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Research Paper

Diffusion-Weighted MRI for Intracranial Tumor Differentiation: Analyzing the Role of Apparent Diffusion Coefficient Values

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ABSTRACT: *Magnetic Resonance Imaging (MRI) has become a standard non-invasive method for evaluating brain lesions, offering highly detailed structural data. However, traditional MRI faces limitations in differentiating between various tumor components, peritumoral edema, and healthy brain tissue. Diffusion-Weighted Imaging (DWI), an advanced MRI modality, overcomes some of these challenges by measuring water molecule movement within tissues, providing additional insights for precise tumor evaluation. This study explores the diffusion characteristics of intracranial tumor components using DWI. Forty patients with intracranial tumors underwent both conventional MRI and DWI, utilizing an echo-planar diffusion imaging protocol to create apparent diffusion coefficient (ADC) maps. Absolute ADC values were calculated for tumor components, peritumoral edema, and normal brain tissue. Meningiomas emerged as the primary extra-axial lesions with higher ADC values than those of normal tissue, while gliomas—primarily astrocytomas—constituted the main intra-axial lesions with mean ADC values of 1.2 ± 0.69 x 10 ⁻ ³ mm²/s. This study concludes that DWI significantly enhances the diagnosis and characterization of intracranial neoplasms, improving differentiation between tumor components and surrounding tissues.*

KEYWORDS: *Diffusion Weighted Imaging (DWI), Apparent Diffusion Coefficient (ADC), intra axial lesions, extra axial lesion*
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I. INTRODUCTION

Brain tumors represent the most prevalent primary tumors within the central nervous system (CNS) (1), often posing significant health risks due to their abnormal and uncontrolled growth. Intracranial masses primarily comprise brain tumors, which can be categorized into primary tumors and secondary (metastatic) tumors, with the latter more common in adults (2). In pediatric cases, brain tumors rank as one of the top causes of cancer-related mortality (3, 4).

India has shown a lower incidence of CNS tumors compared to global averages, with 2.6 per 100,000 cases among males and 1.6 per 100,000 among females, accompanied by substantial mortality (5, 6). Conventional MRI has long been valued in the detection and assessment of brain tumors due to its ability to distinguish various soft tissues. Utilizing MRI sequences like T1, T2, and proton density-weighted imaging, traditional MRI can assess the tumor's location, size, and morphology, providing an essential foundation for diagnosis.

However, traditional MRI lacks precision in grading, classifying, and evaluating the aggressiveness of brain tumors (7). Diffusion-weighted imaging (DWI) addresses this limitation, enabling better discrimination between tumor invasion, normal tissue, and perifocal edema (8). By leveraging image contrast based on water molecule motion, DWI quantifies diffusion alterations, which are represented through the apparent diffusion coefficient (ADC). This study assesses DWI's effectiveness in enhancing brain tumor detection and characterization by evaluating ADC values across various intracranial tumor types.

II. MATERIALS AND METHODS

This study involved 40 patients who underwent DWI and conventional MRI. Participants represented a broad age range and were referred for brain MR imaging. All scans were performed using a Siemens Magnetom Avanto 1.5 Tesla MRI scanner. Patients with intracranial mass lesions qualified for inclusion, excluding those with metallic implants, pacemakers, metallic foreign bodies, cochlear implants, or pregnancy.

The imaging protocol encompassed MR brain imaging in T1-weighted axial, coronal, and sagittal planes, T2 FLAIR, and DWI sequences. The DWI sequences generated trace and DWI images; the trace images served as a clinical diagnosis reference, while ADC maps calculated ADC values for further exploration of observed abnormalities.

ADC values were measured for tumor components, peritumoral edema, and normal brain tissue using regions of interest (ROIs) placed manually. Measurements were automated, reported in 10^{-3} mm²/sec units, and analyzed as mean ADC values with standard deviation (SD). Pearson's correlation test assessed statistical relevance, with a p-value of ≤ 0.05 deemed statistically significant.

III. RESULTS

The study cohort comprised 40 patients, aged 6 to 69 years, with a gender distribution of 22 males and 18 females. Intra-axial lesions were observed in 28 patients, while 12 patients presented extra-axial lesions. Of the 40 total lesions, 38 were neoplastic, while 2 were infectious (tuberculomas).

