Vascular Health and Risk Management Dovepress

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Non-Contrast MRI Sequences for Ischemic Stroke: A Concise Overview for Clinical Radiologists

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Abstract: Ischemic stroke is the second leading cause of mortality and morbidity worldwide. Due to the urgency of implementing immediate therapy, acute stroke necessitates prompt diagnosis. The current gold standards for vascular imaging in stroke include computed tomography angiography (CTA), digital subtraction angiography (DSA) and magnetic resonance angiography (MRA). However, the contrast agents used in these methods can be costly and pose risks for patients with renal impairment or allergies. The aim of this paper is to provide a comprehensive overview of current MRI techniques and sequences for evaluating ischemic stroke, emphasizing the importance of non-contrast options and their clinical implications for radiologists in the diagnosis and management of ischemic stroke. Standard MRI sequences—such as T1-weighted imaging (T1WI), T2-weighted imaging (T2WI), fluid-attenuated inversion recovery (FLAIR), diffusion-weighted imaging (DWI), DWI-FLAIR mismatch, and apparent diffusion coefficient (ADC)—are essential for determining infarct location, volume, and age. Additionally, incorporating susceptibility-weighted imaging (SWI) sequence aids in identifying signs of hemorrhagic transformation within the infarcted region. Advanced techniques like arterial spin labeling (ASL) can serve as a non-contrast alternative for mapping cerebral blood flow (CBF) and allowing for comparison between infarcted and healthy brain areas. Adding ASL to the routine sequence allows ASL-DWI mismatch analysis that is useful for quantifying salvageable tissue volume and facilitate timely recanalization, while time-of-flight (TOF) MRA and magnetic resonance venography (MRV) help assess venous thrombosis, stenosis, or arterial occlusions. Finally, MR spectroscopy can provide insights into critical brain metabolites, including N-acetylaspartate (NAA), and lactate (Lac) to determine patient prognosis. Current MRI technology provides a myriad of sequence options for the comprehensive evaluation of ischemic stroke without the need for contrast material. A thorough understanding of the advantages and limitations of each sequence is crucial for its optimal implementation in diagnosis and treatment.

Keywords: non-contrast MRI, ischemic stroke, MRI sequences

Introduction

Ischemic stroke is currently the second leading cause of mortality and morbidity worldwide.[1] The World Health Organization has predicted that stroke will become the second most common cause of death by 2030, with a 10.3% rate of all deaths occurring after heart attacks.[1,2] Owing to its acute nature, stroke diagnosis still relies heavily on clinical manifestations. However, a study of 8839 patients presenting with clinical stroke manifestations found that 19–30% of the suspected infarct cases were not actually caused by stroke. Considering this high mimicry rate, it is crucial for radiologists to maximize the use of multiple imaging modalities for a more accurate diagnosis and aid clinicians to classify it to stroke sub-types such as cardioembolic stroke, large or small vessel disease, or other etiology.[3–7]

Received: 20 May 2024
Accepted: 8 November 2024
Published: 26 November 2024

CT-scan has been the backbone of stroke diagnosis for many decades due to its short acquisition time and widespread availability. In recent years, a lot of progress has been made to elevate the diagnosis of cerebrovascular disease where utilization of MR-Angiography (MRA), CT-angiography (CTA), and digital subtraction angiography (DSA) is widely used to gain information on brain perfusion and vascular evaluation with the MRA as the best and least invasive option. However, these imaging modalities require contrast material, which presents some limitations.[8–10]

The first limitation is the high cost of an MRI scan with contrast material which is still considered expensive in many health centers worldwide. At Wahidin Sudirohusodo Hospital in Indonesia for example, the price of a non-contrast brain MRI scan versus a contrast-enhanced brain MRI scan will result in a 28% increase in the cost. In the United States, the disparity is even greater, with a non-contrast brain MRI costing 57% less than its contrast enhanced counterparts. This could be a dealbreaker for some patients, particularly those who are not covered by insurance.[11]

In addition to pricing issues, MRA examinations with gadolinium-based contrast media (GBCM) pose an increased risk of nephrogenic systemic fibrosis (NSF) in patients undergoing kidney replacement therapy, acute kidney injury, or stage 4 or 5 chronic kidney disease (CKD).[12] Multiple studies have reported immediate and non-immediate hypersensitivity reactions to GBCM such as coldness, nausea, vomiting, headache, paresthesia, myalgia, arthralgia, thrombophlebitis, urticaria, angioedema, and anaphylaxis.[13–15] Furthermore, the previously held belief that GBCM are entirely safe for individuals with intact blood–brain barrier (BBB) integrity has been challenged by a post-mortem study. This research revealed the accumulation of gadolinium in neuronal tissues, despite the absence of detectable intracranial abnormalities. Notably, deposits were primarily found in the globus pallidus, thalamus, dentate nucleus, and pons, with the highest concentration observed in the dentate nucleus.[16]

In 2012, Allen et al published an influential article advocating for standard MRI sequences to assist radiologists in assessing and staging strokes across five phases: early hyperacute, late hyperacute, acute, subacute, and chronic. The sequences discussed included T1-weighted imaging (T1WI), T1WI with contrast, T2-weighted imaging (T2WI), fluid-attenuated inversion recovery (FLAIR), diffusion-weighted imaging (DWI), apparent diffusion coefficient (ADC), and susceptibility-weighted imaging (SWI)/gradient echo (GE) sequences.[17] Since then, additional sequences have become available for clinical implementation, such as arterial spin labeling (ASL), a form of perfusion-weighted imaging (PWI) that does not require contrast material and provides enhanced information regarding penumbra compared to the DWI-FLAIR mismatch.[18] In this mini review, we aim to offer a concise overview of both standard and advanced MRI sequences to optimize assessment of ischemic stroke patients without the need for contrast agents.

