The Role of Computed Tomography Imaging and Hounsfield Unit Value in the Management of Acute Stroke in the Emergency Department - A Systematic Review

Ms. Chandana Ramachandraiah [1], Dr. Nirmala Rajesh[2], Dr. Praveen Kumar John[3], Mr. Prajwal Adgur Ravikumar[4]

[1]Ms. Chandana Ramachandraiah, Research Scholar, Department of Medical Imaging Technology, Allied health Sciences, Srinivas University, Mukka, Mangalore, Karnataka, India, 574146 Email: chanduchandanar1995@gmail.com ORCID ID: https://orcid.org/0009-0008-3751-0908 Contact No. : 7353647518

[2]Dr. Nirmala Rajesh, Associate Professor, Department of Physiology, Srinivas Medical College, Srinivas University, Mukka, Mangalore, Karnataka, India, 574146, Email: nimmiraj.naidu@gmail.com ORCID ID: https://orcid.org/0009-0007-8419-359X

[3]Dr. Praveen Kumar John, Professor, Department of Radiodiagnosis and Imaging, A.J. Institute of Medical Science and Research Centre, Mangalore, Rajiv Gandhi University of Health Sciences-Bangalore, Karnataka, India – 575004. E-mail: drpraveenjohn@yahoo.com ORCID ID: https://orcid.org/0009-0006-1259-4805

[4]Mr. Prajwal Adgur Ravikumar, Assistant Professor, Department of Medical Imaging Technology, A.J. Institute of Allied Health Science, Mangalore, Rajiv Gandhi University of Health Sciences-Bangalore, Karnataka, India – 575004. E-mail: prajwalaryan017@gmail.com ORCID ID: https://orcid.org/0009-0005-6011-2295

Abstract

Stroke is one of the most common yet lethal condition, in the present day which requires proper management. There were lot of cases reported where patient suffered death because of improper diagnosis. The management of stroke refers to the assessment of severity of ischemia. Hence it plays a vital role in patients' chance of survival. The handling of the stroke starts from the emergency department which relies on modalities like Computed Tomography (CT) for quick diagnosis, decision making and treatment. CT with the ability to visualize the cross-sectional anatomy assist to figure out the gravity of the condition by measuring the degree of attenuation by X-rays. The attenuation level is then expressed using a scale called Hounsfield unit (HU) value. The HU value reflects the visual density of the tissue which supports in Interpretation and diagnosis between Ischemic and Hemorrhagic stroke. The article reviews about the usefulness of CT and HU value by Emergency Department management for the purpose of acute stroke.

Key Words

Computed Tomography, Hounsfield Unit, Acute Stroke, Emergency Department, National Institutes of Health Stroke Scale

Introduction

Acute stroke, a severe medical emergency that involves a sudden interruption of blood supply to the brain, is difficult to treat because of the high morbidity and mortality. Stroke is the second leading cause of global death and a primary source of long-term disability; projections suggest that the incidence of stroke will rise more than double in the next 30 years [1,2]. Ischemic and hemorrhagic types are the main condition types, and ischemic strokes are far more prevalent [3]. Management depends on rapid intervention; time is brain is the principle that must be invoked by rapid restoration of cerebral blood flow to prevent neurological damage [4]. Despite these advances, treatment Modalities have only recently benefited from recent advancements in clinical treatments such as mechanical thrombectomy and thrombolysis, however disparities in access to care persist, especially in low- and middle-income countries [2,5]. Studying and looking for prevention of stroke is an ongoing necessity, because the substantial health-care costs of stroke reinforce its huge impact on public health [2].

The crucial need for identification of acute stroke in the emergency department (ED) within short time to be diagnosed accurately within the ED underscores the importance of early intervention in affecting patient outcome. Treating illness as soon as possible, within the first 4.5 to 6 hours of symptom onset, is especially important because it allows effective intravenous thrombolysis and endovascular thrombectomy treatments that can save approximately 1.9 million neurons per minute of delay [6,7]. Second, implementation of such standardized assessment instruments as the National Institutes of Health Stroke Scale (NIHSS) has been promising for improving prehospital diagnosis and expediting treatment decisions [8]. Additionally, in light of the shortage of neurologists, innovative strokes care models, like emergency physician led stroke care, are needed [9]. On the whole, rapid diagnosis and treatment reduce the risk of permanent disability or death associated with acute strokes [7,10].

