size was measured manually using the region of interest drawing technique. The average apparent diffusion coefficient value was calculated within the affected areas and was compared to the matching location in the opposite healthy hemisphere. Follow-up imaging results were classified based on whether the lesions had reversed, progressed, or remained unchanged.

### **Data Collection**

Patient demographic characteristics, including age, gender, and known risk factors, were documented in a structured manner. Time from symptom onset to imaging and clinical scoring with the National Institutes of Health Stroke Scale, together with functional scales of the Modified Rankin and Barthel Index, was recorded. Imaging variables, including baseline lesion volume on diffusion weighted imaging measured in cubic centimeters, average apparent diffusion coefficient value expressed in standard diffusion units, percentage reduction of apparent diffusion coefficient compared to normal tissue, and follow-up lesion behavior, were systematically collected.

### **Statistical Analysis**

Statistical calculations were completed with the help of IBM SPSS software version twenty-six. Average values and standard deviations were used for continuous data, while frequencies and percentage values were applied to categorical

variables. Pearson correlation tests were used to analyze the association between imaging data and functional recovery scores, including the National Institutes of Health Stroke Scale, Modified Rankin Scale, and Barthel Index. Group comparisons between favorable and unfavorable outcome groups were evaluated with independent t-tests and chi-square tests depending on data type. Multivariable regression analysis was applied to determine significant predictors of clinical recovery. A p-value below zero point zero five was considered to indicate statistical significance in all performed tests.

**Table 1:** Baseline Demographic and Clinical Characteristics of Study Population.

Variable	Value
Total number of patients	234
Mean age (years)	61.2 ± 11.8
Male gender	142 (60.7%)
Female gender	92 (39.3%)
Mean time from onset to MRI	5.6 ± 2.1 hours
Most common symptom	Hemiparesis (76.9%)
Other common symptoms	Aphasia (52.6%), Facial asymmetry (38.0%)

**Table 2:** Distribution of DWI/ADC Findings and Ischemic Stroke Characteristics.

Parameter	Value
DWI-positive patients	205 (87.6%)
Anterior circulation infarcts	143 (69.7% of DWI-positive)
Posterior circulation infarcts	62 (30.3% of DWI-positive)
Mean DWI lesion volume	18.5 ± 9.7 cm <sup>3</sup>
Mean ADC value in infarcted regions	0.42 ± 0.08 × 10 <sup>-3</sup> mm <sup>2</sup> /s
Percentage ADC reduction (vs. normal)	34.5 ± 6.2%

## RESULTS

### Patient Demographics and Baseline Characteristics

A total of 234 patients were included in this prospective study. The mean age of the study population was 61.2 ± 11.8 years, with a male predominance accounting for 142 (60.7%) of the cases. The average time from symptom onset to MRI examination was 5.6 ± 2.1 hours. The most frequent presenting clinical feature was unilateral motor weakness (76.9%), followed by speech disturbances (52.6%) and facial asymmetry (38.0%). Table 1 summarizes the baseline demographic and clinical characteristics of the study participants.

### Distribution of DWI and ADC Abnormalities

MRI with DWI and ADC sequences revealed acute infarcts in 205 (87.6%) patients. Among these, DWI hyperintensity with corresponding ADC hypointensity was detected predominantly in the

anterior circulation (69.7%), whereas posterior circulation strokes were observed in 30.3% of cases. Mean lesion volume on DWI was 18.5 ± 9.7 cm<sup>3</sup>, while the mean ADC value within infarcted regions was significantly reduced at 0.42 ± 0.08 × 10<sup>-3</sup> mm<sup>2</sup>/s. The distribution of ischemic changes by territory and mean ADC values is detailed in Table 2.

### Association of Imaging Findings with Clinical Recovery

At hospital discharge, 132 (56.4%) patients had a favorable neurological outcome defined as a modified Rankin Scale (mRS) score ≤2. Patients with smaller baseline DWI lesion volumes (mean 12.9 ± 4.7 cm<sup>3</sup>) and less severe ADC reductions showed significantly better clinical recovery compared to those with larger lesions (p < 0.001). A strong correlation was observed between lower baseline NIHSS scores, smaller DWI volumes, and better recovery outcomes. These comparative findings between favorable and unfavorable recovery groups are summarized in Table 3.

**Table 3:** Comparison of Imaging Parameters Based on Recovery Outcome at Discharge.

Variable	Favorable Outcome (n=132)	Poor Outcome (n=102)	p-value
Mean baseline DWI volume (cm <sup>3</sup> )	12.9 ± 4.7	25.3 ± 8.1	<0.001
Mean ADC value (×10 <sup>-3</sup> mm <sup>2</sup> /s)	0.48 ± 0.06	0.38 ± 0.05	<0.001
Percentage ADC reduction (%)	29.7 ± 5.3	39.8 ± 4.7	<0.001
Mean baseline NIHSS score	9.2 ± 3.5	17.5 ± 5.2	<0.001

### Follow-up DWI/ADC Changes and Clinical Outcome

A follow-up MRI was performed in 88 patients between days 5 and 7. Among these, DWI reversal (partial resolution of initial diffusion abnormality) was observed in 34 (38.6%) patients. Patients demonstrating DWI reversal exhibited greater improvements in NIHSS and mRS scores at 30 days compared to those with stable or progressive DWI lesions (p = 0.002). Table 4 outlines the relationship between follow-up imaging changes and functional recovery.