Standard MRI Sequences

T1WI, T2WI and FLAIR

Standard sequences used in ischemic stroke imaging begin with T1-weighted imaging (T1WI) and T2-weighted imaging (T2WI). These sequences excel at revealing anatomical details, with tissues containing a higher water content appearing darker on T1WI and brighter on T2WI. Notably, T2WI can detect lesions associated with vasogenic edema as early as 6 hours after onset, as illustrated in Figure 1. Another key standard sequence for acute cerebral infarction is fluid-attenuated inversion recovery (FLAIR) (Figure 2), which employs a long Time Echo (TE) to suppress normal cerebrospinal fluid (CSF). This suppression enhances the identification of stroke edema by contrasting the hyperintense infarct lesion against normal structures and surrounding fluids.[19–22]

Diffusion Weighted Imaging and Apparent Diffusion Coefficient (DWI-ADC)

Diffusion weighted imaging (DWI) is a crucial sequence that can be used to identify hyperacute lesions. This sequence detects restriction in the movement of water molecules, which will appear hyperintense within minutes when there is restriction of intracellular water transport due to sodium potassium pump malfunction (cytotoxic edema) under ischemic conditions.[22] DWI is typically paired with an ADC map (Figure 3) to determine the true infarcted areas that appear bright on DWI and dark on the ADC map in acute condition (Figure 1). If the area is bright in both DWI and ADC, the suspected area is likely not a true infarct, but a "T2 shine-through" phenomenon.[19] DWI sequence and ADC map is very important in distinguishing the age of the infarct. When the DWI signal is still bright but the ADC map starts to appear

Sequence	Early Hyperacute (0-6 hrs)	Late Hyperacute (6 – 24 hr)	Acute (24hr – 1 week)	Subacute (1-3 week)	Chronic (>3 week)
Etiology[22]	Cytotoxic edema	Vasogenic edema	Resolving edema	Resolved edema/ Pseudonormalize	Gliosis/ Encephalomalacia
T1WI[17]					
T2WI				*	
FLAIR					
DWI				*	*
ADC				*	
SWI[25]					**
	Low	Low	High chance > 48 hrs	Low	Low***
ASL (CBF)[24]	55 mL/100g = normal; <23 mL/100g = reversible; < 12 mL/100 g = irreversible ASL-DWI mismatch = (+) penumbra				
MRS[23] Naa/Cr	1.68±0.29	1.56±0.27 (↓)	↓↓	↓↓↓	>1mo. 0.43±0.12(↓)
Lac/Cr	-1.29±0.27	-1.49±0.35 (↑)	↑↑	↑↑↑	>1 mo. -0.07±0.11(↓)

Hypointense Isointense Hyperintense Variable with rim

Figure 1 Roles of Non-Contrast MRI Sequences in Various Phases of Ischemic Stroke. Data from Allen, 2012,[17] Tong, 2014,[22] Lin, 2014,[23] Aracki-Trenkic, 2020,[24] and Weerink, 2023.[25]

Notes: *Signal changes as time progress. **Hemorrhage appearance when present; notice signal changes as blood products evolve from oxyhemoglobin (high), deoxyhemoglobin (low), methemoglobin (high with low signal rim), to hemosiderin (variable signal with prominent low signal rim). ***chance of hemorrhagic transformation in each phase of ischemic stroke.

normal (pseudonormalize) it means the lesion is around 10–14 days, after that, DWI will start to become **isointense** until gliosis started to form, changing DWI to hypointense in the chronic stage (Figure 1).[17] Besides its role in determining age of infarct, DWI is also the determining sequence in classifying stroke into its etiologic cause such as TOAST (Trial of ORG 10172 in Acute Stroke Treatment) classification, where a lesion measured <15 mm in DWI sequence is categorized into a lacunar infarct or a small vessel disease, while lesions measured >15 mm can be classified as either a large vessel disease or a cardioembolic stroke.[7]

When a penumbra area is suspected and MR perfusion is not available, DWI-FLAIR mismatch can be used as a proxy marker to determine lesion age in patients with unknown stroke onset. DWI-FLAIR mismatch is present when a lesion is visible on DWI without matching parenchymal hyperintensity in the corresponding region on FLAIR (Figure 3). This implies that the area is already undergoing cytotoxic edema, but the blood–brain barrier (BBB) has not been compromised or the vasogenic edema has not yet developed to its full size. Presentation of this mismatched area can aid in selecting suitable patients for intravenous thrombolysis therapy (IVT). Studies have also shown that patients presenting with DWI-FLAIR mismatched areas have shorter onset-to-hospital door times and better outcomes than those with DWI-FLAIR match.[18,27–29]