Noncontrast Computed Tomography (NCCT) plays an important role in the diagnosis and patient management of acute stroke in particular the distinction between hemorrhagic and ischemic stroke, which is essential for the timely thrombolysis and improved patient outcomes [11]. Relatively, the Hounsfield Unit (HU) values which measure tissue density on Computed Tomography (CT) scans through assessment of stroke severity and prognosis are important. For example, anthropomorphic virtual brain lesions of acute ischemic stroke (AIS) have specific HU values, namely, mean values of 18.90 ± 6.40 HU, that can be distinguished from old cerebral infarction (OCI) and leukoaraiosis (LA) [12]. HU values can also be used to distinguish tandem occlusions from isolated occlusions with a significant difference in thrombus attenuation of tandem vs isolated occlusions [13]. Additionally, HU metrics are associated with clinical outcome in patients treated with intravenous thrombolysis, and suggest they may serve as prognostic indicators [14]. Consequently, the integration of HU values in CT imaging of acute stroke improves diagnostic accuracy and treatment strategy in acute stroke management [15].

This systematic review aims to determine the role of CT imaging in the treatment of both contemporary and acute stroke in the emergency department. The purpose of this review is to evaluate clinical implications of CT Modalities in differential diagnosis and treatment decisions in acute ischemic stroke emphasizing between Ischemic and hemorrhagic strokes. Additionally, it will evaluate the diagnostic accuracy of these imaging techniques and how they may affect the outcome of the patient. This review synthesizes current literature in order to highlight the critical role CT imaging has on optimizing acute stroke management.

Overview of Acute Stroke

A stroke, or cerebrovascular accident (CVA), is a medical emergency that is caused when blood flow to part of the brain becomes blocked, cutting off oxygen and nutrients to the brain. In minutes the attention goes to probably one of the most important biological institutions in the world - the brain cells start to die. The two basic types, ischemic and hemorrhagic, are distinguished as stroke. About 84% of cases is ischemic stroke due to the sudden stoppage of the blood supply mainly by embolism or thrombosis leading to the insufficiency of continuous oxygen supply to the brain tissue [16,17]. Embolic strokes and thrombotic strokes, where a clot travels from another part of the body, and the cohort of clots forming in situ because of vascular stenosis or occlusion [17,18]. On the other hand, hemorrhagic stroke occurs due to the rupture of blood vessels, and as a result bleeding inflicts in the brain and there are subtypes like intracerebral hemorrhage and subarachnoid hemorrhage, which are usually due to trauma or aneurysm rupture [16, 19]. Diagnosis and management require a knowledge of these classifications, since each type requires a different therapeutic approach [20].

Acute stroke management is clinically important with the urgent need to detect and treat stroke early to prevent permanent brain damage and disability, and in the critical 'golden hour' following symptom onset. Acute ischemic stroke (AIS) is a time dependent condition which treatment with intravenous thrombolysis and/or mechanical thrombectomy has a significant impact on outcome. Earlier treatment with thrombolysis has been shown to impact probability of good and excellent outcomes 90 days post TIA: Odds ratios 1.40 for excellent and 1.38 for good in patients receiving thrombolysis within 1 hour compared to later windows of treatment [21]. Additionally, early management strategies based on stabilization hemodynamics, observations vitals, and rehabilitation schemes for preventing further complications and for faster recovery are [22,23]. Even mobile stroke unit integration has been shown to facilitate faster initiation of treatment after acute stroke, highlighting the value of rapid response in acute care of stroke [24].

Role of CT Imaging in Acute Stroke

Noncontrast computed tomography (NCCT) is essential to initial screening for hemorrhagic stroke, the efficacious way to see blood in the brain thereby facilitating rapid differentiation from ischemic strokes and administration of thrombolytic therapy [11, 25]. Specific signs on CT such as the 'insular ribbon' suggest potential infarction; early ischemic changes, including hypodensity, loss of cortical sulci, and hyperdense arteries, can be identified on CT [26]. CT imaging, however, is limited in detecting ischemic strokes within first few hours post onset when early signs may be subtle and not always present, resulting in false negatives [26,27]. As well, CT perfusion and CT angiography provide additional sensitivity for early ischemic detection, but noncontrast CT may miss important changes in acute stroke evaluation [27,28].

