Published September 1, 2011

Emergency Department Imaging in the Evaluation of Stroke Syndromes
A Practical Guide for the Emergency Physician

Michael L. Epter, DO

Associate Professor & Program Director

University of Nevada Emergency Medicine Residency

Education Chair - AAEM

Medical Director, Clark County Las Vegas Unified Paramedic Program

Stroke continues to be a leading cause of morbidity and disability with an annual incidence in the United States of over 795,000 cases.[1] As advances in imaging continue to evolve and the diagnostic options increase, the emergency physician faces the growing challenge of tailoring imaging to optimize therapeutic options within the constraints of time sensitive guidelines. The objective of this article is to (1) appraise the value of non-contrast head CT in the diagnostic workup of stroke syndromes, (2) differentiate amongst other neuroimaging techniques that are beginning to be more frequently utilized in the evaluation of stroke, and (3) formulate a diagnostic strategy for the practicing emergency physician to be used in this select patient population.

Stroke syndromes have historically been classified on the basis of their neuroanatomic distribution (e.g. anterior or posterior circulation). From a clinical as well as prognostic standpoint, stroke syndromes can be divided into lacunar and cortical strokes since this distinction has both therapeutic and disposition implications. Lacunar infarcts are caused by occlusion of arterioles that supply deeper structures within the brain (white matter, thalamus, basal ganglia) and brain stem and represent approximately 20-25% of all ischemic strokes.[2] Although most are clinically silent, five lacunar syndromes have been delineated - pure motor (most common), pure sensory, sensori-motor (rare), clumsy hand dysarthria, and ataxic hemiparesis.[3] Lacunar infarcts have a better

prognosis than cortical infarcts. Cortical infarcts involve occlusion of major intracranial vessels (e.g. carotid artery/vertebrobasilar artery) and their branches. As a result, larger areas of the brain are affected with resultant deficits more pronounced (e.g. aphasia syndromes - language expression, comprehension; visual loss, change in mental status, weakness, dysphagia, neglect, etc.) and poorer prognostic outcome.[3]

The diagnostic workup of stroke syndromes begins with evaluation of the cerebral parenchyma. The three goals in evaluation are to exclude intracranial hemorrhage (ICH), (2) exclude conditions that mimic cerebral ischemia, and (3) detect ischemic tissue - in order to select those patients eligible for thrombolytic therapy within the appropriate time window (4.5 hours in selected patients [4, 5]) and minimize potential morbidity.[1, 6, 7] Whether CT or MR is utilized in the initial diagnostic workup of suspected stroke patients, both will evaluate the cerebral parenchyma8 and strict adherence to performance of one of these tests within the recommended guideline of door to brain imaging within 25 minutes and door to interpretation time of 45 minutes should be the main targets.[2, 9] Non-contrast Head CT (NCCT)

The most commonly utilized means to evaluate the cerebral parenchyma for stroke syndromes is NCCT scan [6,9] based on its availability, cost, and high sensitivity in the exclusion of ICH.[7] Given its widespread and practical use within ED's, and the importance for the emergency physician to accurately interpret NCCT in suspected stroke syndromes, a brief review is presented with an emphasis on neuroanatomy, arterial distribution, and areas of focus for identification of early ischemic changes on NCCT (discussed later):