Susceptibility Weighted Imaging (SWI)

Susceptibility weighted imaging (SWI) is a sequence based on a gradient (GRE) pulse. This sequence can detect magnetic field inhomogeneities caused by T2* effects that appears when blood products exist (Figure 3) or when

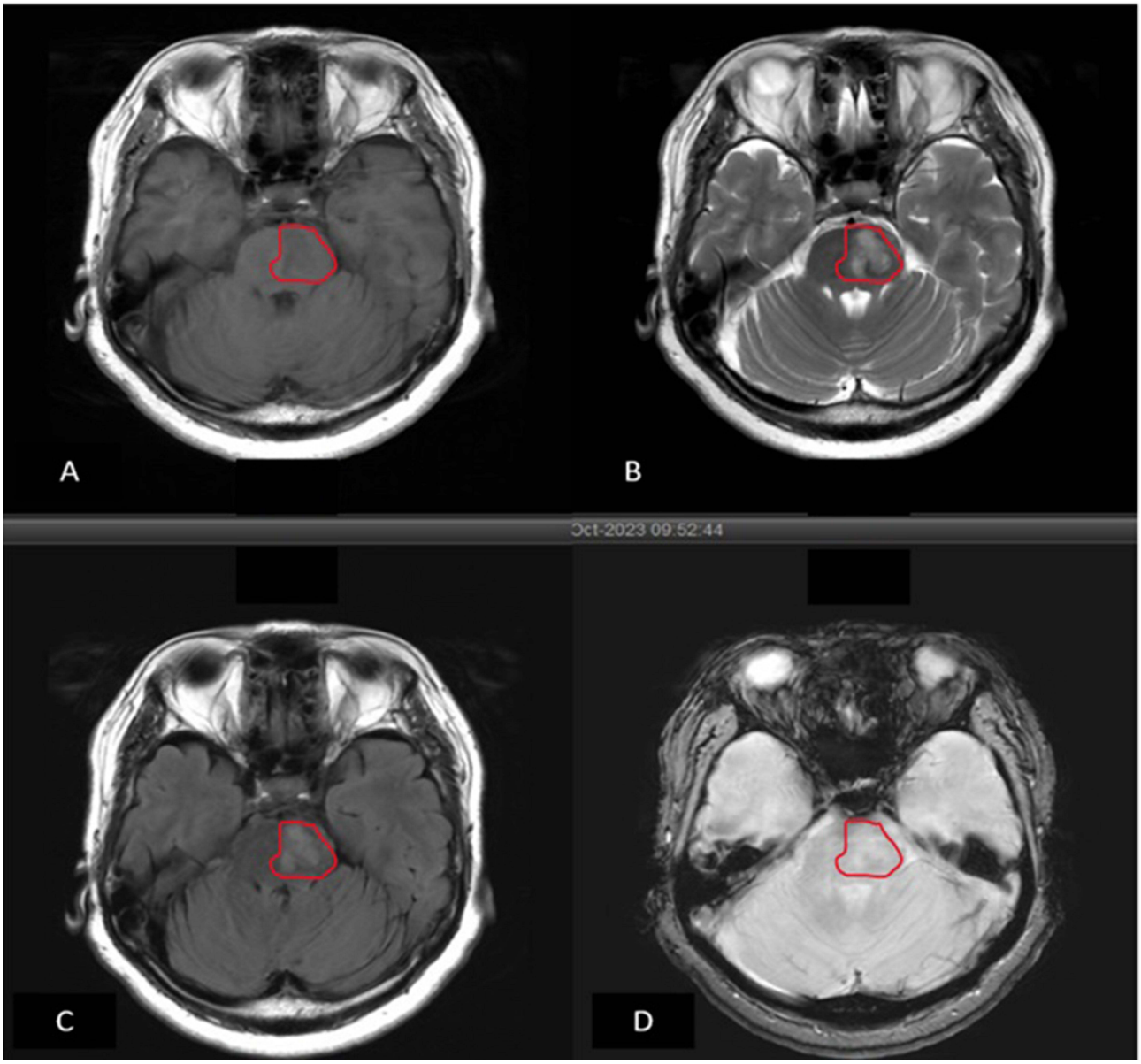

Figure 2 Standard MRI sequences in a 64-year-old female presenting with hemiparesis and dysarthria. MRI shows a pontine lesion (red circle) that appears slight hypointense in T1WI (**A**), hyperintense in T2WI (**B**) and FLAIR (**C**), with no dark area (blooming) on SWI (**D**), confirming acute ischemic stroke with no hemorrhagic transformation.

calcium are present. The SWI uses a high-resolution 3D-GRE sequence with flow compensation to depict field inhomogeneities. When magnetic field distortion exists in the presence of blood products or calcium, signal loss due to T2* dephasing and spatial mismapping occurs, resulting in the formation of susceptibility artifacts (*blooming*). It is also worth noting that *blooming* can occur when gases, lipids, and free radicals (such as those found in abscesses) are present. However, they can be distinguished using other MRI sequences with fat suppression and clinical information.[26]