Comparison with MRI in acute stroke diagnosis

Whilst each technique (i.e. Computed Tomography (CT) and Magnetic Resonance Imaging (MRI) each has unique strengths and weaknesses that limit its application in clinical settings. Because of its fast acquisition time, CT is especially useful in emergency situations like cranio-cerebral trauma or acute stroke owing to the need for a timely diagnosis [29]. Moreover, CT is more widely available and less expensive than MRI, which often necessitates having it done in specialized facilities and takes longer to scan [29,30]. Unfortunately, CT has been shown to use ionizing radiation, a risk that naturally occurs in an environment but may be greater in vulnerable populations, such as pregnant women [29]. Similar to MRI, CT excels at hard tissue contrast in contrast to MRI which does particularly well in soft tissue and brain pathologies due to length of the scan and contraindications to use in patients with certain implants [29,31]. Therefore, clinical context and identified diagnostic need dictate which modality, CT or MRI, should be chosen [32].

Hounsfield Unit (HU) Values in CT Imaging

Computed tomography (CT) has a critical metric in terms of Hounsfield Unit (HU) scale which quantifies the tissue density by the linear attenuation coefficients of different tissues and can differentiate normal and pathological condition. Normally, HU values for gray and white matter are around 34.54 for gray matter and 28.25 for white matter [33]. Acute infarcts HU values are larger than 19 [34] and subacute and chronic infarcts are from 9.5 to 19 or less than 9.5, respectively [34]. HU values of hemorrhagic tissue are generally significantly higher than those of normal brain tissue [33,34], typically well above those of normal brain tissue. In acute stroke scenarios clinical conditions and HU values correlate, and serve as guidance for interventions [35,36], so it is important to be familiar with typical HU values.

Application of HU Values in Acute Stroke

In the assessment of acute stroke, HU values are of great importance since low HU values reflect infarction [12, 37] areas at risk due to low blood flow are also indicated by low HU values. It helps differentiate between hemorrhagic and ischemic strokes if one knows that hemorrhagic lesions are areas of high HU whereas ischemic strokes less commonly show lower HU [38,39]. In addition, the hypoperfusion intensity ratio (HIR) is a predictive tool of tissue viability, which differentiates the penumbra that can salvage from the core that is irreversibly damaged infarct, with lower HIR values being associated with improved clinical outcome and reduced infarct growth in animal models [12,39]. This system does lead to better decisions made in acute stroke management, including selection of mechanical thrombectomy and improvements in patient care [12,39].

Uses of HU value in Decision-Making

In ischemic stroke patients, prognosis and state of brain tissue is important information in clinical decision making for thrombolysis and thrombectomy and HU values play a key role in this. The higher HU ratios given here have been associated with better clinical outcome post intravenous thrombolysis (IVT), and lower HU differences with larger infarct volumes, suggesting that HU values are potentially prognostic to the efficacies of treatment [14]. also imaging techniques determining the probability or 'penumbra' of the brain tissue which may benefit from reperfusion are required to determine which patients might benefit from reperfusion therapy. Diffusion and perfusion weighted Magnetic Imaging Resonance (MRI) modalities provide quantitation of both the infarct core and penumbral regions, and have allowed assessment of risk and benefit of treatment [40,41]. Additionally, selection of these patients for mechanical thrombectomy is aided by use of the Alberta Stroke Program Early CT Score (ASPECTS) and penumbral image [42].

Technological Advances in CT Imaging

CT perfusion (CTP) and CT angiography (CTA) are advanced CT techniques that have tremendous value in evaluating and treating illnesses such as acute ischemic stroke, coronary artery disease, as well as planning for surgery. Critical functional data on cerebral blood flow from CTP allows infarct volumes and ischemic penumbra to be precisely delineated, which is an essential feature of tailored treatment strategies in stroke patients [15]. In coronary interventions, CTA is crucial for assessing vascular calcification, a powerful determinant of (PCI) procedural outcomes [43]. Additionally, CTA enables more precise performance of surgical procedures such as deep inferior epigastric perforator (DIEP) flap breast reconstruction, without increasing the risk of complications [44]. These advanced imaging modalities are overall useful for comprehensive evaluations, improved treatment planning, and improved patient outcomes in broad clinical applications [45,46].