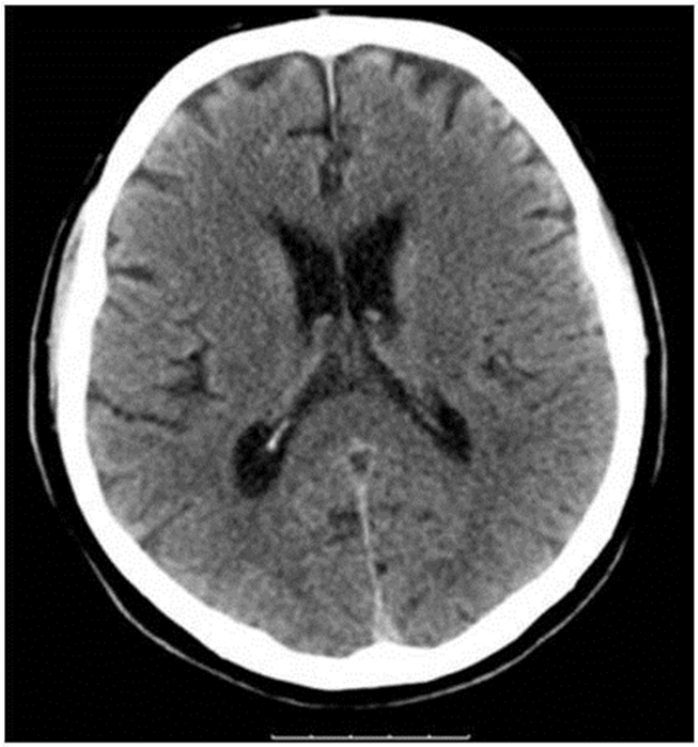


Figure 1: Normal NCCT

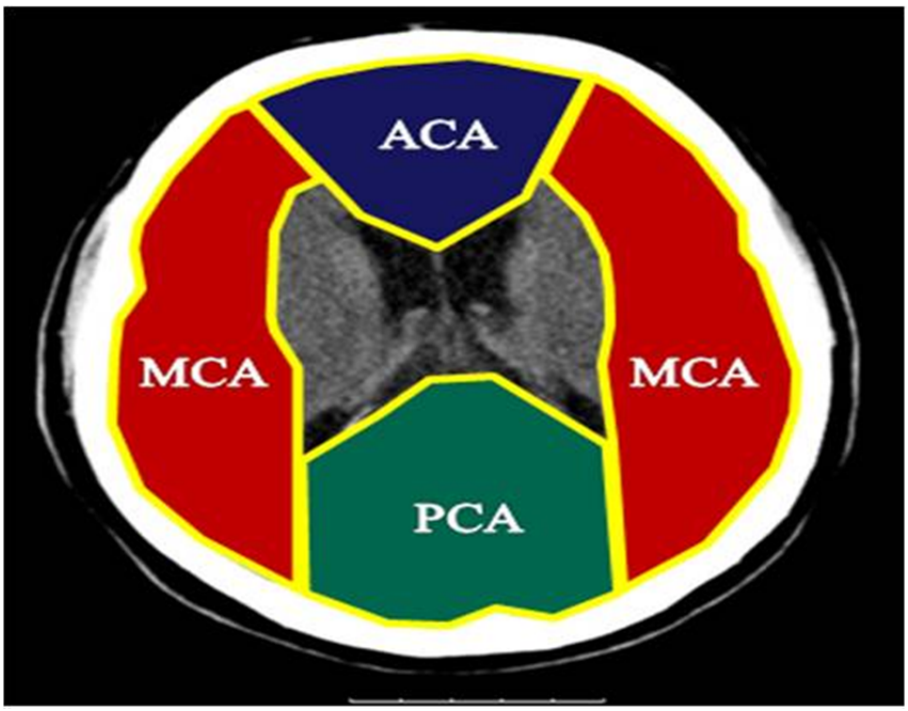


Figure 2: Cerebral Arterial Distribution

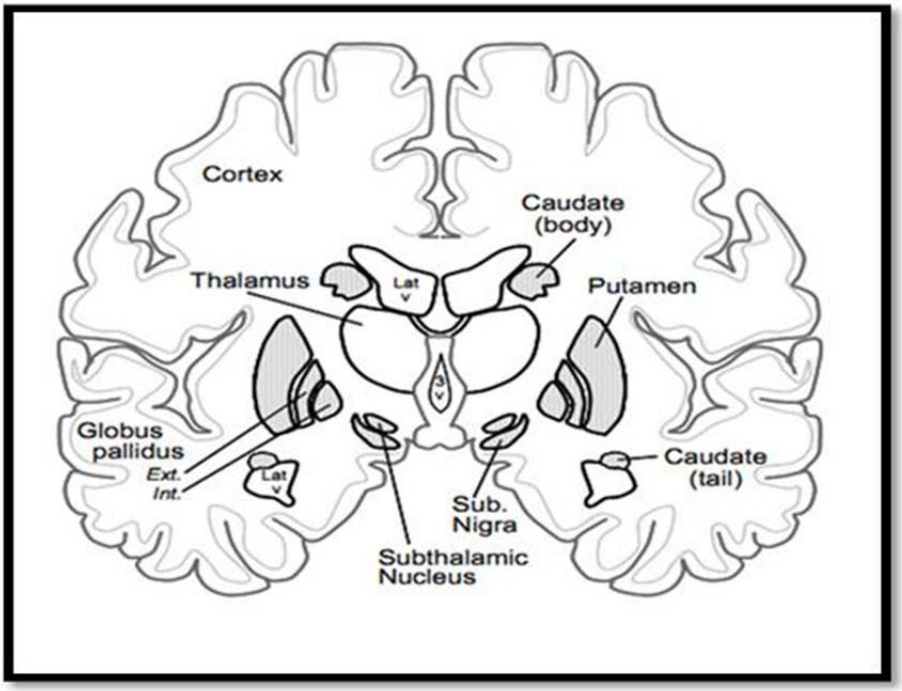


Figure 3

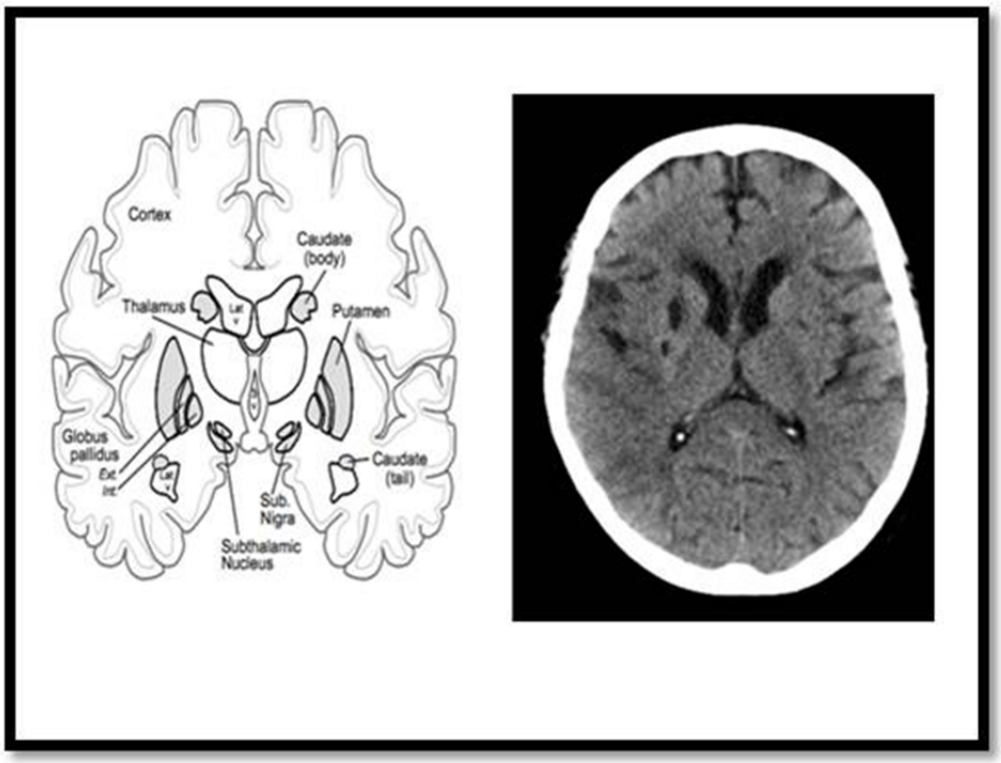


Figure 4: Comparison of coronal images.

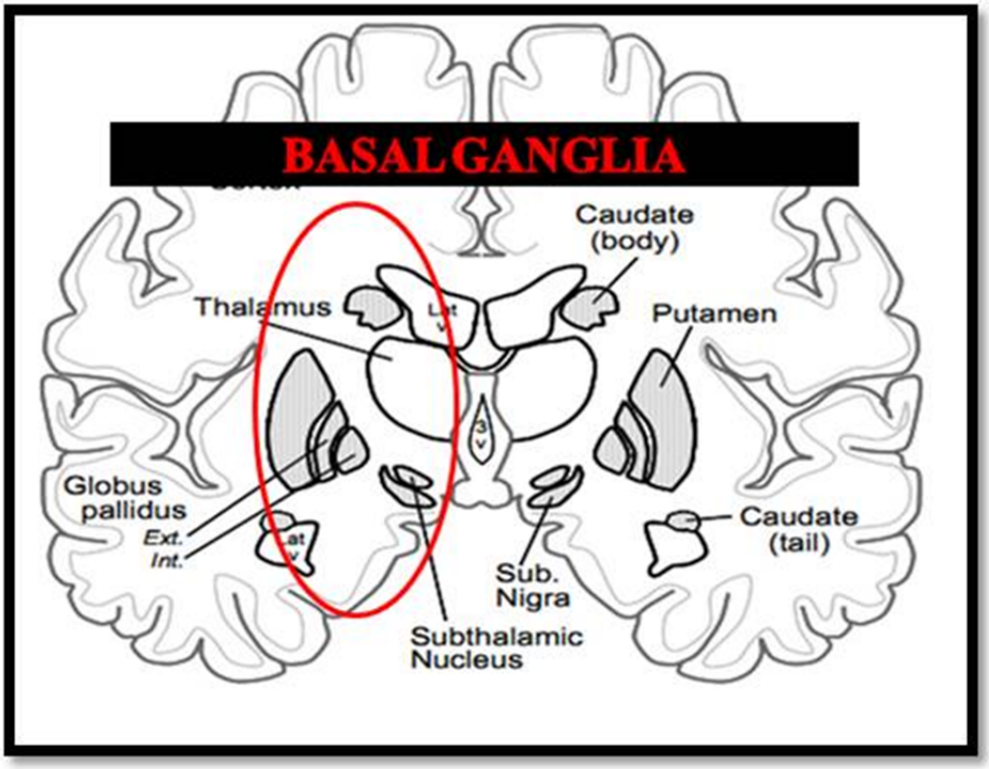


Figure 5: Basal ganglia - composed of the caudate, putamen, globus pallidus, and subthalamic nucleus.