SWI is useful for detecting hemorrhagic transformation in patients with ischemic stroke. It is important to understand that the appearance of the blood differs according to its onset. Blood products consist of plasma, red blood cells, white blood cells, and platelets. However, the main component detectable by the SWI sequence is the hemoglobin content of red blood cells. Hb can be present in four different forms: oxyhemoglobin (diamagnetic), deoxyhemoglobin (paramagnetic), methemoglobin (paramagnetic), and hemichromes. Differences in these hemoglobin magnetic properties make hemorrhage appear different on MRI depending on their location and age. In the hyperacute phase, oxyhemoglobin is the main contributor to the MRI signal, with few T2* effects, making it appear bright on SWI. Deoxyhemoglobin then forms

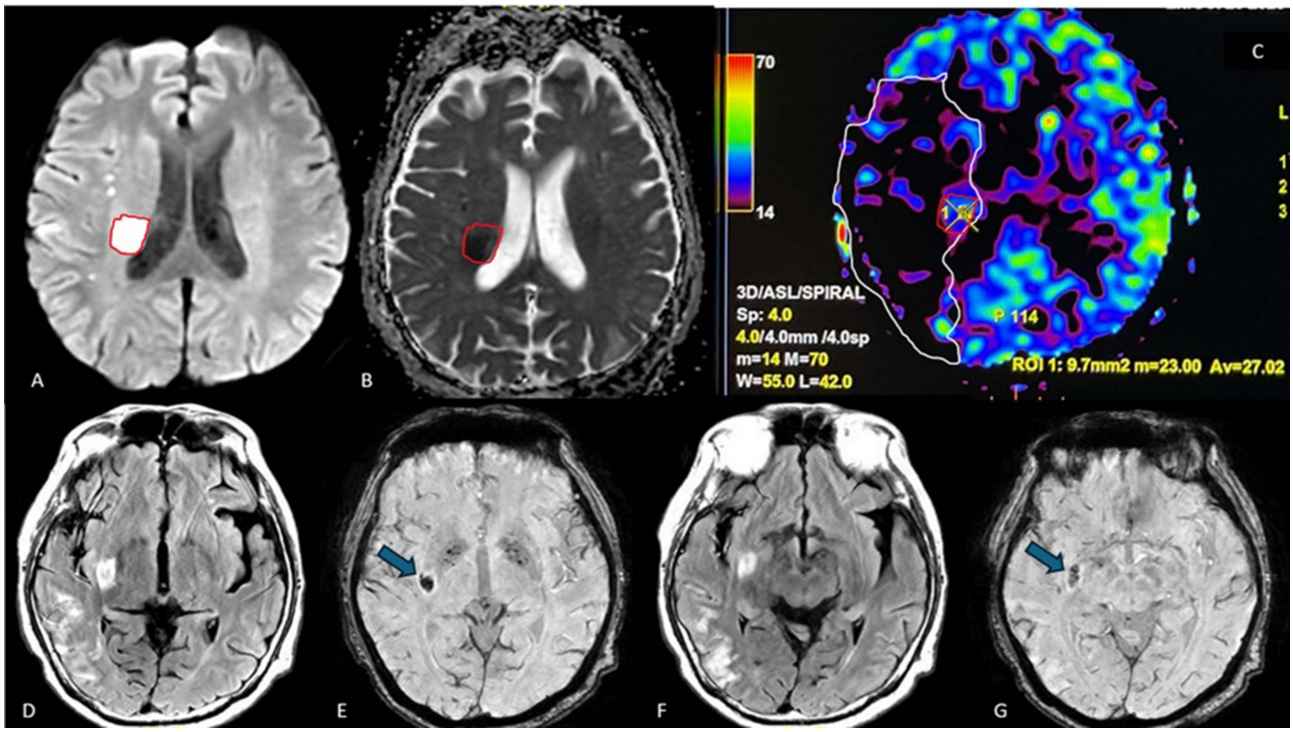

Figure 3 MRI imaging findings in a 73-year-old male presenting with left hemiparesis. MRI revealed multiple infarcts of the Corona radiata visible in DWI (**A**) and ADC (**B**) marked by red outline. On ASL MR-perfusion, extensive hypoperfusion can be seen in the right middle cerebral artery (MCA) territory marked by white outline which was not visible in DWI (perfusion-diffusion mismatch), suggesting a large area of penumbra (**C**). There were also infarcts at the right external capsule, occipital lobe, and the lentiform nucleus visible in FLAIR (**D** and **F**), with an appearance of blooming artefact on SWI (arrow), confirming presence of micro bleeding that may progress to hemorrhagic transformation (**E** and **G**).

in the periphery of the blood pool, which appears as a ring of low intensity around bright oxyhemoglobin. In the acute stage, all oxyhemoglobin already turns into paramagnetic deoxyhemoglobin, which appears as a dark lesion in SWI. In the subacute stage, deoxyhemoglobin leaves the circulation and heme iron undergoes oxidation into the ferric (Fe^{3+}) form, which is a strong paramagnetic methemoglobin that will appear dark on SWI. As the blood ages into its chronic form, increased water content due to lysis of the red blood cells causes a high or variable signal in the middle with a rim of dark signal composed of methemoglobin (Figure 1).[26] Chances of an ischemic stroke to undergo a hemorrhagic transformation are at the highest in its acute stage within 48 hours up to 5 days. Chances of hemorrhagic transformation or micro bleeding in an ischemic stroke is low in hyperacute, subacute, or chronic stage (Figure 1).[17]