**Table 4:** Follow-up MRI Changes and Their Correlation with 30-Day Functional Outcome.

Follow-up Imaging Pattern	Number of Patients (n=88)	Mean mRS at 30 Days	p-value
DWI reversal	34 (38.6%)	1.8 ± 0.9	0.002
Stable lesions	31 (35.2%)	3.4 ± 1.2	
Lesion progression	23 (26.1%)	4.2 ± 1.5	

### Multivariate Analysis of Predictors of Clinical Recovery

Multivariate logistic regression analysis identified baseline DWI lesion volume, mean ADC value, and baseline NIHSS score as independent predictors of favorable clinical recovery at 30 days. Adjusted odds ratios (OR) demonstrated that smaller infarct volumes and higher ADC

values significantly increased the likelihood of good outcomes, while higher baseline NIHSS was associated with worse recovery. Table 5 provides details of the regression analysis.

**Table 5:** Multivariate Logistic Regression for Predictors of Favorable Clinical Recovery.

Predictor Variable	Odds Ratio (OR)	95% Confidence Interval (CI)	p-value
Baseline DWI volume (per cm <sup>3</sup> decrease)	1.12	1.05 – 1.22	<0.001
Mean ADC value (per 0.01 increase)	1.18	1.09 – 1.32	<0.001
Baseline NIHSS score (per point decrease)	1.24	1.13 – 1.41	<0.001

### Discussion

The value of diffusion-weighted imaging together with apparent diffusion coefficient mapping has been firmly established in the assessment of acute ischemic stroke by numerous studies from recent years.<sup>12</sup> The frequent use of these imaging sequences has been shown to improve the detection of brain infarcts at earlier stages when compared with older imaging techniques. Many published reports have confirmed that the sensitivity of diffusion-weighted imaging is significantly higher during the first hours after the onset of symptoms.<sup>13</sup> Early brain injury has been detected more efficiently through this technique than with conventional modalities, and this improvement has been especially noted in stroke cases involving the posterior circulation. Imaging accuracy has been enhanced in these cases because diffusion-weighted imaging is less affected by technical limitations that have been reported with other methods.<sup>14</sup>

Several investigations have observed that the identification of acute infarcts by diffusion-weighted imaging is possible within minutes after the blockage of cerebral arteries.<sup>15</sup> Traditional

imaging has been associated with frequent failures in these early hours, whereas diffusion-weighted imaging has revealed brain tissue abnormalities with a much greater level of accuracy. Clinical research has indicated that the detection of smaller cortical infarcts and lesions in deep brain regions has been improved through the application of diffusion-weighted imaging. This has supported its preferred status among neuroimaging techniques for the diagnosis of acute ischemic stroke.<sup>16</sup>

The assessment of tissue viability using apparent diffusion coefficient mapping has also been examined in multiple studies, and it has been reported as a useful tool for estimating the severity of brain damage. Extensive literature has suggested that lower apparent diffusion coefficient values are strongly related to more serious injury within the brain. These measurements have reflected restricted water movement, which has been accepted as a marker of cytotoxic edema and irreversible neuronal loss.<sup>17</sup> Conversely, higher apparent diffusion coefficient values within diffusion-restricted areas have been reported to correspond with partial cell survival. This distinction has been noted in many clinical studies where patients with higher apparent diffusion coefficient values have experienced improved functional outcomes.

Previous studies have frequently examined the relationship between diffusion-weighted imaging lesion size and the degree of clinical recovery in patients with acute stroke.<sup>18</sup> A clear pattern has been documented where individuals with smaller lesion volumes on early imaging have shown significantly greater chances of achieving functional independence after treatment. This trend has been consistent across anterior and posterior circulation strokes, which has further validated the predictive value of diffusion-weighted imaging lesion size.<sup>19</sup> Larger lesion volumes have been associated with poorer recovery, which has been shown in several outcome-based studies.

Follow-up imaging using diffusion-weighted imaging and apparent diffusion coefficient mapping has been utilized in different clinical investigations to monitor the progression or regression of ischemic lesions. The partial or full reversal of abnormal diffusion signals during the days following stroke onset has been associated with favorable functional recovery in many patient groups. The phenomenon of diffusion-weighted imaging reversal has been suggested to indicate successful reperfusion and salvage of threatened brain tissue.<sup>20</sup> This finding has been reinforced through the observation that individuals with diffusion reversal on subsequent imaging have shown higher rates of neurological improvement.<sup>21</sup>

Similarly, the normalization of apparent diffusion coefficient values during follow-up imaging has been proposed in previous research as a positive indicator of recovery.<sup>22</sup> Partial restoration of diffusion levels within previously affected areas has been correlated with better clinical outcomes, while persistent reductions in apparent diffusion coefficient values have been indicative of irreversible infarction. This differentiation has supported the usefulness of longitudinal diffusion imaging in predicting stroke recovery trajectories.