Artificial intelligence (AI) tools created to automate stroke diagnosis from CT scans based on Hounsfield Unit (HU) values greatly improve stroke diagnosis accuracy. Where class imbalance is a concern, and where Random Forest classifiers are used, AI systems have shown very high accuracy rates (as high as 94.6%) in predicting stroke cases by leveraging imaging data and overcoming class imbalances using Random Over Sampling [47]. AI-based interpretation of non-contrast CT scans in resource limited settings significantly accelerated treatment of acute stroke patients from a median time to intervention of 80 minutes to 58.5 minutes [48]. Additionally, Explainable AI (XAI) integration promotes transparency for the transparency into AI models thus supporting towards increase trust on the part of healthcare providers and patients that is critical for clinical decision making [49]. Overall, AI-based scientific advances have been used to enhance diagnostic accuracy whilst determining optimal treatment strategies and thereby optimize stroke care outcomes [50].

Potential for Improving Stroke Outcomes

The addition of other biomarkers and technologies to CT imaging significantly increases the potential for improving clinical outcomes in stroke management. Integration of radiomic features from intra thrombus and peri thrombus regions in CT scans augmented prognostic accuracy post endovascular thrombectomy (AUC = 0.87) outperforming single region models [51]. Further, deep learning models coupled with CTP and clinical metadata can accurately predict outcomes with accuracy exceeding 0.77 for functional outcomes [52] Additionally, machine learning methods based on clinical and neuroimaging data have demonstrated superior prediction performance, particularly with integrated models exceeding the performance of conventional risk scoring systems [53]. Furthermore, by adding an interdisciplinary approach, diagnostic precision is improved as we enhance therapeutic interventions in a timely manner, which improves patient outcomes [54,55].

Conclusion

Computed Tomography is considered to be a trailblazer modality for the assessment of stroke by the emergency department for its Invision ability, availability and quick action. This first line imaging tools uses HU value in order to solve interpretation problems with respect to acute stroke and aid precise decision making associated with diagnosis and therapy. It's safe to say there is a always a lot of room for advancements such as Ai which can ultimately make the process of overall stroke management much easy, reliable, accurate and rapid.

References:

1. Carolina, Capirossi., Antonio, Laiso., Leonardo, Renieri., Francesco, Capasso., Nicola, Limbucci. Epidemiology, organization, diagnosis and treatment of acute ischemic stroke. European Journal of Radiology Open, (2023). doi: 10.1016/j.ejro.2023.100527.

2. Tracy, E., Madsen., Angela, M., Malek., Warren, D., Lo. Temporal Trends in Stroke Hospitalizations, Treatment Modalities, and Mortality. Neurology, (2022) 99:1023-1024. doi: 10.1212/WNL.0000000000201475.

3. Almas, S., Shamshiev., Almas, Y., Saduakas., M.A., Zhakubaev., Askar, Matkerimov., Talgat, Demeuov., Rustam, O., Makkamov., N., Yerkinbayev., A., Kozhamkul., D.M., Appazov., N., Begim., D., Davletov. Stroke: a comprehensive overview of trends, prevention, and treatment (literature review). Vestnik hirurgii Kazahstana, (2024). doi: 10.35805/bsk2024iii010.

4. Tasneem, F., Hasan., Hunaid, Hasan., Roger, E., Kelley. Overview of Acute Ischemic Stroke Evaluation and Management. Biomedicines, (2021). 9(10):1486-. doi: 10.3390/BIOMEDICINES9101486.

5. Nikolaos, Ntoulias., Alex, Brehm., Marios-Nikos, Psychogios. Current Status of and Future Developments in Acute Stroke Management. Stomatology, (2023). 12(13):4477-4477. doi: 10.3390/jcm12134477

6. Acute Stroke. (2023). 536-546. doi: 10.1002/9781119616870.ch47.

7. Ernesto, Cristiano, Lauritano., Federica, Nicoletta, Sepe., Maria, Mascolo., R, Boverio., Luigi, Ruiz. Diagnosis and Acute Treatment of Ischemic Stroke. Reviews on Recent Clinical Trials, (2022). 17 doi: 10.2174/1574887117666220617103114.