Advanced MRI Sequences

Arterial Spin Labelling (ASL)

Ischemic stroke imaging is incomplete without the evaluation of cerebral perfusion to depict oxygen and nutrient delivery to the brain tissue by blood flow. To obtain MR perfusion without contrast, ASL can be employed to map the global perfusion of the brain measured in mL/100 gr/min. Unlike traditional MR perfusion that requires exogenous tracers (contrast media), ASL sequence magnetically labels arterial blood water protons as an endogenous tracer. This feature makes ASL excellent as MR-perfusion substitute in patients that are sensitive to contrast media such as children or very old patients that may have renal insufficiencies or other complicating diseases.[30]

ASL provides mapping of cerebral blood flow (CBF) in all areas of the brain, making it possible to measure absolute cerebral blood flow (aCBF) or relative cerebral blood flow (rCBF) of the infarcted area compared to the contralateral normal area.[24] In terms of absolute CBF measurement, a normal mean for CBF value is approximately 55 mL/100 g/min. Under ischemic conditions, a CBF of 23 mL/100 g/min is considered reversible with rapid reperfusion. However, a CBF measured less than 12 mL/100 g/min indicates expected irreversible structural and functional damage. Another way to

use ASL is to measure rCBF, where rCBF value >49.7% indicates a more favorable outcome (Figure 1).[24] An example of ASL aCBF quantification can be seen in Figure 3 showing an aCBF of 27 mL/100 g/min, which is considered salvageable if prompt reperfusion was done.

ASL can also be used to perform perfusion-diffusion mismatch (ASL-DWI mismatch) analysis (Figure 3) to identify areas at risk (penumbra) that might be salvageable with prompt recanalization.[31] The concept of this mismatch is parallel to the DWI-FLAIR mismatch previously discussed; however, instead of serving as a proxy marker for the penumbra, the ASL-DWI mismatch is more accurate at identifying true penumbral regions. This is because ASL can detect areas that are already undergoing hypoperfusion, even before neuronal cells are damaged causing restricted diffusion.[18] This ability is especially useful in detecting patients with transient ischemic attack (TIA) or predicting future stroke occurrences where neurological deficit may already be present, but cytotoxic edema has not yet developed. When this marker of penumbra is present with an onset of less than 4 h old, the patient can be treated with intravenous thrombolytics, whereas those with an onset later than 4 h old should be managed with endovascular intervention. The fact that ASL perfusion does not require the evaluation of renal function before MRI scanning can help reduce door-to-needle time, which can shift the treatment from invasive to non-invasive intervention while saving more brain cells from ischemic damage.[29,32–34]

There are some limitations to ASL. Compared to contrast enhanced PWI, ASL does not have the ability to measure cerebral blood volume (CBV), mean transit time (MTT), and time to peak (T-max). However, ASL is very sensitive to minor perfusion alteration with 93% agreeability with contrast enhanced PWI.[34] Some pitfalls also need to be avoided during ASL interpretation. The first pitfall is the technical issue, in which white matter perfusion usually has a significantly weaker signal than gray matter due to poor sensitivity. Susceptibility artifacts arising from blood products, calcification, metallic materials, and skull base areas can also present as dark signals, mimicking reduced CBF. On the other hand, existing motion artifacts can produce an image of ring hyperintensity (high signal), mimicking increased CBF. Other pitfalls arise from the physiological changes in the brain. For example, pediatric patients generally have higher CBF peaking at 3–8 years old which decreases over time. Younger patients also have a higher signal in the occipital area owing to better visual cortex activation. ASL signal is also low in watershed areas because blood in these areas may still be inside arteries rather than reaching capillary beds when the image is acquired; this condition is called the "border zone sign".[35]

Time-of-Flight (TOF) MRA and MRV

A time-of-flight (TOF) magnetic resonance angiography and magnetic resonance venography (Figure 4) sequence can be used to evaluate brain vascularity on non-contrast MRI. TOF MRA provides a contrast between blood vessels and the surrounding stationary tissues by inducing blood inflow effects. The results are presented as a three-dimensional (3D) model of the cerebral arteries, suitable for the identification of cerebral vascular pathologies, such as thrombus, aneurysms, or arteriovenous malformations.[36]

However, it is worth noting that TOF-MRA has a limitation compared to contrast enhanced MRA. Because TOF-MRA relies on blood flow, the image is produced with longer acquisition time with higher risk of motion artifact. This is the reason why TOF-MRA is typically performed with a smaller field of view (FOV) that only includes intracranial vessels, excluding extracranial vessel.[37] This limitation can pose a challenge for interventional radiologists, who require detailed information about the brachiocephalic arteries to access intracranial vessels for endovascular intervention.

