Magnetic Resonance Imaging in Ischemic Stroke Diagnosis: A Systematic Review of Its Diagnostic Value

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Abstract- Strokes are one of the world's major causes of morbidity and mortality, accounting for 10% of all deaths. They are mostly ischemic in origin, meaning that when an artery is blocked, oxygen and nutrients are taken away from the brain, causing tissue death. The best post-stroke care depends on early diagnosis, and magnetic resonance imaging (MRI) has emerged as a key diagnostic technique for stroke, particularly acute ischemic stroke (AIS). When assessing strokes, CT is frequently utilized as the initial imaging modality. Nevertheless, there are golden hours or a window of opportunity for treatment during which brain tissue can be preserved; therefore, a treatment requires an imaging technique that can provide a detailed account of the process by identifying the penumbra and infarct core. The role of MRI in diagnosing and treating ischemic stroke, its function in detecting ischemic stroke, its advantages over other imaging modalities, and its use in treatment planning using advanced MRI technology, including Diffusion-Weighted Imaging (DWI), Perfusion-Weighted Imaging (PWI), DWI-PWI mismatch, Magnetic Resonance Angiography (MRA), and the incorporation of machine learning techniques, have all been covered in a literature search that was conducted using a variety of databases and articles published between 2010 and 2024. Even though MRI has better diagnostic accuracy, issues like cost, accessibility, and longer scan times still prevent it from being widely used. Nevertheless, MRI's capacity to distinguish between infarct core and penumbra, along with new machine learning applications, makes it a vital tool for enhancing patient outcomes in stroke care.

Keywords: Magnetic resonance imaging, Ischaemic stroke, Perfusion-weighted imaging, Diffusion-weighted imaging, Magnetic resonance angiography.

INTRODUCTION

A stroke is a medical disorder marked by an abrupt reduction in blood flow to the brain tissue, which results in a shortage of oxygen and nutrients, which damages or kills brain cells. Stroke is the most preventable cause of mortality and causes over 10% of deaths globally [1], and is been categorized as ischemic accounting for about 70%, caused by a blockage, or hemorrhagic accounting for 30%[2], resulting from a ruptured blood vessel, with the resulting neurological deficits varying based on the affected area of the brain. [3]. Stroke doesn’t have a definitive cause but it’s been associated with risk factors such as high blood pressure, diabetes mellitus, smoking which varies from region to region [4]. Ischemic Stroke being the most common type, occurs when there is a blockage of an artery supplying the brain tissue, due to a blood clot or atherosclerosis [5]. The blockage or obstruction causes disruption of oxygen and nutrient supply to the brain tissue resulting in neuronal damage or death [6]. Early diagnosis and intervention are crucial to decrease the level of damage and also to improve the prognosis[7] [5]

PATHOPHYSIOLOGY OF ISCHEMIC STROKE

Following the occlusion of a major cerebral artery, the brain can be delineated into two distinct zones. The region of brain tissue immediately beyond the occlusion experiences minimal to no blood flow, leading to rapid infarction, a condition known as the core of the infarct. In other areas of the brain, despite being still viable, there is an abnormally low blood flow, putting them at risk of progressing to infarction. This at-risk region is referred to as the Penumbra[7]. Stroke imaging diagnosis includes clinical, but imaging modalities are needed for the confirmation and the extent of the damage done. So many clinical scales have been established for stroke diagnosis such as Face Arm Speech Time (FAST), Cincin nati

Prehospital Stroke Scale (CPSS), Los Angeles Prehos pital Stroke Scale (LAPSS), and Melbourne Ambulance Stroke Scale (MASS)], and severity grading scores [such as Los Angeles Motor Scale (LAMS), Kurashiki Prehospi tal Stroke Scale (KPSS), and National Institutes of Health Stroke Scale (NIHSS)] trying to facilitate the early and rapid diagnosis of stroke for proper utilization of the stroke golden time[1], [8].

