

Beyond the Clock: The Pivotal Role of Advanced MRI in Revolutionizing the Diagnosis and Management of Brainstem Stroke

Anirudda Deshpande, M.D., DM, DNB, FRCP, SCE Neurology¹; Vikram Khardenavis, MBBS, DM²; Aakash Shetty, MBBS, M.D., DM, DNB³; Ganesh Samudrala, MBBS⁴; Alla Dinesh, MBBS⁵

¹ Department of Care of the Elderly & Stroke, Altnagelvin Hospital, Londonderry, Northern Ireland, UK

² Department of Neurology, Madurai Medical College, Alwarpuram, Madurai, Tamil Nadu, India

³ Department of Neurology, University of Alberta, Edmonton, Canada

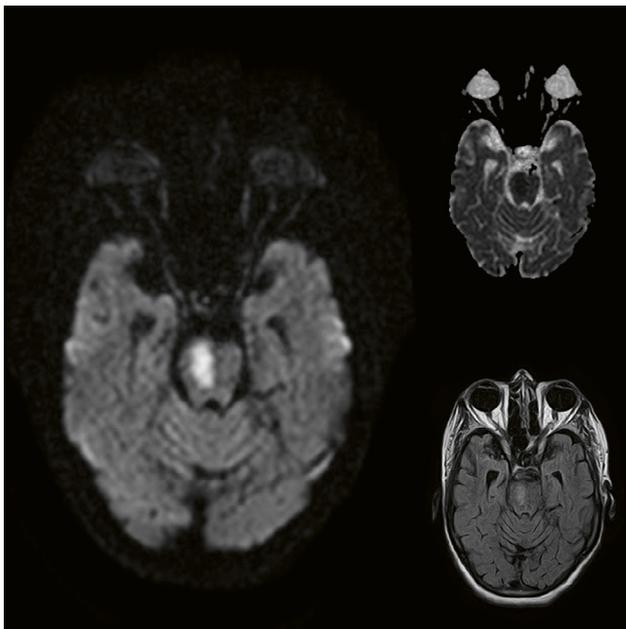
⁴ Medisure Diagnostics, Warangal, Telangana, India

⁵ Salus Medical Diagnostics, Hyderguda, Hyderabad, Telangana, India

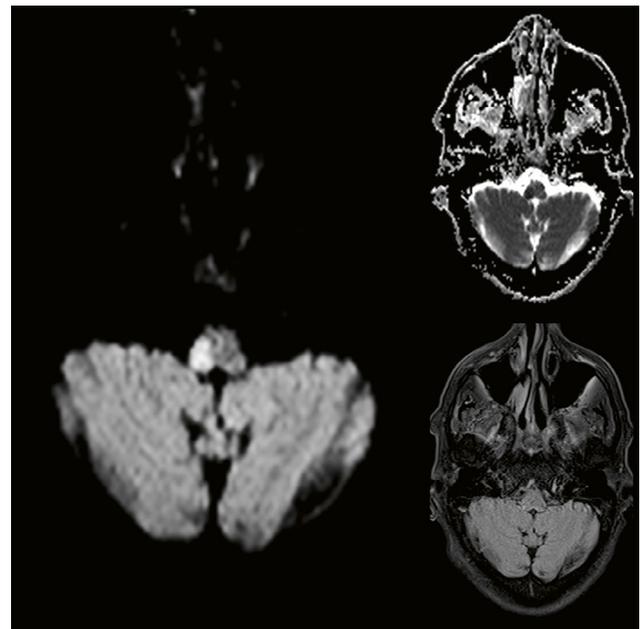
Abstract

The brainstem, a compact neural structure housing critical life-sustaining nuclei and white matter tracts, presents a unique diagnostic challenge when ischemic injury occurs. Its anatomical complexity and the non-specific nature of presenting symptoms often lead to diagnostic delays or misdiagnosis. Computed tomography is notoriously insensitive to acute brainstem ischemia. This review articulates the indispensable role of advanced magnetic resonance imaging (MRI) as the unequivocal gold standard for diagnosing brainstem stroke. We detail how specific

MRI sequences — particularly high-resolution diffusion-weighted imaging on modern platforms like the MAGNETOM systems — enable precise anatomical localization, facilitate differential diagnosis, and provide prognostic information. Furthermore, we explore the emerging potential of advanced techniques like diffusion tensor imaging and high-resolution vessel wall imaging in refining our understanding of brainstem stroke pathophysiology and in guiding future therapeutic strategies.