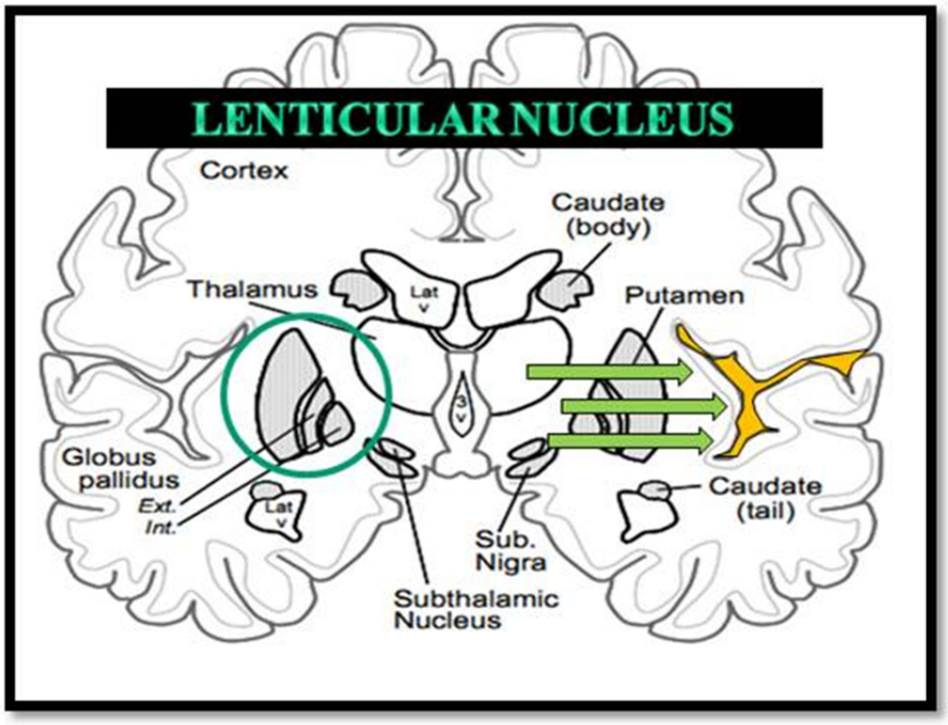


Figure 6: Lenticular Nucleus - composed of the putamen and globus pallidus (medial to putamen). Due to their lens shape, they are referred to as the lenticular nucleus. On NCCT, the putamen and globus pallidus appear as one structure (radiologically indistinguishable). The insular ribbon (green arrows) and sylvian fissure (yellow highlight).

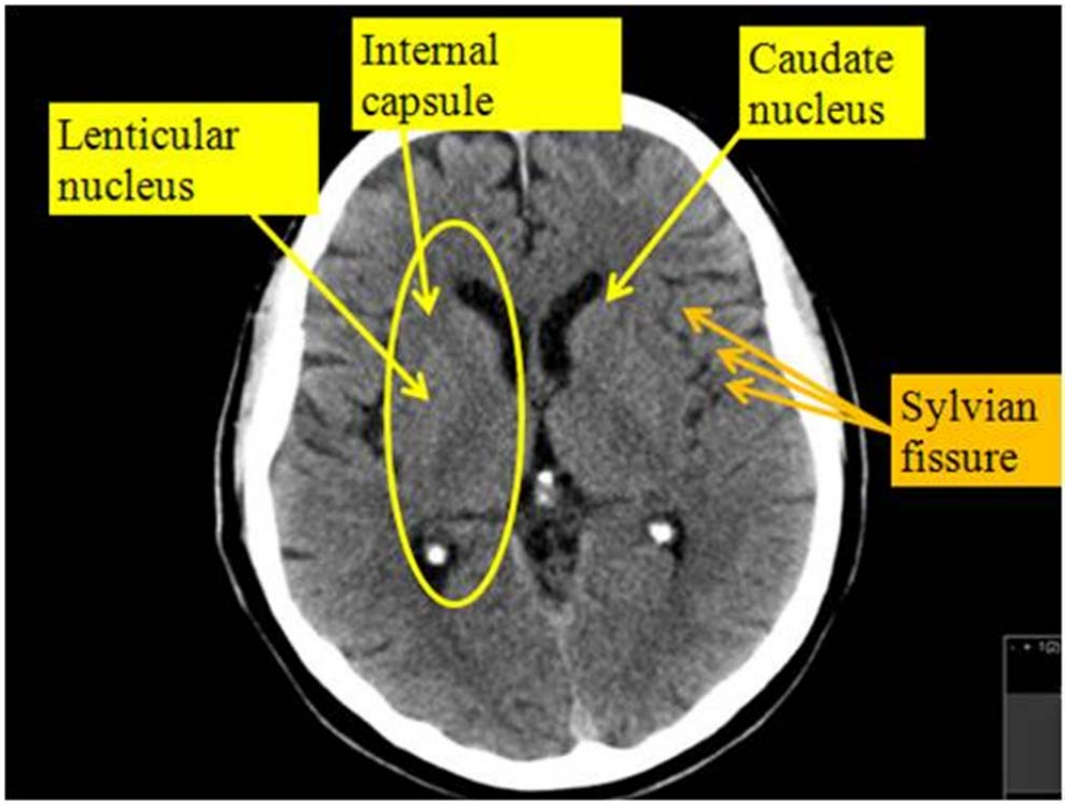


Figure 7: NCCT demonstration of basal ganglia (oval) with internal capsule, lenticular nucleus, caudate and sylvian fissure (orange arrows).

A useful mnemonic to use during initial NCCT evaluation for those syndromes that may mimic stroke (and are exclusion to the use of thrombolytic therapy) is "HATS."