MRI is among the frontier imaging modalities that play an important role in the diagnosis of neurological disorders such as ischemic and hemorrhagic, MRI modality have proven to be more sensitive and specific than CT in diagnosing acute ischemic stroke. Approximately 80% of infarcts are detected within 24 hours[9]. It has a very high accuracy in the detection of acute ischemic stroke and is used in ruling out other neurological conditions that present clinically with similar symptoms. MRI plays a significant role in the early detection and precise diagnosis of both ischemic and hemorrhagic strokes. Its high sensitivity allows for accurately identifying acute ischemic stroke (AIS) and helps distinguish it from other conditions that might mimic stroke symptoms [2], [6]. Routine stroke imaging sequences include diffusion-weighted imaging (DWI) with apparent diffusion coefficient (ADC) maps, T2- weighted (T2W), fluid attenuation inversion recovery (FLAIR), T2 gradient echo (GRE) or susceptibility-weighted imaging (SWI), fast spin echo T2W, and T1-weighted (T1W) sequences[10]. Misdiagnosis can lead to missed opportunities for timely and proven therapies for stroke, such as tissue plasminogen activator (tPA) or endovascular treatments[11]. Multimodal neuroimaging, using either a CT or MRI approach, can identify the type, location, and severity of the lesion (ischemia or hemorrhage) [12].

Ischemic Stroke Diagnosis

Clinical assessment is firstly use in stroke, but however imaging is need to establish a definitive diagnosis to rule out stroke mimics, one of the most important components of stroke diagnosis is recognizing the infarct core and surrounding penumbra, which are critical for establishing the best treatment strategy[13]. Important variables including lesion size, thrombus presence, and brain micro bleeds can now be seen more clearly because to advancements in MRI technology [14]. Therapeutic choices, such as the application of antiplatelet medications or surgical procedures, are guided by these advancements. Several MRI modalities are used in current standards, including diffusion-weighted imaging (DWI)-perfusion-weighted imaging (PWI) mismatch for penumbra assessment, magnetic resonance angiography (MRA) for thrombus detection, and T2-weighted MRI to rule out intracerebral haemorrhage [13]. Diffusion- and perfusion-weighted MRI offers diagnostic insights that are not obtainable through neurological exams, CCT, or conventional spin-echo MRI [4], [15]. Recent developments also include the application of machine learning techniques to MRI images, which help automate stroke classification and prediction, particularly for ischemic stroke [9], [16]. Advanced imaging, such as perfusion imaging and noninvasive vascular imaging, has become increasingly important in managing acute ischemic stroke and guiding potential endovascular treatments[6], [17]. While CT is often the first imaging test used, MRI can be a valuable alternative, especially in extended time windows for selecting patients for reperfusion therapy [3]

Ischemic Stroke Treatment

Intravenous thrombolysis (IVT) and endovascular treatment (EVT) are the currently available reperfusion therapies for patients with acute ischemic stroke (AIS) which represents one of the leading causes of long-term disability and mortality worldwide. It is well-known that the target of IVT and EVT is the rescue of ischemic penumbra, the reversibly damaged brain tissue at risk for infarction, located around the irreversibly injured infarct core[18]

Infarct Core and Penumbra

The concept of the ischemic penumbra was formulated based on animal experiments showing functional impairment and electrophysiologic disturbances with decreasing flow to the brain below-defined values that are necessary for its optimal function i.e the threshold for function and the part of brain tissue that has been irreversibly damaged due to the further decreased in blood supply i.e the infarction threshold. The perfusion range between these thresholds was termed the "penumbra," and restitution of flow above the functional threshold could reverse the deficits without permanent damage[19]. In an ischemic stroke, the infarct core and ischemic penumbra are areas of the brain with different levels of damage and potential for recovery[20]. The infarct core is the area of the brain that has already suffered irreversible damage and is destined to infarct, regardless of reperfusion. It is also known as the established infarct.

Ischemic penumbra was initially studied in the laboratory using animals after middle cerebral artery occlusion (MCAO), the ischemic penumbra has been documented as a severely hypoperfused, functionally impaired, but still viable cortex that can regain its function and escape infarction if it is reperfused before a certain time has elapsed[21]. The area of the brain that's at risk of infarction can be saved if reperfusion occurs. It's located around the infarct core and contains cells that are still viable but functionally impaired. The main goal of acute stroke intervention is to prevent the penumbra from becoming an established infarct. The ability to differentiate between the infarct core and the penumbra is important for identifying patients who would benefit most from treatment. Imaging techniques like positron emission tomography, single-photon-emission computed tomography, and computed tomography perfusion scan can help with this differentiation

Stroke Golden Hours

The term "stroke golden hours" refers to the critical first 60 minutes after a stroke occurs. During this time, there is the greatest opportunity to restore blood flow and prevent brain damage. Stroke patients are more likely to survive if they receive treatment with a clot-busting drug called Tissue Plasminogen Activator within this period[22]. Administering thrombolysis with alteplase within a narrow therapeutic window is an effective treatment for acute ischemic stroke[23]. The treatment and outcomes of acute ischemic stroke depend heavily on time, prompting the implementation of time-saving measures at every stage of the treatment process[19]. While these changes have led to shorter treatment times within the hospital, it remains uncertain whether they have resulted in a higher number of patients receiving treatment within 60 minutes of symptom onset—often referred to as the Golden Hour[24].