1 DWI, ADC, and FLAIR images of acute right paramedian pontine infarction.



2 DWI, ADC, and FLAIR images of right lateral medullary infarction.

1. Introduction: The diagnostic conundrum of brainstem stroke

Brainstem strokes, accounting for 10%–15% of all ischemic strokes, are neurological emergencies of the highest order [1]. Their presentation can be misleading: vertigo, nausea, diplopia, ataxia, and crossed sensory-motor deficits can easily be mistaken for peripheral vestibulopathies, metabolic disorders, or even psychological events. This diagnostic ambiguity, coupled with the profound limitations (due to bone artifact) of non-contrast computed tomography (CT) in visualizing the posterior fossa, creates a perilous gap in early care. The advent of magnetic resonance imaging (MRI) has fundamentally closed this gap, transforming brainstem stroke from a clinical enigma into a precisely imageable entity.

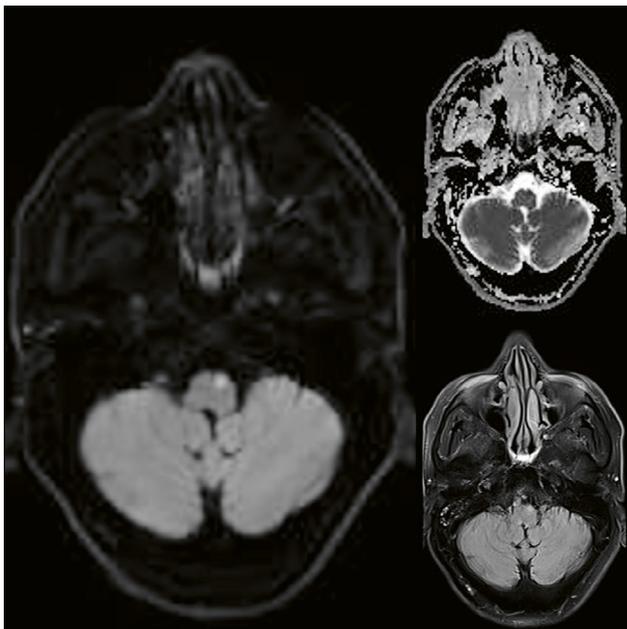
2. The armamentarium of MRI sequences: A tailored approach

A comprehensive MRI protocol is critical. Modern scanners offer optimized sequences that are pivotal for assessment.

2.1. Diffusion-weighted imaging (DWI): The cornerstone of acute diagnosis

DWI is the most critical sequence in the acute setting (< 24 hours), revealing restricted diffusion as hyperintensity within minutes of ischemia onset [2]. Its value in brainstem stroke is unparalleled:

- **Unmatched sensitivity:** DWI sensitivity for acute brainstem infarction exceeds 95%, compared to < 50% for CT, and lower for standard MRI sequences [3].



3 DWI, ADC, and FLAIR images of left medial medullary infarction.

- **Anatomical precision:** The high resolution of modern DWI sequences (e.g., using RESOLVE to minimize echo-planar imaging (EPI) distortion) allows clinicians to pinpoint the infarct to specific structures — e.g., the medial medulla (anterior spinal artery (ASA) territory) versus the lateral medulla (posterior inferior cerebellar artery (PICA) territory) — directly informing the vascular etiology and prognosis.

2.2. Fluid-attenuated inversion recovery (FLAIR) and T2-weighted imaging

While less sensitive than DWI in the hyperacute phase, these two sequences become positive after several hours and are excellent for depicting subacute and chronic infarcts. They provide essential context, helping to distinguish acute from chronic lesions.