H - Hemorrhage

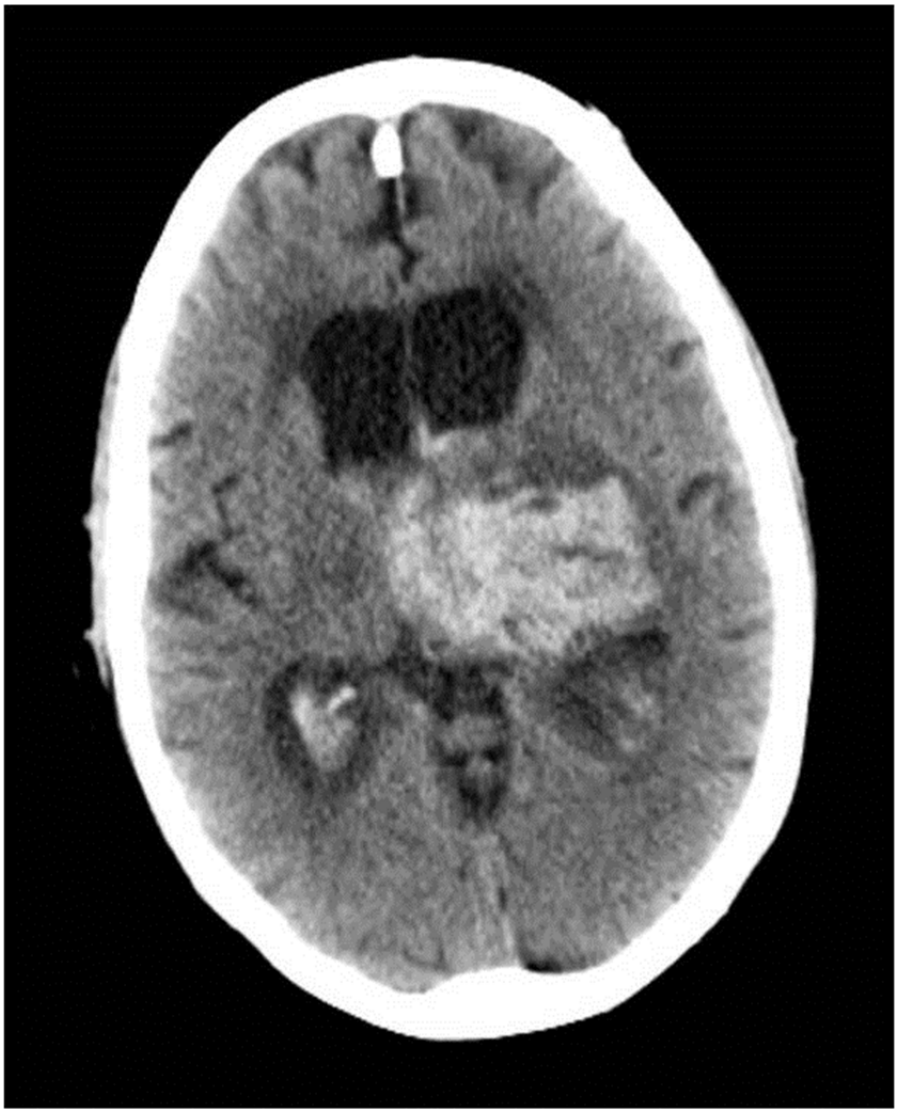


Figure 8: Large IPH of the left thalamus with intraventricular extension

Aneurysm/AVM

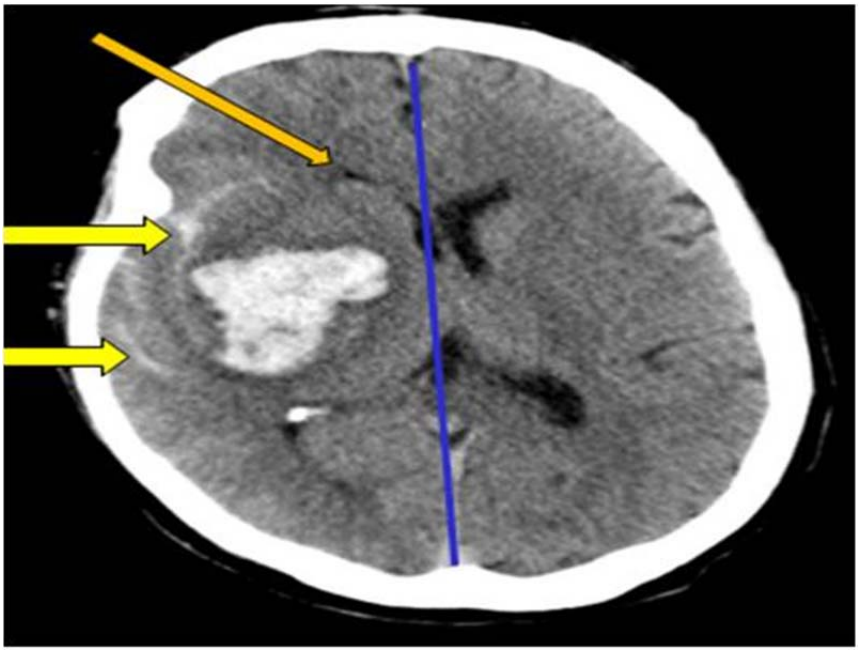


Figure 9: Large right basal ganglia parenchymal hemorrhage with associated edema and subarachnoid hemorrhage (yellow arrows); effacement right lateral ventricle (orange arrow); right to left midline shift (solid blue line). Underlying pathology found to be due in part to AVM.

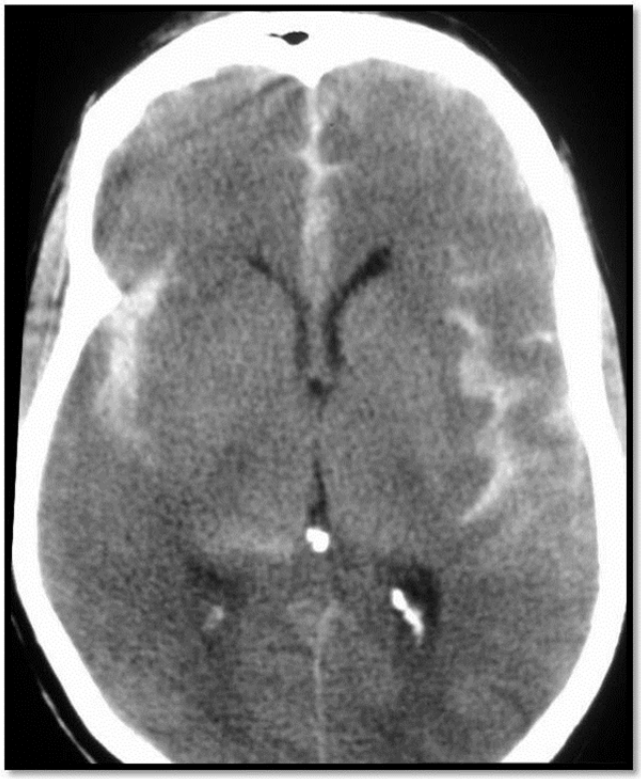


Figure 10: Subarachnoid hemorrhage - blood within the sylvian fissures and the interhemispheric fissure.