AIM OF THE REVIEW

The study aim to review the role and efficiency of MRI in detection of ischemic stroke changes and its usefulness in treatment plans.

METHODOLOGY

A thorough review of published papers available in the literature has been conducted discussing the importance of MRI in diagnosing ischemic stroke, exploring the latest developments in MRI technology, and examining the various applications of MRI in ischemic stroke imaging. Specifically, the focus was on the identification of the infarct core, penumbra, thrombus, and the integration of machine learning techniques in MRI.

The literature reviewed papers published on role of MRI in the diagnosis of ischemic stroke, advances in MRI technology, and applications of MRI ischemic stroke imaging focusing on infarct core, penumbra and thrombus identification, machine learning techniques in MRI and so on.

A comprehensive literature search has been conducted on peer-reviewed journal articles, clinical studies, meta-analyses, and reviews published between 2010 and 2024. The following electronic databases are been used for the search: Scopus, Springer, PubMed, Google Scholar, Science Direct, Cochrane Library, IEEE Xplore, Shodhganga

Keywords used in the search will include combinations of MRI in stroke diagnosis, ischemic stroke imaging, hemorrhagic stroke detection" Thrombus detection using MRI, machine learning in MRI for stroke, perfusion-weighted imaging (PWI), diffusion-weighted imaging (DWI), magnetic resonance angiography (MRA)

Articles focusing on clinical applications of MRI, technological advancements, and therapeutic implications in stroke diagnosis will be prioritized.

INCLUSION AND EXCLUSION CRITERIA

Inclusion Criteria

Articles published in English between 2010 and 2024.

Studies focusing on the use of MRI for the diagnosis of ischemic or hemorrhagic strokes.

Research articles, clinical trials, and meta-analyses that have been published on MRI

Studies comparing MRI to other imaging techniques (e.g., CT, CCT).

Exclusion Criteria

Studies that do not focus on MRI-based stroke diagnosis.

Articles published before 2010, except landmark studies critical to the review.

Non-peer-reviewed articles

RESULTS

Relevant information from selected articles has been extracted using a standardized data extraction form. The extracted data include Study type and the research design (clinical study, review, trial), Patient demographics (age, gender, stroke type), MRI modality used (DWI, PWI, MRA), Key findings on MRI's diagnostic role in stroke, Comparisons with other imaging techniques (e.g., CT), Therapeutic implications (tPA, antiplatelet therapy, surgery), the use of machine learning techniques.

The data has been organized into thematic areas showing the roles of MRI in stroke diagnosis and its superiority over remaining imaging modalities, including MRI for ischemic stroke detection, MRI for hemorrhagic stroke diagnosis, advanced MRI imaging techniques such as PWI, DWI, and MRA, the Use of machine learning in MRI for stroke classification, and functional MRI.

Different Authors, years of publications, methodologies, and their main key findings have been reported, showing the key role of MRI in stroke imaging and the need to adopt MRI as a routine and conventional tool for initial clinical diagnosis.