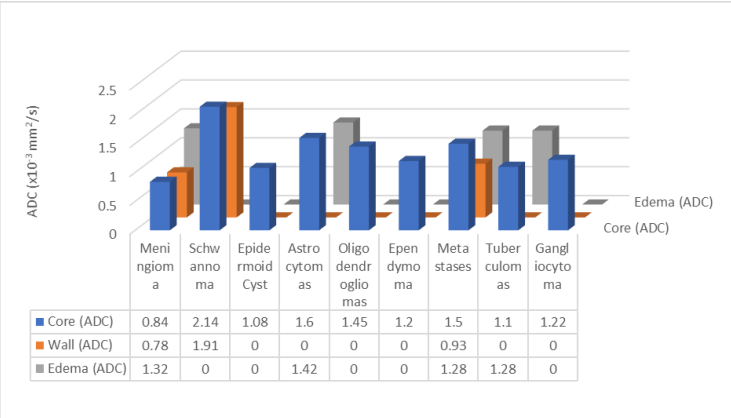
Among the extra-axial lesions, 9 cases of meningioma displayed iso-intense signals in both core and wall regions on DWI, with an ADC core mean of $0.84 \pm 0.2 \times 10^{-3}$ mm²/s. Schwannomas, identified in 2 cases, presented hypointense cores and hyperintense walls on DWI, with core ADC values averaging 2.14×10^{-3} mm²/s and peripheral values at 1.10×10^{-3} mm²/s. One epidermoid cyst case exhibited hyperintense DWI signals, likely due to diffusion restriction and the T2 shine-through effect. The cyst's core ADC mean was $1.08 \pm 0.12 \times 10^{-3}$ mm²/s.

Gliomas accounted for 21 cases among the intra-axial lesions. Of these, 11 were astrocytomas, displaying low DWI signal intensity, with parenchymal ADC means of $1.60 \pm 0.45 \times 10^{-3}$ mm²/s and peritumoral edema ADC means of $1.42 \pm 0.36 \times 10^{-3}$ mm²/s. Oligodendrogliomas (8 cases) lacked diffusion restriction, with core ADC means of $1.45 \pm 0.41 \times 10^{-3}$ mm²/s. Ependymomas displayed relatively restricted diffusion on DWI, with an ADC mean of 1.2×10^{-3} mm²/s.

Four metastatic cases lacked a clear DWI pattern, with core ADC values averaging $1.5 \pm 0.21 \times 10^{-3}$ mm²/s and wall ADC means of $0.93 \pm 0.030 \times 10^{-3}$ mm²/s. Surrounding edema recorded an ADC mean of $1.28 \pm 0.20 \times 10^{-3}$ mm²/s. Two tuberculomas showed hypointense cores on DWI, with iso-intense walls and hypointense edema, and a core ADC mean of $1.10 \pm 0.10 \times 10^{-3}$ mm²/s. Lastly, one gangliocytoma case exhibited a DWI hyperintense signal, with a core ADC of 1.22×10^{-3} mm²/s.

Tumor Type	Core (ADC)	Wall (ADC)	Edema (ADC)
Meningioma	0.84	0.78	1.32
Schwannoma	2.14	1.91	-
Epidermoid cyst	1.08	-	-
Astrocytoma	1.6	-	1.42
Oligodendrogliomas	1.45	-	-
Ependymoma	1.2	-	-
Metastases	1.5	0.93	1.28
Tuberculomas	1.1	-	1.28
Gangliocytoma	1.22	-	-

Table 1: Apparent Diffusion Coefficient in intra axial and extra axial masses



	Meningioma	Schwannoma	Epidermoid Cyst	Astrocytomas	Oligodendrogliomas	Ependymoma	Metastases	Tuberculomas	Gangliocytoma
Core (ADC)	0.84	2.14	1.08	1.6	1.45	1.2	1.5	1.1	1.22
Wall (ADC)	0.78	1.91	0	0	0	0	0.93	0	0
Edema (ADC)	1.32	0	0	1.42	0	0	1.28	1.28	0