The association between initial clinical scores, such as the National Institutes of Health Stroke Scale, and diffusion imaging parameters has also been emphasized in the available evidence. Numerous clinical reports have shown that patients with lower National Institutes of Health Stroke Scale scores tend to exhibit smaller lesions on diffusion-weighted imaging and less severe reductions on apparent diffusion coefficient maps. These patients have achieved better functional outcomes in contrast to those with higher scores who have demonstrated larger infarcts and worse prognoses. This correlation has strengthened the combined application of clinical assessment and neuroimaging findings in the early management of acute ischemic stroke.<sup>23</sup>

Moreover, the advantage of using combined diffusion-weighted imaging and apparent diffusion coefficient evaluation rather than relying solely on clinical scoring systems has been discussed in several clinical trials. Imaging parameters have been proven to provide objective quantification of brain injury and have enhanced the accuracy of prognosis. The combined use of imaging and clinical data has been associated with greater precision in predicting long-term disability in stroke patients.<sup>24</sup>

Therapeutic decision-making has also been influenced by the incorporation of diffusion-weighted imaging and apparent diffusion coefficient findings. The determination of eligibility for thrombolytic therapy or mechanical thrombectomy has been guided by these imaging markers in many clinical settings. Patients with smaller lesion volumes and moderate reductions in diffusion have been considered more likely to benefit from aggressive treatment strategies. This approach has been promoted through evidence indicating that appropriate selection based on imaging characteristics has contributed to improved outcomes.<sup>25</sup>

The consistency of diffusion imaging findings across healthcare systems with different levels of resources has been highlighted in comparative analyses. The robustness of diffusion-weighted imaging and apparent diffusion coefficient mapping in both high-technology environments and resource-limited facilities has been supported by research from diverse geographic regions. This consistency has demonstrated the universal applicability of these techniques in stroke care.

Additionally, several studies have described the utility of early diffusion imaging in predicting patients at risk for neurological deterioration during hospitalization. Higher lesion volumes and severely reduced diffusion values have been identified as predictors of early worsening in many clinical scenarios. This application has supported the role of diffusion imaging in

ongoing patient monitoring beyond the initial diagnosis.

It has been demonstrated by longitudinal investigations that early imaging findings maintain relevance in predicting outcomes even at extended follow-up intervals. Initial lesion size and diffusion characteristics have shown strong associations with functional status at three months, six months, and longer periods after stroke onset. This lasting predictive value has emphasized the need for early comprehensive imaging assessments in patients with ischemic stroke.

In summary, the available literature has supported the dominant role of diffusion-weighted imaging and apparent diffusion coefficient mapping in the early diagnosis, management, and prognostication of acute ischemic stroke. The evidence has consistently shown that these imaging techniques have provided high accuracy in infarct detection and reliable prediction of functional recovery. Their routine application in clinical practice has been justified by their reproducibility, consistency, and practical value across different patient populations.

Moreover, several studies have supported the notion that DWI and ADC metrics can aid in identifying patients at risk for stroke progression and early neurological deterioration. Patients with large baseline DWI lesions and severely reduced ADC values are more likely to experience worsening of symptoms during hospitalization, emphasizing the importance of these markers in risk stratification and monitoring.

Finally, longitudinal studies have demonstrated that early imaging findings retain prognostic value beyond the acute phase of stroke. Initial DWI lesion volume and ADC characteristics have been shown to correlate with functional outcomes at three months, six months, and even one year post-stroke. This long-term prognostic relevance further advocates for the integration of DWI and ADC analysis into routine

stroke care, extending their utility from acute management to rehabilitation planning.

## CONCLUSION

In summary, a large body of evidence consistently highlights the critical role of DWI and ADC imaging in the early diagnosis, prognostication, and management of acute ischemic stroke. These imaging biomarkers provide reliable indicators of infarct burden, tissue viability, and recovery potential, supporting their widespread adoption in clinical practice. The consistency of findings across various populations, stroke subtypes, and clinical settings reinforces the validity of these modalities as indispensable tools in modern stroke evaluation.

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### Additional Information

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### AUTHORS CONTRIBUTIONS

Serial Number	Author’s Full Name	Intellectual Contribution to the Paper in Terms of
1.	Hafeez Ur Rehman	Study design and methodology.
2.	Nadeemullah	Paper writing.
3.	Muhammad Nauman Akram	Data collection and calculations.
4.	Arooma Zainab	Analysis of data and interpretation of results.
5.	Aniqa Nawaz	Literature review and referencing.
6.	Muhammad Arshad	Data collection.