TOF MRV is a gradient echo-based sequence that achieves saturation using a short-interval radiofrequency (RF) pulse, meaning that the sequence mainly relies on "flow enhancement" by suppressing stationary protons around the vessels. Time acquisition for TOF-MRV is approximately 5–8 min and is an excellent method to show flow reduction in certain areas of the cerebral vein. Unfortunately, unlike regular MRV with contrast, TOF-MRV cannot detect flow direction or quantify flow. Another limitation of TOF-MRV is the detection of thrombi in subacute conditions because the methemoglobin content in subacute dural sinus thrombosis can appear hyperintense at T1. A short time repetition (TR) interval can cause a "thrombus shine-through" effect in TOF-MRV, making the thrombus appear as if it has a normal venous patency.[38]

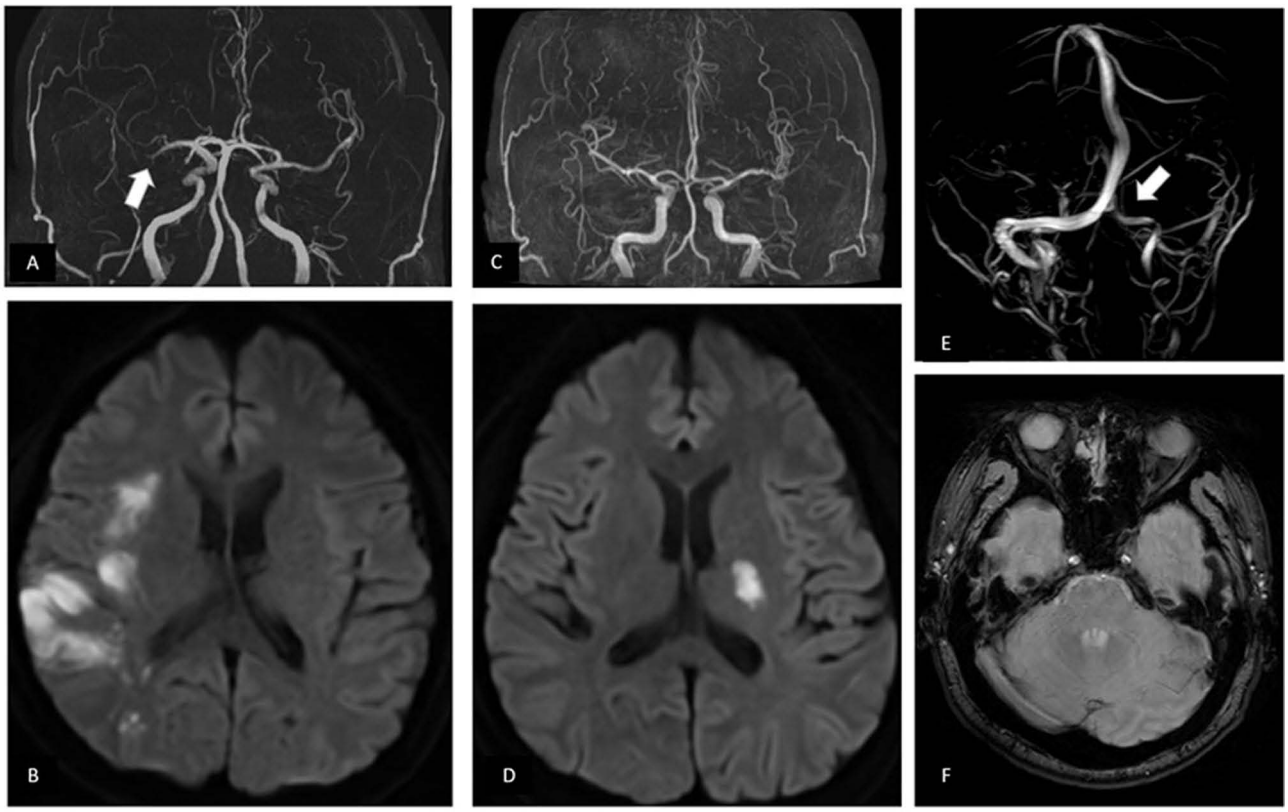

Figure 4 An example of large vessel disease of a 52-year-old male with left hemiparesis. TOF-MRA shows occlusion on the 2nd branch of the middle cerebral artery (M2) (white arrow) heading to inferior posterior area (**A**). DWI sequence shows restricted diffusion at the external capsule and Wernicke's areas (**B**). An example of small vessel disease showing on a 40-year-old male with right hemiparesis. TOF MRA shows no visible occlusion in TOF-MRA (**C**) despite a visible lesion at the internal capsule on DWI sequence (**D**). TOF-MRV shows hypoplasia of the left sinus transverse, sigmoid, and jugular vein (white arrow) confirmed in T2 axial plane (**E**).

Although TOF-MRA/MRV does not have the capability to provide information on directionality or vascular flow velocity, it provides excellent spatial resolution of arterial and venous vessels, which is sufficient to evaluate the presence of thrombus, stenosis, or aneurysm.[39]

Information provided by TOF-MRA can also aid in determining the TOAST subtypes of stroke where the presence of stenosis in intracranial without the presence of cardioembolic etiology will classify the stroke as a large vessel disease (LVD) stroke (Figure 4), while absence of stenosis will classify it into small vessel disease (SVD) stroke (Figures 4 and 5).[7]

MR-Spectroscopy (MRS)