Tumor

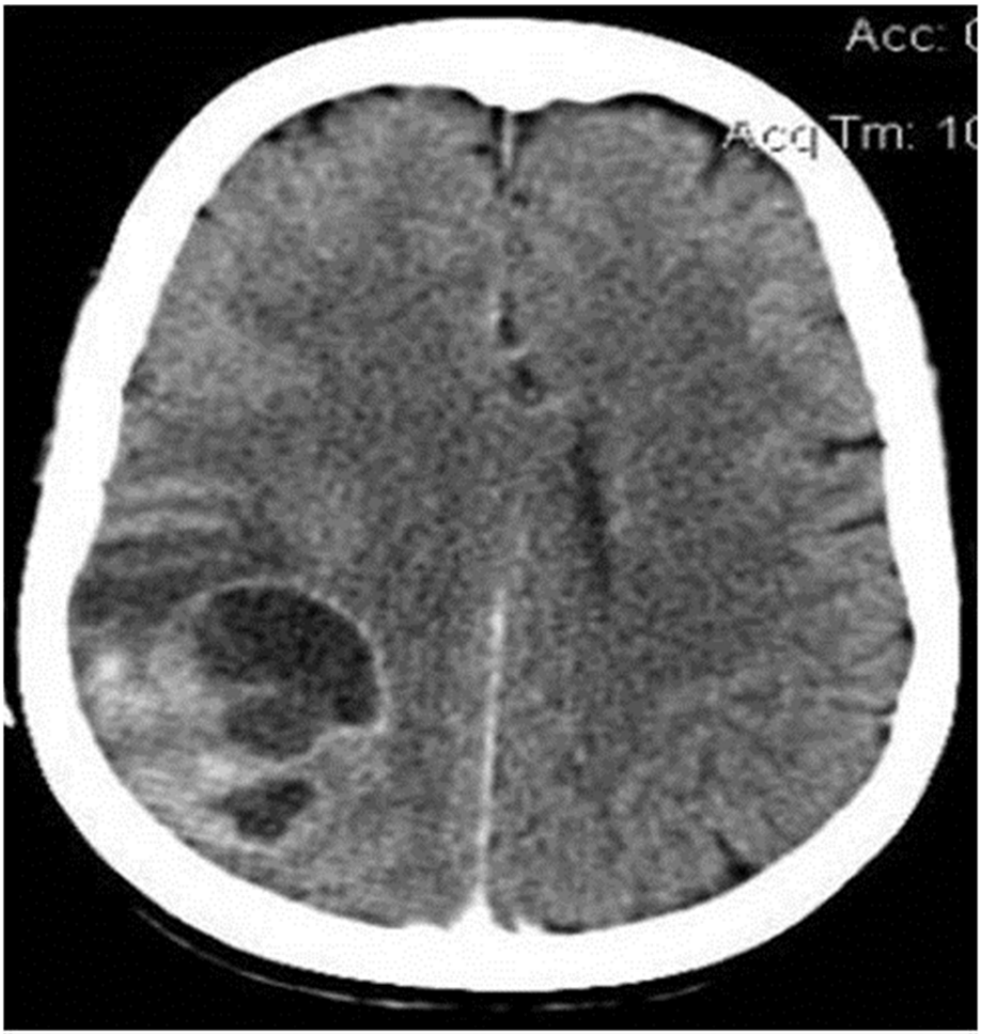


Figure 11: Tumor

Space occupying lesion

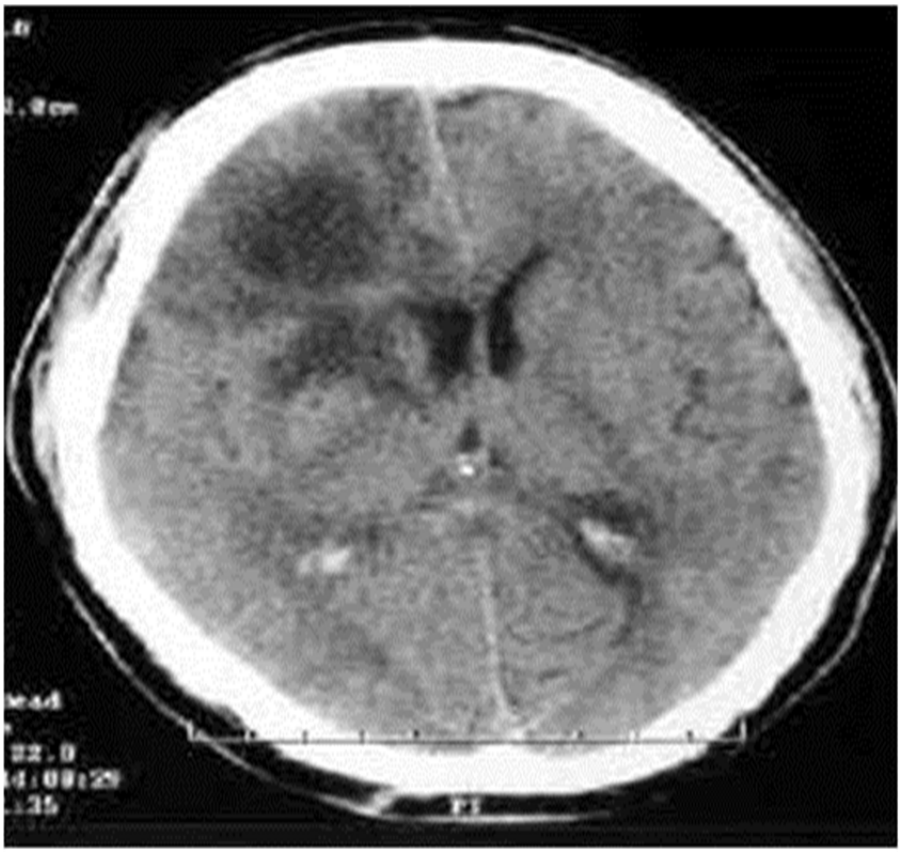


Figure 12: Space occupying lesion

Early Ischemic Changes (EIC) on NCCT

Eight findings on NCCT suggest EIC-5 were defined in ECASS (European Cooperative Acute Stroke Study).[10] Due to the fact that those patients with early swelling and large infarcts had increased risk of hemorrhage and increased morbidity and/or mortality after administration of t-PA, these signs require adequate recognition. Nearly 75% of patients will have findings consistent with EIC on NCCT within 3 hours of symptom onset.[11] EIC have prognostic value [12, 13] but aside from hypoattenuation of > ⅓ MCA territory, do not preclude the use of t-PA within three hours of stroke onset. [4, 10, 14, 15] While the ability to detect these findings is variable with poor inter-rater and intra-rater reliability,[16, 17] formal training in neuroradiology is not required.[4] In order to enhance detection of EIC on NCCT, the Alberta Stroke Program Early CT Score (ASPECTS) was developed in 2001. This

semiquantitative scoring system subdivides the MCA territory into 10 regions and scores a point for each region that does not reveal ischemic change. For those regions that show ischemic change, zero is assigned. ASPECTS scores ≤7 correlate with poor outcome.[15] While the ASPECTS scoring system has been shown to increase inter-rater reliability for EIC up to 71-89%[11], the practical application of this system within the ED is limited.

Another means to increase intra and inter-rater reliability is the ABC/2 method. Using geometric models to determine volumes of infarct and perfusion mismatch, infarcted tissue (lesions) is measured in 3 multiplanar, perpendicular axes.[18] Utilizing the axial CT slice (Figure 13) with the largest region of involvement,"A" (length of infarct) and "B" (width of infarct) are measured. "C" is the number of axial slices the infarcted area appears on multiplied by slice thickness. A value is obtained through the following formula: (AxBxC/2). Values between 70 and 100cm3 correlate with an infarct size of approximately ⅓ MCA territory and a score >100cm^3 is used to exclude patients from stroke trials and thus precludes the use of t-PA.[1, 8, 18] The evaluation of the ABC/2 method has yet to be studied in the emergency department but has shown high intrarater and inter-rater reliability (71-99%) when tested amongst radiologists.[18]

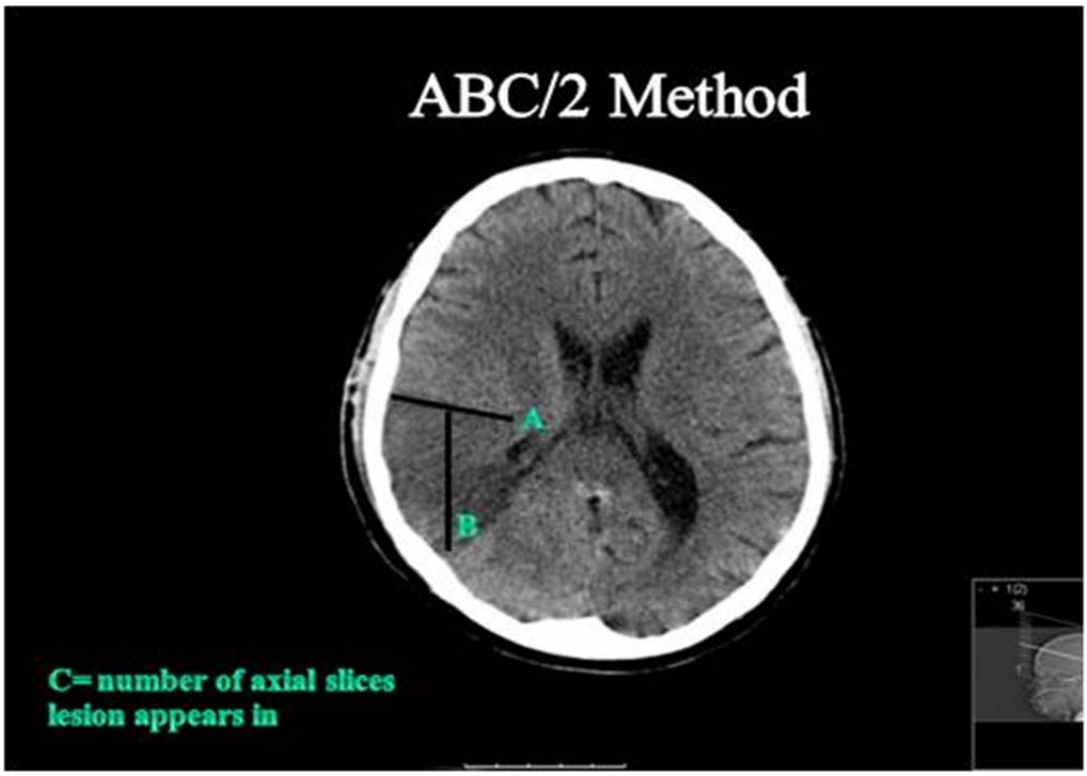


Figure 13: ABC/2 method.