8. Streamlining Acute Stroke Care by Introducing National Institutes of Health Stroke Scale in the Emergency Medical Services: A Prospective Cohort Study. Stroke, (2022). 53(6):2050-2057. doi: 10.1161/strokeaha.121.036084

9. Karen, Greenberg., Erol, Veznedaroglu., Kenneth, M., Liebman., Zakaria, Hakma., Thomas, Kurtz., Mandy, J., Binning. Stroke thrombolysis given by emergency physicians: The time is here. American Journal of Emergency Medicine, (2023). 68:98-101. doi: 10.1016/j.ajem.2023.03.026

10. Smital, D., Patil., Rosanna, Rossi., Duaa, Jabrah., Karen, Doyle. Detection, Diagnosis and Treatment of Acute Ischemic Stroke: Current and Future Perspectives. Frontiers in medical technology, (2022). 4 doi: 10.3389/fmedt.2022.748949

11. Computed Tomography-Based Evaluation of Cerebrovascular Disease. (2022). 660-675.e3. doi: 10.1016/b978-0-323-69424-7.00047-8

12. Yun, Peng., Chunyuan, Luo., Heng, Wang., Kening, Sun., Fang-Jen, Lin., Jou-Kou, Wang., Yunjiang, Rao., Richard, E., Fan., Lirong, Gong., Xiao-Yu, Sun. Feasibility of CT attenuation values in distinguishing acute ischemic stroke, old cerebral infarction and leukoaraiosis. BMC Medical Imaging, (2024). 24(1) doi: 10.1186/s12880-024-01340-2

13. Ruben, Mühl-Benninghaus., Julia, Dressler., Alena, Haußmann., Andreas, Simgen., Wolfgang, Reith., Umut, Yilmaz. Utility of Hounsfield unit in the diagnosis of tandem occlusion in acute ischemic stroke. Neurological Sciences, (2021). 42(6):2391-2396. doi: 10.1007/S10072-020-04798-4

14. Zhengqi, Zhu., Ru, Zhang., Kaixuan, Ren., Ruochen, Cong., Xiangyang, Zhu., Li, Zhu., Tianle, Wang. The prognosis prediction significance of Hounsfield unit value for stroke patients treated by intravenous thrombolysis. BMC Medical Imaging, (2021). 21(1):62-62. doi: 10.1186/S12880-021-00592-6

15. Sreehari, Panicker., Zachary, M., Wilseck., Leanne, Y., Lin., J., J., Gemmete. CT Imaging Computed Tomography/Computed Tomography Angiography/Perfusion in Acute Ischemic Stroke and Vasospasm. Neuroimaging Clinics of North America, (2024). 34(2):175-189. doi: 10.1016/j.nic.2024.01.004

16. Jahangir, Moini., Amparo, Gutierrez., Nicholas, G., Avgeropoulos. Stroke. (2023). 153-168. doi: 10.1016/b978-0-323-95901-8.00002-x

17. Chih-Ping, Chung. Types of Strokes and Their Differential Diagnosis. Primer on Cerebrovascular Diseases, (2017). 372-376. doi: 10.1016/B978-0-12-803058-5.00077-1

18. Douglas, J., Gelb. Stroke. (2024). 123-164. doi: 10.1093/med/9780197772904.003.0004

19. Hardik, Amin., Joseph, Schindler. Classification of Stroke. (2017). 51-62. doi: 10.1007/978-3-319-39605-7_7

20. Doris, Kung., Thy, Nguyen., Ritu, Das. Ischemic Stroke and Hemorrhagic Stroke. (2019). 95-106. doi: 10.1007/978-3-030-11132-8_11

21. Fahad, S., Al-Ajlan., Ahmed, Alkhiri., Abdulfattah, Al-Amri., Bandar, Al-Ghamdi., Ahmed, A, Almaghrabi., Abdullah, Alharbi., Nayef, Alansari., Ahmed, Z., Almilibari., Muzna, Hussain., Heinrich, J., Audebert., James, C., Grotta., Ashfaq, Shuaib., Jeffrey, L., Saver., Adel, Alhazzani. Golden Hour Intravenous Thrombolysis for Acute Ischemic Stroke: A Systematic Review and Meta-Analysis. Annals of Neurology, (2024). doi: 10.1002/ana.27007