MR-spectroscopy (MRS) is an interesting sequence that can be added to ischemic stroke imaging for metabolite information in addition to the anatomical information provided by other sequences. ^{1}H MRS is a noninvasive non-contrast sequence that quantifies metabolites in tissues using signal resonances from hydrogen protons. The presence and concentration of this metabolite will then be presented in different peak amplitudes in static magnetic fields in parts per million (ppm), usually between 0 and 4. Unlike regular brain MRI, which can view the whole brain within minutes owing to its high hydrogen (water) content, most mobile chemicals are present in very low concentrations and require a much longer acquisition time. Hence, the analysis is usually restricted to a small region of interest (ROI), which typically covers an area of only 1–10 mm^3 compared to 1–10 cm^3 in regular MRI sequences. In addition, even with this small ROI, only chemicals with a concentration of $\geq$ 0.5 umol/g can be detected with MRS, some large immobile macromolecules and phospholipids, myelin, proteins, RNA and DNA are considered "invisible" to MRS.[40]

Many metabolites can be observed in MRS, but the most important metabolite to be observed in ischemic stroke is N-acetylaspartate (NAA), which serves as a marker of viable neurons and axons. When NAA is lowered, it indicates neural loss or death, which can occur in ischemic or other pathological conditions. Lactate (Lac) is another important

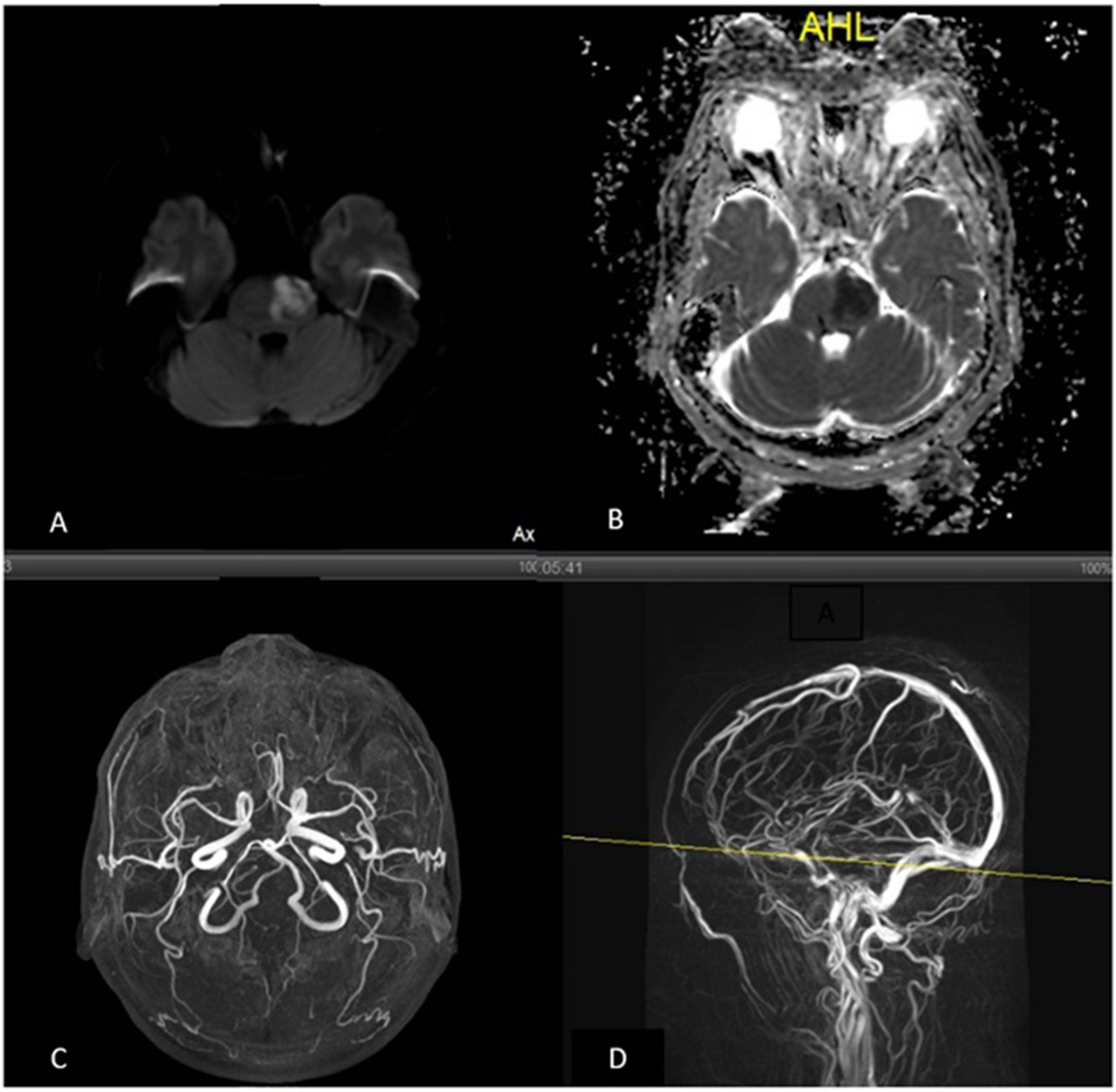

Figure 5 Similar patient from Figure 2, with a pontine lesion that appears hyperintense on DWI (**A**), confirmed to be a restricted diffusion area with a corresponding dark area on ADC map (**B**). There is no significant occlusion of the basilar artery on TOF-MRA (**C**) and no visible stenosis on TOF-MRV (**D**). This vascular information classifies the patient into small vessel disease stroke.