2.3. High-resolution 3D T2-weighted sequences (SPACE, CISS)

Sequences like sampling perfection with application-optimized contrasts using different flip angle evolution (SPACE) and constructive interference in steady state (CISS) provide exquisite anatomical detail of the brainstem parenchyma and surrounding cisterns. They are invaluable for ruling out non-ischemic mimics like demyelination, infection, or compressive tumors.

2.4. Magnetic resonance angiography (MRA)

Time-of-flight (TOF) MRA non-invasively assesses the vertebrobasilar circulation, which is the lifeblood of the brainstem. Identifying basilar artery occlusion (an often fatal but treatable emergency) or vertebral artery dissection is a critical component of the MRI exam, which directly guides urgent endovascular therapy.

3. The clinical impact: From diagnosis to prognosis

Several clinical examples are shown in Figures 1–3. They all highlight DWI and FLAIR which are the most utilized contrasts in the acute brainstem stroke setting. However, all capabilities of MRI contribute to the diagnosis as well as prognosis of the patient.

3.1. Resolving diagnostic uncertainty

The most immediate impact of MRI is ending diagnostic doubt. A patient with vertigo and nystagmus can have a definitive diagnosis of lateral medullary stroke (Wallenberg syndrome) confirmed by a tiny DWI hyperintensity. This prevents misdiagnosis as benign positional vertigo and ensures that appropriate secondary prevention is initiated.

3.2. Informing etiology and management

The pattern of infarction on MRI points to the underlying mechanism:

- **Large artery atherosclerosis:** Infarcts in the proximal vascular territory
- **Small penetrating artery disease (lacunar):** Small, deep infarcts (< 1.5 cm) in the pons or midbrain
- **Artery-to-artery embolism:** Larger, wedge-shaped cortical-subcortical infarcts
- **Vertebral artery dissection:** An infarct in the lateral medulla or PICA territory with a crescent sign on axial T1-weighted fat-saturated images of the vertebral artery

This etiological classification is essential for tailoring long-term management, such as selecting dual antiplatelet therapy for minor stroke, or high-intensity statins for atherosclerosis.

3.3. Prognostic implications

The location and extent of the lesion on MRI are powerful prognostic indicators. A small, unilateral pontine lacune carries a vastly different prognosis than a large, bilateral “locked-in” pontine infarct or “top of the basilar” syndrome affecting the midbrain and thalami.

4. Future directions and advanced techniques

The evolution of MRI continues to refine our understanding of brainstem stroke. **Diffusion tensor imaging (DTI)** can map the disruption of critical white matter tracts (e.g., corticospinal tracts), providing biomarkers for motor recovery potential. **High-resolution vessel wall imaging** can directly visualize plaque inflammation or dissection flaps in the vertebrobasilar system, offering insights into pathophysiology that lumenography (MRA/CTA) cannot. Modern MR scanners are usually equipped with susceptibility-weighted imaging (SWI) which is very sensitive to T2* variations and, hence, can detect microbleeds, a sign of cerebral small vessel disease that may influence anticoagulation decisions.

Quantitative susceptibility mapping (QSM)¹ will take SWI one step further by quantifying the susceptibility variation. This may have potential benefits for hemorrhagic stroke

patients [6] and may also enable new insights into the complex processes following acute ischemic stroke [7].

5. Conclusion

Advanced MRI has changed the landscape of brainstem stroke management. It has evolved from a mere diagnostic tool to a comprehensive guidance system for acute triage, etiological classification, and prognostic stratification.

By leveraging a multimodal protocol on a technologically advanced MRI platform, clinicians can overcome the inherent challenges of brainstem anatomy, ensure accurate and timely diagnosis, and provide patients with highly informed and effective care pathway. The continued integration of these sophisticated imaging techniques into clinical protocols is essential for further improving outcomes in this complex patient population.

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Contact

Anirudda Deshpande, M.D., DM, DNB, FRCP, SCE Neurology
Consultant, Department of Care of the Elderly & Stroke
Altnagelvin Hospital
Glenshane Road
Londonderry, Northern Ireland, BT47 6SB
United Kingdom
anirudda.deshpande@westerntrust.hscni.net



¹ Work in progress. QSM is currently under development and is not for sale in the U.S. and in other countries. Its future availability cannot be ensured.