22. James, P., Ho., William, J., Powers. Contemporary Management of Acute Ischemic Stroke. Annual Review of Medicine, (2024). doi: 10.1146/annurev-med-050823-094312

23. Ricardo, Rigual., B., Fuentes., E., Díez-Tejedor. Management of acute ischemic stroke. (2023). doi: 10.1016/j.medcle.2023.06.032

24. Jason, Mackey., Jose-Miguel, Yamal., Stephanie, A., Parker., Kelly, Silnes., Suja, S., Rajan., Asha, P, Jacob., Mengqi, Wang., Noopur, Singh., William, J., Jones., Ilana, Spokoyny., Babak, B., Navi., Jeffrey, L., Saver., James, C., Grotta. Golden Hour Treatment With tPA (Tissue-Type Plasminogen Activator) in the BEST-MSU Study. Stroke, (2023). 54:415-425. doi: 10.1161/STROKEAHA.122.039821

25. C., Federau., M., Wintermark. CT, CT-Angiography, and Perfusion-CT Evaluation of Stroke. Primer on Cerebrovascular Diseases, 686-694. doi: (2017). 10.1016/B978-0-12-803058-5.00131-4

26. Nikola, D, Dimic., Radiša, Vojinović. Early CT signs of cerebral infarction: Incidence and significance. (2013). 10(1):3-6. doi: 10.5937/PONS1301003N

27. Ahmed, Deif., Mohamed, Shaker., Abeer, Abdelzaher, Ibrahim. Added value of CT perfusion and CT angiography in detection of early ischemic stroke: Comparison with noncontrast CT. The Egyptian Journal of Radiology and Nuclear medicine, (2015). 46(4):1111-1118. doi: 10.1016/J.EJRNM.2015.07.014

28. Jeremy, L, Rempel., Richard, I., Aviv. Current advances in CT imaging of stroke. Imaging in Medicine, (2010). 2(2):165-179. doi: 10.2217/IIM.10.6

29. Aikaterini, Fitsiori., Heimo, Steffen. Neuroradiology for the Ophthalmologist. Klinische Monatsblatter Fur Augenheilkunde, (2021). doi: 10.1055/A-1671-1066

30. Sheila, Rankin. CT and MRI. Surgery (oxford), (2005). 23(5):162-165. doi: 10.1383/SURG.23.5.162.65500

31. Zhou, Ziqi, (Oliver). Discussion about advantages and defects between MRI and CT. (2020). 1(1) doi: 10.25236/AJMHS.2020.010105

32. Zhong-Jie, Yang., Ming, Li., Aiju, Guo., Yong-Hui, Liang., Peng, Fang. Imaging features and clinic value of mri and ct in diagnosis of clear cell renal cell carcinoma. Food Science and Technology International, (2021). doi: 10.1590/FST.40520

33. Mishra, D. & Ghimire, Ram & Chand, R. & Thapa, Niranjan & Panta, Om. Evaluation of Hounsfield Unit in adult brain structures by CT. Journal of Institute of Medicine. (2016). 40. 10.59779/jiomnepal.724.

34. Arun, S, Govind., Suresh, Sukumar., Winniecia, Dkhar. Grading of cerebral infarction using CT-hounsfield unit to report the hounsfield unit in acute, subacute and chronic stroke. (2015).