Fig. 1: ADC values of different components in intra axial and extra axial masses

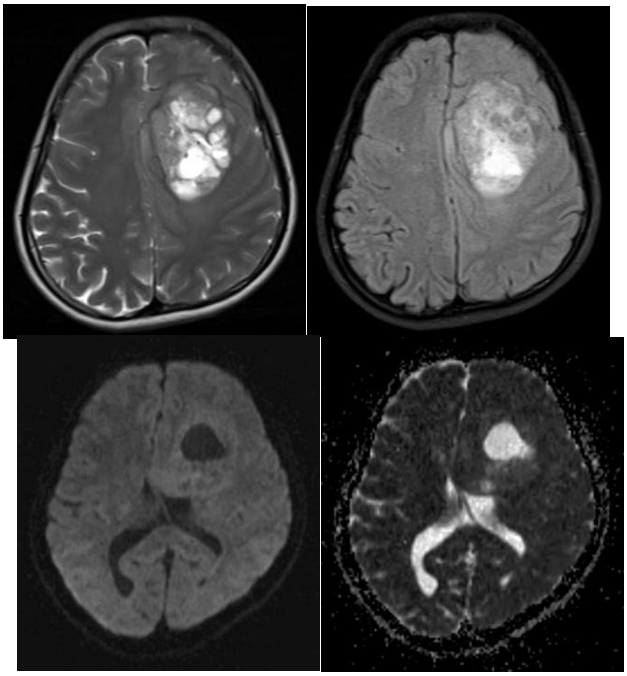


Fig 2: A 32 year – old female patient with high grade glioma. (a) T2 weighted image (b) T2 FLAIR (c) Diffusion weighted image (d) ADC map

IV. DISCUSSION

This study underscores DWI's potential in differentiating brain lesions through ADC values, revealing significant variability across lesion types and providing valuable insights for clinical diagnostics. The primary extra-axial group consisted of meningiomas, which exhibited higher ADC values than normal brain tissue, consistent with findings from Alexey Surov et al. (9).

Schwannomas exhibited higher ADC values compared to meningiomas, which aligns with prior research demonstrating significant ADC differences between these tumor types. The mean core ADC for schwannomas ($2.14 \pm 0.1 \times 10^{-3}$ mm²/s) exceeded that of meningiomas, achieving a high level of statistical significance ($P < 0.01$) (10). This higher diffusivity in schwannomas likely results from lower cellular density in Antoni B regions, a characteristic linked to increased diffusivity.

The primary intra-axial group was gliomas, with 11 cases identified as WHO grade II astrocytomas. The elevated ADC values observed in these low-grade astrocytomas align with research by Hassanejad et al., who found that astrocytomas exhibit higher ADC values due to lower cellular density (11). E.J. Lee et al. further corroborated these findings, showing an inverse relationship between ADC and astrocytic tumor grade (12).

A unique finding in this study was the epidermoid cyst's high DWI intensity coupled with a low ADC value. Cristina Andica et al. observed similar characteristics in epidermoid cysts, attributed to restricted diffusion within keratin-rich concentric layers, creating high signal intensity on DWI and low ADC values (10, 11).

For oligodendrogliomas, ADC values were not effective in differentiating them from astrocytomas, diverging from findings by Marion Simits, who showed that DWI could distinguish oligodendrogliomas through their higher ADC values (13). However, small sample size limitations may contribute to this discrepancy.
In cases of metastases, the ADC patterns were inconsistent, echoing findings by Mourad et al., who indicated that DWI improves glioma and metastasis differentiation accuracy, though specific ADC markers for metastases remain limited (14). Tuberculomas exhibited a lower mean ADC than both metastases and gliomas, yet the difference lacked statistical significance. Lastly, a single gangliocytoma presented a core ADC similar to that observed in ependymomas, highlighting DWI's versatility in characterizing uncommon lesions.
This study acknowledges limitations in sample size and tumor variety, recommending further research with a more extensive cohort and broader tumor types to solidify these observations.

V. CONCLUSION

Diffusion-Weighted Imaging (DWI) and Apparent Diffusion Coefficient (ADC) mapping serve as powerful non-invasive methods for evaluating intracranial tumors. These imaging techniques provide effective differentiation among tumor types, peritumoral edema, and normal brain tissue by analyzing their unique diffusion properties. This study highlights that meningiomas, gliomas, and other brain lesions display distinct ADC values, which contribute to improved diagnosis and tumor characterization. The combined use of DWI and ADC mapping enhances diagnostic precision and supports clinical decision-making in brain tumor management.

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