For ease of recall of EIC, the mnemonic "**HOLES**" can be utilized to identify these findings.

H-Hyperattenuation of Vessel

Hyperattenuation of vessel is noted as an increased density on NCCT scan (Figures 13&14). This finding may represent a thrombus and can be found in any cerebral vessel - although most commonly associated with the middle cerebral artery (hyperdense MCA sign). The hyperdense MCA sign (Figure 13) is noted to be present in ⅓-½ of all cases of angiographically proven thrombosis - its absence on NCCT does not however, exclude thrombosis. False positives can be seen in patients who are dehydrated or those with partial volume averaging with the adjacent calvarium. The hyperdense MCA sign is a poor prognostic indicator when present [9, 19] with a 32% positive predictive value for fatal outcome.[20] Derex et al. noted that patients with a hyperdense MCA sign also had a higher risk of hemorrhage following thrombolysis. [21] Despite the potential morbidity, this sign is not a radiologic contraindication to thrombolysis and t-PA has been shown to be beneficial in these patients.[19]

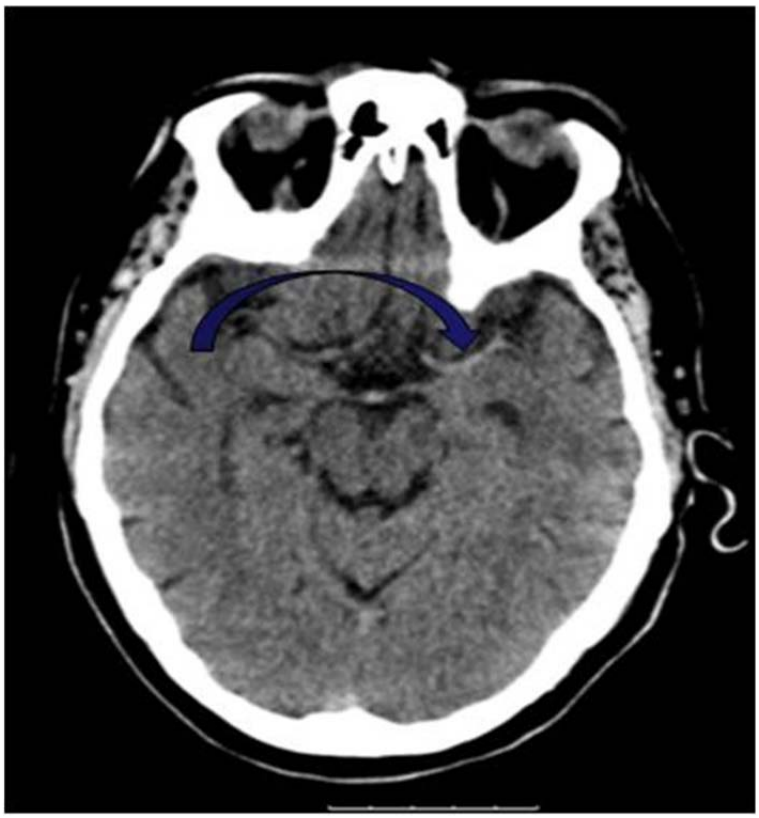


Figure 14: Dense artery sign (blue arrow)

When the thrombus is seen in a small branch of the MCA, this is called the "dot sign" (Figure 15). Identification of the dot sign begins with identification of the sylvian fissure (Figure 7). The MCA "dot sign" (Figure 15) has been shown to have a high specificity for acute thrombus in the terminal branches (M2/M3) of the MCA.[22]

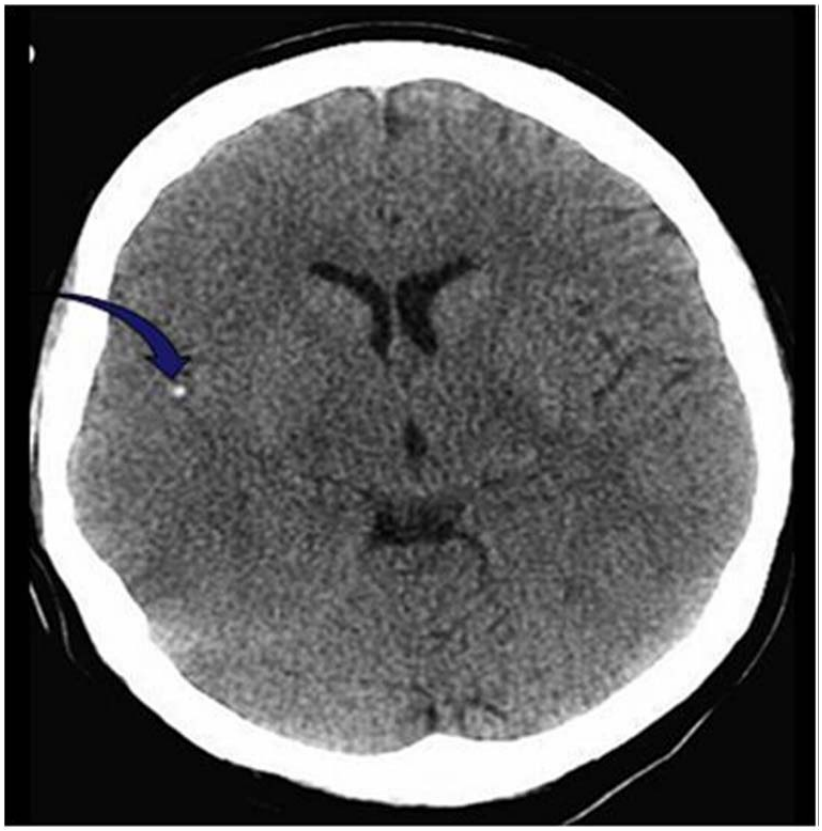


Figure 15: Dot sign (blue arrow)

H-Hypoattenuation of the basal ganglia

A gradient of hypoperfusion following occlusion of cerebral vessel(s) leads to hypoattenuation of the basal ganglia and loss of distinction amongst the nuclei (e.g. caudate nucleus, lentiform nucleus)[1] (Figure 16).