35. Ehsan, Samei., Jocelyn, Hoye. CT-Based Quantification. (2020). 289-304. doi: 10.1007/978-3-030-26957-9_15

36. Roberto, Molteni. Prospects and challenges of rendering tissue density in Hounsfield units for cone beam computed tomography. Oral Surgery, Oral Medicine, Oral Pathology, and Oral Radiology, (2013). 116(1):105-119. doi: 10.1016/J.OOOO.2013.04.013

37. Sana, Rehman., Arsalan, Nadeem., Arbab, Burhan, Uddin, Kasi., Ali, Husnain., Summaiyya, Waseem., Sohail, Kumar., Syed, Muhammad, Owais., Nasreen, Banu., Dhairya, A., Lakhani., Hamza, Salim., Risheng, Xu., Vaibhav, Vagal., Yasmin, Aziz., Argye, E., Hillis., Victor, Urrutia., R., Llinás., Elisabeth, B., Marsh., Richard, Leigh., Hanzhang, Lu., Adam, A., Dmytriw., Adrien, Guenego., Gregory, W., Albers., Jeremy, J., Heit., Tobias, D., Faizy., Vivek, Yedavalli. Role of Hypoperfusion Intensity Ratio in Vessel Occlusions: A Review on Safety and Clinical Outcomes. American Journal of Neuroradiology, ajnr.A (2024). 8557-ajnr.A8557. doi: 10.3174/ajnr.a8557

38. Xiaohong, Qiao., Fuhao, Zheng., Manman, Wei., Zhenming, Zhao. The ratio of the maximum density values: a new method for predicting hemorrhagic transformation in acute ischemic stroke patients undergoing mechanical thrombectomy. Frontiers in Neurology, (2024). doi: 10.3389/fneur.2024.1357689

39. Zhong-Ping, Ai., Liang, Jiang., Boxiang, Zhao., Haobo, Su., Xindao, Yin., Yu-Chen, Chen. Hypoperfusion intensity ratio correlates with angiographic collaterals and infarct growth in acute stroke with thrombectomy.. Current Medical Imaging Reviews, (2023). 19(13):1561-1569. doi: 10.2174/1573405619666230123142657

40. Fabien, Scalzo., May, Nour., David, S, Liebeskind. Data science of stroke imaging and enlightenment of the penumbra. Frontiers in Neurology, (2015). 6:8-8. doi: 10.3389/FNEUR.2015.00008

41. Hyunna, Lee., Kyesam, Jung., Dong-Wha, Kang., Namkug, Kim. Fully Automated and Real-Time Volumetric Measurement of Infarct Core and Penumbra in Diffusion- and Perfusion-Weighted MRI of Patients with Hyper-Acute Stroke.. Journal of Digital Imaging, (2020). 33(1):262-272. doi: 10.1007/S10278-019-00222-2

42. Gabriel, Broocks., Helge, Kniep., Matthias, Bechstein., Uta, Hanning., André, Kemmling., Jens, Fiehler., Lukas, Meyer. O09/90 Thrombectomy in ischemic stroke patients with large core but minor or absent ischemic changes on non-enhanced computed tomography. Abstracts, (2023). doi: 10.1136/jnis-2023-esmint.9

43. Atomu, Tajima., F., Bouisset., H., Ohashi., Koshiro, Sakai., Takuya, Mizukami., Maurizio, Lodi, Rizzini., Diego, Gallo., Claudio, Chiastra., Umberto, Morbiducci., Ziad, A., Ali., James, C., Spratt., Hirohiko, Ando., Tetsuya, Amano., Pieter, Kitslaar., Adriaan, Wilgenhof., Jeroen, Sonck., Bernard, De, Bruyne., Carlos, Collet. Advanced CT Imaging for the Assessment of Calcific Coronary Artery Disease and PCI Planning. (2024). doi: 10.1016/j.jscai.2024.101299

44. Shani, George. Advanced imaging techniques in deep inferior epigastric perforator (DIEP) flap breast reconstruction: The role of CT angiography. Cancer research, statistics and treatment, (2023). 6(1):152-153. doi: 10.4103/crst.crst_59_23

45. Mamatha, Bhat. Ct angiography. (2024). doi: 10.52458/9788196919528.2024.eb.ch-13

46. Jacek, Kwiecinski., Anna, Oleksiak., Mariusz, Kruk., Antoni, Zysk., Artur, Debski., Paul, Knaapen., Stefan, P., Schumacher., Umberto, Barbero., Adam, Witkowski., Cezary, Kępka., Maksymilian, P., Opolski. Computed tomography perfusion and angiography in patients with chronic total occlusion undergoing percutaneous coronary intervention.. Atherosclerosis, (2023). doi: 10.1016/j.atherosclerosis.2023.06.080