AUTHOR AND YEAR OF PUBLICATION	TITLE OF THE STUDY	METHODOLOGY	MAJOR FINDINGS	LIMITATIONS OF MRI MENTIONED IN THE STUDY
Brunser et al., 2011	Accuracy of Diffusion-Weighted Imaging in the Diagnosis of Stroke in Patients With Suspected Cerebral Infarct	A prospective study wasconducted in Clínica Alemana de Santiago with a sample size of 712 patients from December 2004 to March 2011.	DWI was the best imaging technique for ischemic stroke diagnosis with a sensitivity of 90%, and specificity of 97%	Not mentioned
Palvinar et al., 2018	Role of Imaging in Acute Ischemic Stroke	The exact methodology is not mentioned, Department of Neurology, Universitas Udayana, Bahasa, Indonesia	-MRI has the highest sensitivity for ischemic stroke early diagnosis and management -Advanced imaging techniques are essential for expanding windows for early treatment such as PWI-DWI mismatch for mechanical thrombectomy up to 24hours after stroke onset.	MRI's superior diagnostic value, its routine use in emergency stroke care is limited by availability, longer scanning times, and contraindications (e.g., pacemakers, claustrophobia).
Tedayanto et al., 2022	Magnetic Resonance Imaging in Acute Ischemic Stroke	Not mentioned	-MRI can identify ischemic stroke in the first few hours of commencement. -MRI can distinguish between brain tissue at menace for infarction and brain tissue that has been irreparably damaged. - MRI can identify infarcts and brainstem infarcts, whereas CT scans have difficulty due to the surrounding bone.	MRI is not accessible in all hospitals because of its expensive nature. And also, carrying out an MRI for a stroke takes longer time before treatment is initiated.
B. Kim, et al 2014	Magnetic Resonance Imaging in Acute Ischemic Stroke Treatment	The methodology involves, the application of diffusion-weighted imaging (DWI) to identify the ischemic core, perfusion-weighted imaging (PWI) to identify the ischemic penumbra, the use PWI data calculation and PWI-DWI mismatch to identify salvageable tissue.	- Multimodal MRI can provide useful information for accurate diagnosis of stroke, evaluation of the risks and benefits of thrombolysis, and prediction of outcomes. - The lesion mismatch between PWI and DWI represents potential salvageable tissue, but the optimal threshold to distinguish penumbra from benign oligemia is still debated. - FLAIR signal changes within DWI lesions may indicate ischemic lesion age and risk of hemorrhage after thrombolysis.	

O. Bang, et tal , 2018	Multimodal MRI-Based Triage for Acute Stroke Therapy: Challenges and Progress	- Use of MRI to assess stroke pathophysiology, including ischemic core, perfusion, collaterals, clot, and blood-brain barrier status - Use of automated software for fast post-processing of MRI data, such as RAPID and FAST-COLL - Implementation of a fast MRI protocol (6 minutes) rivaling comprehensive acute stroke CT protocols - Application of machine learning techniques to improve reliability and accuracy of MRI-based triage for endovascular therapy	- MRI can provide more detailed information on stroke pathophysiology compared to CT, including the ischemic core, perfusion, collaterals, clot, and blood-brain barrier status. - MRI-based triage can increase the efficacy of endovascular thrombectomy (EVT) by excluding patients with large infarct cores, but can also increase EVT use in patients considered ineligible under current guidelines. - Advances in MRI techniques, including faster acquisition and post-processing, as well as machine learning algorithms, can facilitate the use of MRI for triage in acute stroke.	
S. Lingaraju et al 2022	Role of MRI in cerebral ischemic stroke	Hospital-based cross-sectional study conducted at teaching hospitals affiliated with J.J.M. Medical College in Davangere, India – -150 cases were studied within 2-year period - Initially planned for 50 cases but expanded to 150 cases due to good availability - All MRI scans were performed on a 1.5T Philips Achieva scanner - MRI protocol included T2-weighted, T1-weighted, FLAIR, DWI, GRE, SWI, and TOF-MRA sequences - Total imaging time was approximately 20 minutes and 53 seconds	- 77.33% of patients had ischemic infarcts, 10.33% had intracerebral hemorrhage, and the remaining had other cerebrovascular pathologies like cerebral venous thrombosis, subarachnoid hemorrhage, and tumors. - The most common vascular territory affected by ischemic stroke was the middle cerebral artery, with a higher incidence on the left side. - Diffusion-weighted imaging (DWI) was found to be a valuable addition to the standard MRI evaluation, helping in the detection of acute infarcts, differentiation of acute from chronic infarcts, and assessment of complex stroke presentations.	
Bryony L. et al 2021	Timing the Ischemic Stroke by Multiparametric Quantitative Magnetic Resonance Imaging	Diffusion-weighted imaging (DWI) to detect acute ischemic changes in the brain - Perfusion-weighted imaging (PWI) to assess cerebral perfusion and identify the ischemic penumbra - Combination of DWI and FLAIR imaging to estimate the age of the ischemic lesion and identify patients within the thrombolysis time window	- Multiparametric MRI, particularly the combination of DWI and quantitative T2 relaxation time, can be used to estimate stroke onset time and assess tissue viability. - Quantitative T2 relaxation time measurements are more accurate than visual or semi-quantitative methods for estimating stroke onset time. - Advanced techniques like MRF and ML can further improve the clinical feasibility and predictive ability of MRI-based stroke timing methods.	