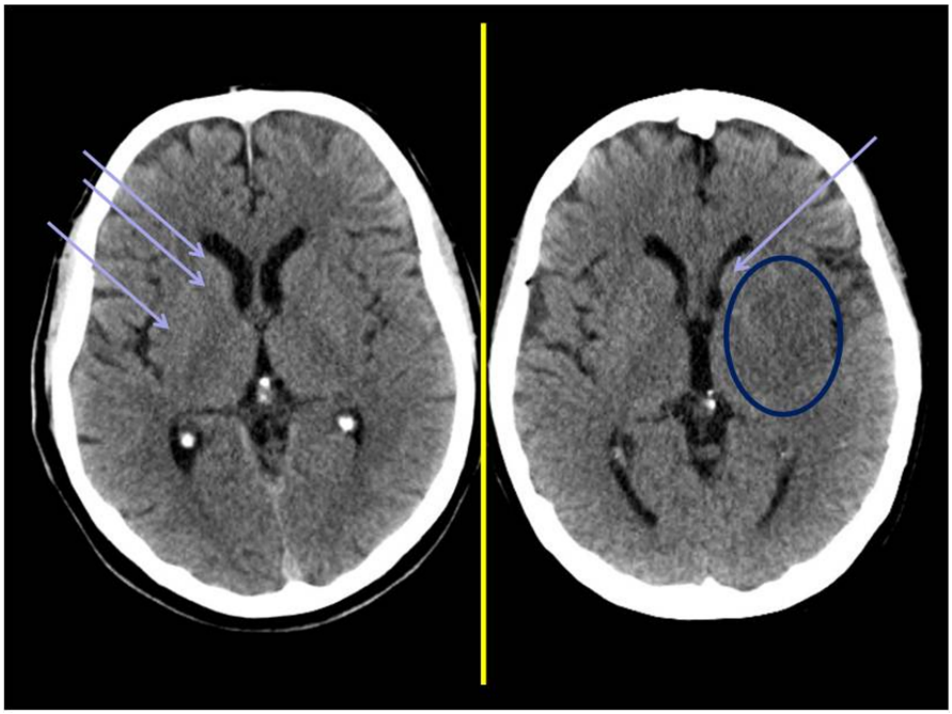


Figure 16: Hypoattenuation of basal ganglia. NCCT on left shows clear distinction of structures of basal ganglia (light blue arrows) while the NCCT on right reveals hypoattenuation of basal ganglia - especially in the area of lentiform nucleus (blue oval).

H-Hypoattenuation of > ⅓ MCA territory

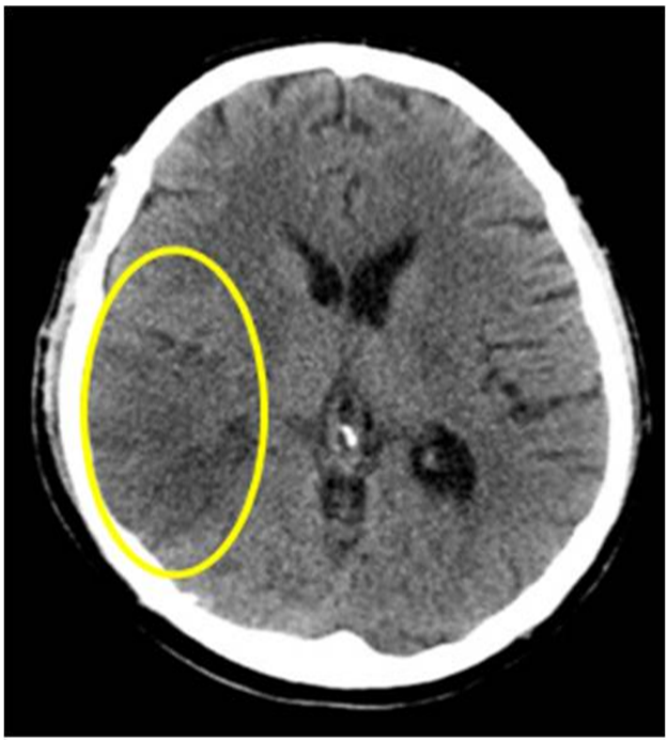


Figure 17: Hypoattenuation of >⅓ right MCA territory (oval).

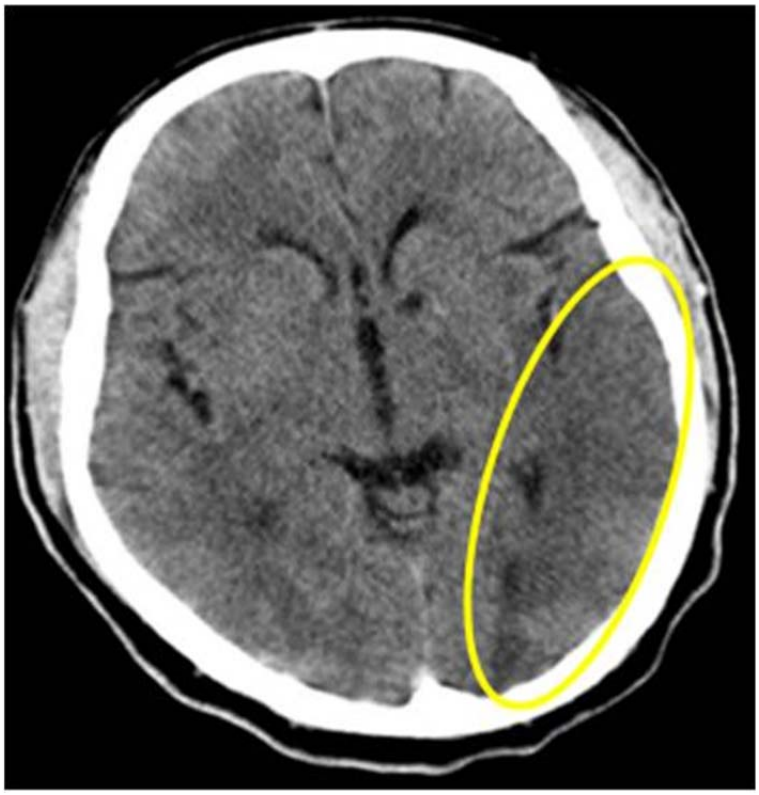


Figure 18: Hypoattenuation of >⅓ left MCA territory (oval).

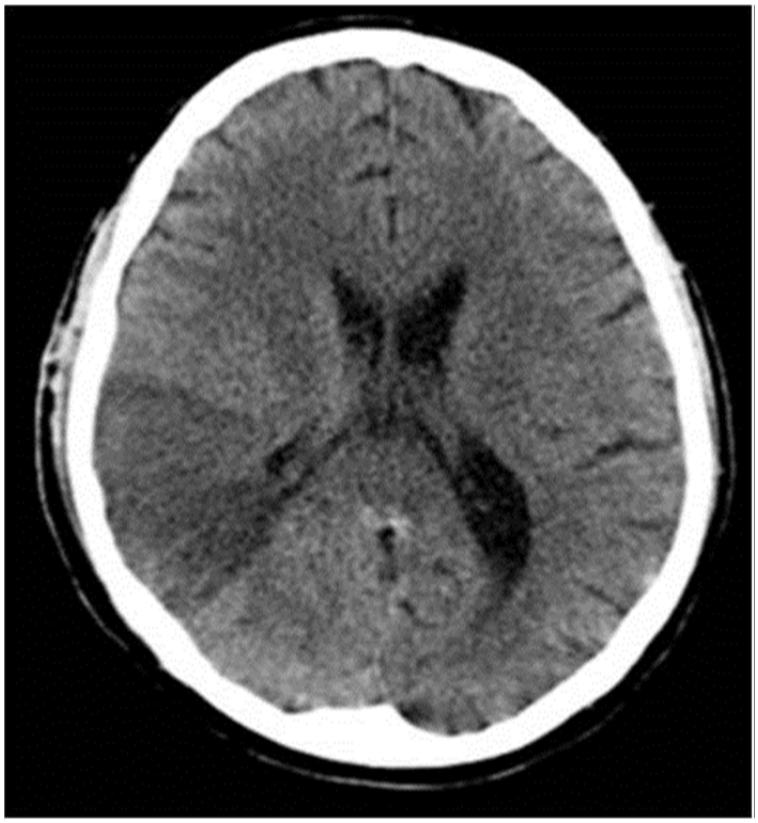


Figure 19: Hypoattenuation of >⅓ right MCA territory (oval).