47. Nazmin, Islam., Hafsa, Binte, Kibria. Enhancing Stroke Prediction through Interpretable AI: Distinguishing Stroke Cases from Non-Stroke Cases. (2023). 1-6. doi: 10.1109/eict61409.2023.10427860

48. Justy, Antony, Chiramal., Jacob, Johnson., Jemin, Webster., Devalina, Nag., Dennis, Robert., Tamaghna, Ghosh., Satish, Golla., Shubham, Pawar., Pranav, Krishnan., Paul, K., Drain., Stephen, J., Mooney. Artificial Intelligence-based automated CT brain interpretation to accelerate treatment for acute stroke in rural India: An interrupted time series study. PLOS global public health, (2024). 4(7):e0003351-e0003351. doi: 10.1371/journal.pgph.0003351

49. Daraje, Kaba, Gurmessa., Worku, Jimma. A comprehensive evaluation of explainable Artificial Intelligence techniques in stroke diagnosis: A systematic review. Cogent engineering (2023)., doi: 10.1080/23311916.2023.2273088

50. Muhammad, Subhan., Shaji, Faisal., Muhammad, Usman, Khan., Ernette, Espiegle., Muhammad, Waqas., Ruqiya, Bibi., Muhammad, Farooq, Haider., Ganesh, Pendli., Salman, Kazmi., Iqra, Yaseen, Khan. Review on AI-Driven Innovations in Stroke Care: Enhancing Diagnostic Accuracy, Treatment Efficacy, and Rehabilitation Outcomes. Journal of Advances in Medicine and Medical Research, (2024). 36(9):309-326. doi: 10.9734/jammr/2024/v36i95578

51. Minda, Li., Jingxuan, Jiang., Hongmei, Gu., Jingli, Wang., Chunhong, Hu. CT-based Intra-thrombus and Peri-thrombus Radiomics for Prediction of Prognosis After Endovascular Thrombectomy: A Retrospective Study Across Two Centers.. (2024). doi: 10.3174/ajnr.a8522

52. Kimberly, Amador., Noah, Pinel., Anthony, Winder., Jens, Fiehler., Matthias, Wilms., Nils, D., Forkert. A cross-attention-based deep learning approach for predicting functional stroke outcomes using 4D CTP imaging and clinical metadata. Medical Image Analysis, (2024). 99:103381-103381. doi: 10.1016/j.media.2024.103381

53. Hongju, Jo., Changi, Kim., Dowan, Gwon., Jaeho, Lee., Joonwon, Lee., Kang, Min, Park., Seon, Hye, Park. Combining clinical and imaging data for predicting functional outcomes after acute ischemic stroke: an automated machine learning approach. Dental science reports, (2023). 13 doi: 10.1038/s41598-023-44201-8

54. Sana, Rehman., Arsalan, Nadeem., Umar, Akram., Abeer, Sarwar., Ammara, Quraishi., Hina, Siddiqui., Muhammad, Abdullah, Javed, Malik., Mehreen, Nabi., Ihtisham, Ul, Haq., Andrew, Cho., Ishan, Mazumdar., Minsoo, Kim., Kevin, Chen., Sadra, Sepehri., Richard, Wang., Aneri, B., Balar., Dhairya, A., Lakhani., Vivek, S., Yedavalli. Molecular Mechanisms of Ischemic Stroke: A Review Integrating Clinical Imaging and Therapeutic Perspectives. Biomedicines, (2024). doi: 10.3390/biomedicines12040812

55. Johanna, M., Ospel., Leon, A., Rinkel., Aravind, Ganesh., Andrew, M., Demchuk., Manraj, K., S., Heran., Eric, Sauvageau., Manish, Joshi., Diogo, C, Haussen., Mahesh, Jayaraman., Shelagh, B., Coutts., Amy, Y.X., Yu., Volker, Puetz., Dana, Iancu., Kyungmi, Oh., Jason, W, Tarpley., Staffan, Holmin., Michael, Kelly., Michael, Tymianski., Michael, D., Hill., Mayank, Goyal. How Do Quantitative Tissue Imaging Outcomes in Acute Ischemic Stroke Relate to Clinical Outcomes. Journal of stroke, (2024). 26(2):252-259. doi: 10.5853/jos.2023.02180