CONCLUSION

Magnetic Resonance Imaging (MRI) has proven to be a superior imaging modality for the diagnosis and management of ischemic stroke, offering high sensitivity and specificity compared to other imaging techniques like CT. The reviewed literature highlights the crucial role of MRI in early stroke detection, infarct core and penumbra identification, and guiding therapeutic decisions such as thrombolysis and endovascular interventions. The integration of advanced MRI techniques, including Diffusion-Weighted Imaging (DWI), Perfusion-Weighted Imaging (PWI), and Magnetic Resonance Angiography (MRA), has enhanced stroke imaging by distinguishing salvageable brain tissue from irreversibly damaged areas. These advancements have expanded treatment windows, improving patient outcomes. Furthermore, the application of machine learning in MRI has improved diagnostic accuracy and efficiency, offering potential for automated stroke classification and triage.

Despite its advantages, MRI faces certain limitations, including high costs, limited availability in emergency settings, longer scan durations, and contraindications in some patients (e.g., those with pacemakers or claustrophobia). While rapid MRI protocols and automated image processing software have been developed to address these challenges, widespread clinical implementation remains restricted by resource constraints. Overall, the evidence supports MRI as an indispensable tool in stroke imaging, with ongoing advancements in technology and artificial intelligence further enhancing its diagnostic and therapeutic applications. Future efforts should focus on improving accessibility, reducing scan times, and integrating AI-driven techniques to optimize stroke management and patient outcomes.

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CONFLICT OF INTEREST

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as potential conflicts of interest.

REFERENCE

[1] N. T. Muhammad, "TYPICAL RADIATION DOSE VALUES FOR ADULT CHEST COMPUTED TOMOGRAPHY AT AMINU KANO TEACHING HOSPITAL," 2023.

[2] K. Nael and W. Kubal, "Magnetic Resonance Imaging of Acute Stroke," *Magnetic Resonance Imaging Clinics of North America*, vol. 24, no. 2, pp. 293–304, May 2016, doi: 10.1016/j.mric.2015.11.002.

[3] C. Vert, C. Parra-Fariñas, and À. Rovira, "MR imaging in hyperacute ischemic stroke," *European Journal of Radiology*, vol. 96, pp. 125–132, Nov. 2017, doi: 10.1016/j.ejrad.2017.06.013.

[4] F. Garaci *et al.*, "Cerebral Multishell Diffusion Imaging Parameters are Associated with Blood Biomarkers of Disease Severity in HIV Infection," *Journal of Neuroimaging*, vol. 29, no. 6, pp. 771–778, Nov. 2019, doi: 10.1111/jon.12655.

[5] W. J. Powers *et al.*, "Guidelines for the Early Management of Patients With Acute Ischemic Stroke: 2019 Update to the 2018 Guidelines for the Early Management of Acute Ischemic Stroke: A Guideline for Healthcare Professionals From the American Heart Association/American Stroke Association," *Stroke*, vol. 50, no. 12, Dec. 2019, doi: 10.1161/STR.0000000000000211.

[6] B. A. Kessler *et al.*, "Rapid-sequence MRI for evaluation of pediatric traumatic brain injury: a systematic review," *Journal of Neurosurgery: Pediatrics*, vol. 28, no. 3, pp. 278–286, Sep. 2021, doi: 10.3171/2021.2.PEDS20852.

[7] R. G. González, "Clinical MRI of acute ischemic stroke," *Magnetic Resonance Imaging*, vol. 36, no. 2, pp. 259–271, Aug. 2012, doi: 10.1002/jmri.23595.

[8] A. M. Brunser *et al.*, "Accuracy of Diffusion-Weighted Imaging in the Diagnosis of Stroke in Patients With Suspected Cerebral Infarct," *Stroke*, vol. 44, no. 4, pp. 1169–1171, Apr. 2013, doi: 10.1161/STROKEAHA.111.000527.

[9] E. H. Tedyanto, K. Tini, and N. A. K. Pramana, "Magnetic Resonance Imaging in Acute Ischemic Stroke," *Cureus*, Jul. 2022, doi: 10.7759/cureus.27224.