metabolite that indicates anaerobic metabolism in ischemic stroke; it increases in the presence of anaerobic glycolysis and in necrotic tissue. It is worth noting that lactate can also be present in the cerebrospinal fluid (CSF) at a concentration of approximately 1 mmol/L; therefore, placement of the ROI should avoid CSF areas to accurately detect lactate. Lactate has great prognostic value in ischemic stroke because its presence indicates severe perfusion impairment, which leads to poor clinical outcomes.[40,41]

MRS can provide metabolite concentration using moles per unit volume; however, absolute quantitation can be very challenging. First, one needs to acquire a water signal as the absolute concentration reference, while eliminating bias from voxel size differences, accounting total gains due to coil loading, receiver gains, and hardware changes. Water reference in tissue with abnormal condition should also be adjusted.[40]

Fortunately, there are ways to make interpretation more practical for faster interpretation on ischemic brain conditions. Clinicians can use peak ratios of one metabolite of interest such as NAA, or Lac by comparing it to another metabolite within the same ROI. For this peak ratio method, a common metabolite used as an internal reference is Creatine (Cr) because this metabolite's concentration is relatively constant whether it is in a normal or pathologic condition. This method was used by Lin (2013) to measure changes in MRS ratios at each stage of infarct. Lin discovers that as soon as ischemic begins, Naa/Cr ratio at the core of infarct will continue to decline from 1.68 ± 0.29 at early hyperacute, to 1.56± at late hyperacute, and continue to decline to about 0.43 ± 0.12 after 1 month. On the other hand, Lac/Cr ratio at the core of infarct will rise significantly from −1.29 ± 0.27 at early hyperacute to −1.49 ± 0.35 at late hyperacute, but the ratio will go down to −0.07 ± 0.11 when it reaches chronic phase (Figure 1). Interestingly, while follow-up Naa/Cr ratio at the core of infarct shows no significant differences between those treated with thrombolytic therapy compared to those who do not, Naa/Cr ratio at the ischemic border region is significantly higher in patients treated with thrombolytic therapy. This implies that the decline of Naa can be slowed down if thrombolytic therapy is given to save the penumbra area.[23,40]

Alternative to metabolite ratio method, we can also scan a contralateral area of the brain lesion as an internal reference to detect how much of this metabolite is decreasing or increasing compared to its supposedly normal contralateral area. However, this method will not be valid when both brain hemispheres are in a pathologic condition.[40]

Conclusion

MRI has many sequence options for evaluating ischemic stroke without the need of contrast materials. Standard sequences such as T1WI, T2WI, FLAIR, DWI, ADC and SWI can be used to differentiate lesions from infarcts from other pathological conditions such as hemorrhagic stroke while also identifying the lesions location, age, and volume. Adding advanced sequences such as ASL, TOF-MRA and MRV, and MR-Spectroscopy will maximize our interpretation of the patient's condition by identifying penumbra area, cerebrovascular patency, as well as information on important brain metabolites such as NAA and Lactate to help clinicians to determine the best treatment and prognostication.

Perhaps the most important information a clinical radiologist can provide when facing an ischemic stroke case is information on the age of the ischemic lesion. When infarct is in the early hyperacute stage (0–6 hours), cytotoxic edema restricts water diffusion, leading to increased signal on DWI and a dark appearance on the ADC map. In the late hyperacute stage (6–24 hours), the breakdown of the blood-brain barrier will result in vasogenic edema, raising the FLAIR signal that will persist until gliosis develops. During the acute phase (24 hours – 1 week), careful attention to SWI is very crucial, as most hemorrhagic transformations may occur at this stage (it is important to notice that not all hemorrhages appears dark on SWI, depending on the age of the hemorrhage). In the subacute phase (1–3 weeks), T2WI, DWI, and ADC may show pseudonormalization to isointense after approximately 10 days. Finally, in the chronic phase (>3 week), encephalomalacia will appear dark on all sequences except T2WI and ADC. Furthermore, if the neurologic symptom is suspected to be in acute stage, ASL should be performed to detect any decline in CBF that may not yet be visible in DWI (ASL-DWI mismatch) to confirm presence of penumbra that requires prompt recanalization. Lastly, MR-Spectroscopy can be added to evaluate the decline of NAA as the marker of neuronal viability and increased lactate as the marker of anaerobic glycolysis to help determine the prognosis of the patients.

As advancements in MRI technology for ischemic stroke continue to evolve and become more accessible globally, it is essential to have a comprehensive understanding of the advantages and limitations associated with each imaging sequence. This knowledge is crucial for optimizing the diagnosis and management of patients with ischemic stroke. Our current review does have some limitations, including potential gaps in the literature and the need for further validation of findings across diverse populations. Furthermore, future research should focus on novel imaging sequences that explore brain metabolites, functional imaging and their roles in ischemic stroke pathophysiology, as this could significantly enhance our understanding and improve clinical outcomes.

Funding

This study was funded by Hasanuddin University, Faculty of Medicine under the grant name of "Hibah Penelitian Kolaboratif Fakultas Kedokteran Universitas Hasanuddin 2023" (Reference No. 1570/UN4.6.2/KEP/2023).

Disclosure

The authors report no conflicts of interest in this work.

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