[10] D. A. Krieger and S. Dehkharghani, "Magnetic Resonance Imaging in Ischemic Stroke and Cerebral Venous Thrombosis," *Topics in Magnetic Resonance Imaging*, vol. 24, no. 6, pp. 331–352, Dec. 2015, doi: 10.1097/RMR.0000000000000067.

[11] P. Bhattacharya, N. Nagaraja, K. Rajamani, R. Madhavan, S. Santhakumar, and S. Chaturvedi, "Early use of MRI improves diagnostic accuracy in young adults with stroke," *Journal of the Neurological Sciences*, vol. 324, no. 1–2, pp. 62–64, Jan. 2013, doi: 10.1016/j.jns.2012.10.002.

[12] C. S. Kidwell and M. Wintermark, "The Role of CT and MRI in the Emergency Evaluation of Persons with Suspected Stroke," *Curr Neurol Neurosci Rep*, vol. 10, no. 1, pp. 21–28, Jan. 2010, doi: 10.1007/s11910-009-0075-9.

[13] R. Rastogi *et al.*, “Recent advances in magnetic resonance imaging for stroke diagnosis,” *Brain Circ*, vol. 1, no. 1, p. 26, 2015, doi: 10.4103/2394-8108.164996.

[14] S. M. Greenberg *et al.*, “Cerebral microbleeds: a guide to detection and interpretation,” *The Lancet Neurology*, vol. 8, no. 2, pp. 165–174, Feb. 2009, doi: 10.1016/S1474-4422(09)70013-4.

[15] J. Röther, “CT and MRI in the Diagnosis of Acute Stroke and Their Role in Thrombolysis,” *Thrombosis Research*, vol. 103, pp. S125–S133, Sep. 2001, doi: 10.1016/S0049-3848(01)00309-7.

[16] A. Subudhi, P. Dash, M. Mohapatra, R.-S. Tan, U. R. Acharya, and S. Sabut, “Application of Machine Learning Techniques for Characterization of Ischemic Stroke with MRI Images: A Review,” *Diagnostics*, vol. 12, no. 10, p. 2535, Oct. 2022, doi: 10.3390/diagnostics12102535.

[17] K. Himmelmann *et al.*, “Neuroimaging patterns and function in cerebral palsy—application of an MRI classification,” *Frontiers in Neurology*, vol. 11, p. 617740, 2021.

[18] E. Fainardi, G. Busto, and A. Morotti, “Automated advanced imaging in acute ischemic stroke. Certainties and uncertainties,” *European Journal of Radiology Open*, vol. 11, p. 100524, Dec. 2023, doi: 10.1016/j.ejro.2023.100524.

[19] W.-D. Heiss and O. Zaro-Weber, “Extension of therapeutic window in ischemic stroke by selective mismatch imaging,” *International Journal of Stroke*, vol. 14, no. 4, pp. 351–358, Jun. 2019, doi: 10.1177/1747493019840936.

[20] M. Paciaroni, E. Medeiros, and J. Bogousslavsky, “Desmoteplase,” *Expert Opinion on Biological Therapy*, vol. 9, no. 6, pp. 773–778, Jun. 2009, doi: 10.1517/14712590902991497.

[21] J.-C. Baron, “Perfusion Thresholds in Human Cerebral Ischemia: Historical Perspective and Therapeutic Implications,” *Cerebrovasc Dis*, vol. 11, no. Suppl. 1, pp. 2–8, 2001, doi: 10.1159/000049119.

[22] I. Health, “What is the Golden Hour in Strokes? Why is it Important?” Accessed: Dec. 09, 2024. [Online]. Available: http://integrishealth.org/resources/on-your-health/2019/may/why-is-the-golden-hour-so-important-when-it-comes-to-stroke

[23] K. Fassbender, C. Balucani, S. Walter, S. R. Levine, A. Haass, and J. Grotta, “Streamlining of prehospital stroke management: the golden hour,” *The Lancet Neurology*, vol. 12, no. 6, pp. 585–596, Jun. 2013, doi: 10.1016/S1474-4422(13)70100-5.

[24] R. Advani, H. Naess, and M. W. Kurz, “The golden hour of acute ischemic stroke,” *Scand J Trauma Resusc Emerg Med*, vol. 25, no. 1, p. 54, Dec. 2017, doi: 10.1186/s13049-017-0398-5.