Hypoattenuation of >⅓ MCA territory is the only other radiologic contraindication besides intracranial hemorrhage to preclude the use of t-PA.[2, 4, 23] The risk of hemorrhagic transformation based on the extent of hypoattenuation is well documented within the literature [6, 24] and was confirmed in the European-Australasian Acute Stroke Scale (ECASS II).[25] von Kummer et al. noted an 85% positive predictive value for fatal outcome with administration of t-PA to this patient population and NCCT finding of multilobar attenuation changes.[26]

O-Obscuration of the sylvian fissue

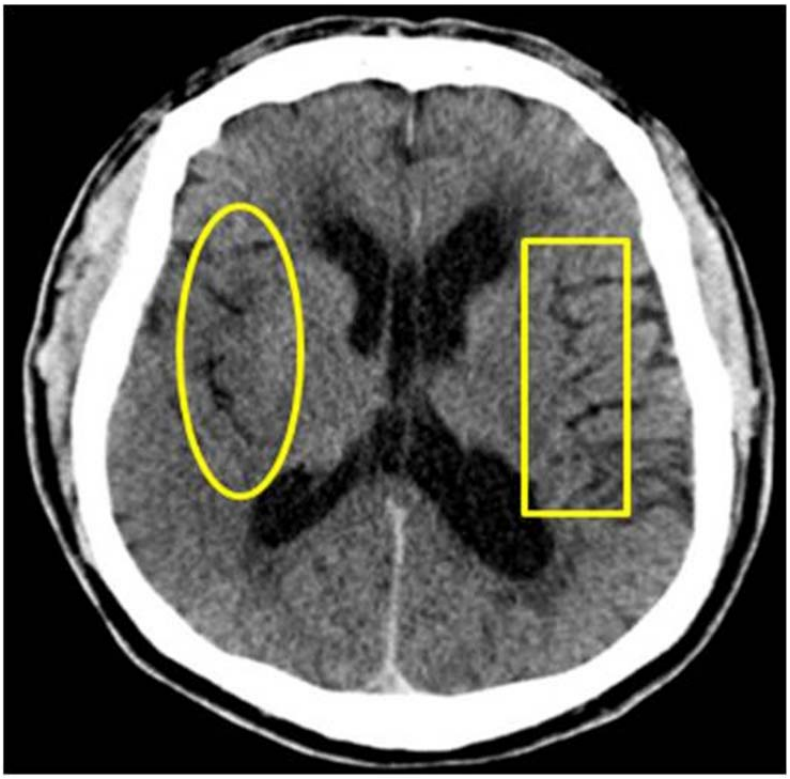


Figure 20: Obscuration of the sylvian fissure (oval). Note the comparison between the normal sylvian fissure on the patient's left (rectangle).

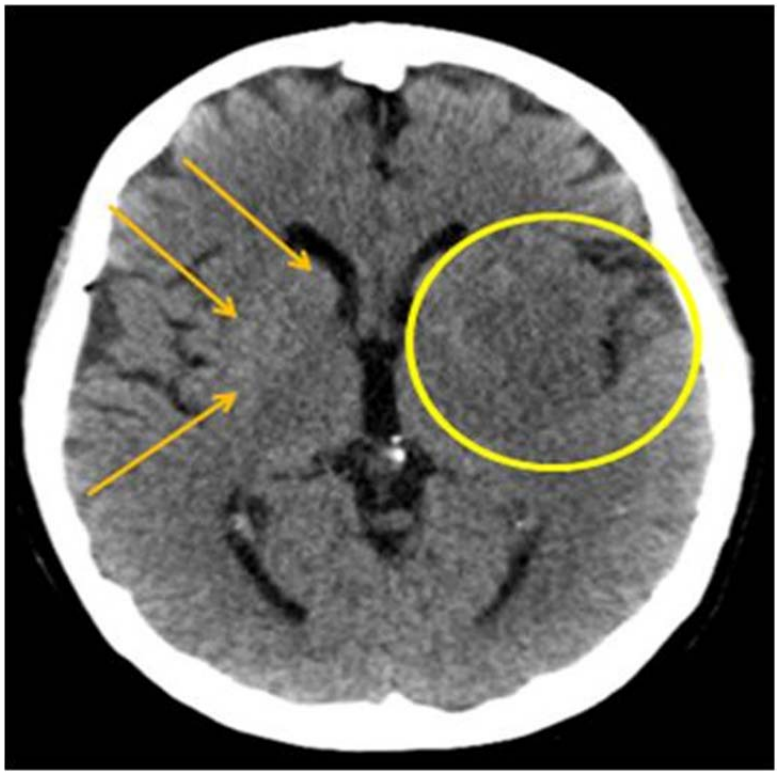


Figure 21: Obscuration of the lenticular nucleus (oval). Note the preservation of the gray-white matter on the patient's right (arrows) as well as the normal sylvian fissure.

L-Loss of gray-white differentiation

Normally, NCCT differentiates gray-white matter as a result of changes within water content between the tissues. Following an ischemic insult to the brain, there is a homogenization of water within the tissue which results in a loss of gray-white differentiation within the basal ganglia as well as cortical and insular ribbons. This is represented in Figure 22.

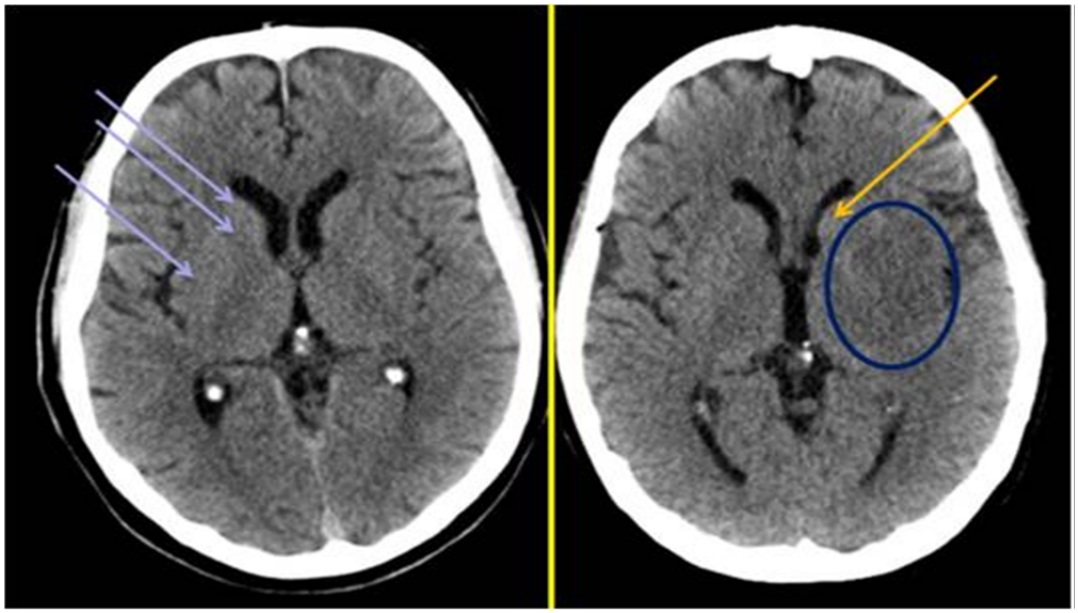


Figure 22: Note the loss of gray-white differentiation in the patient on the right (blue oval). The orange arrow represents the caudate nucleus. The NCCT image on the left represents a normal NCCT scan - note the preservation of the structures (gray-white differentiation) of the basal ganglia as well as internal capsule.

L-Loss of insular ribbon

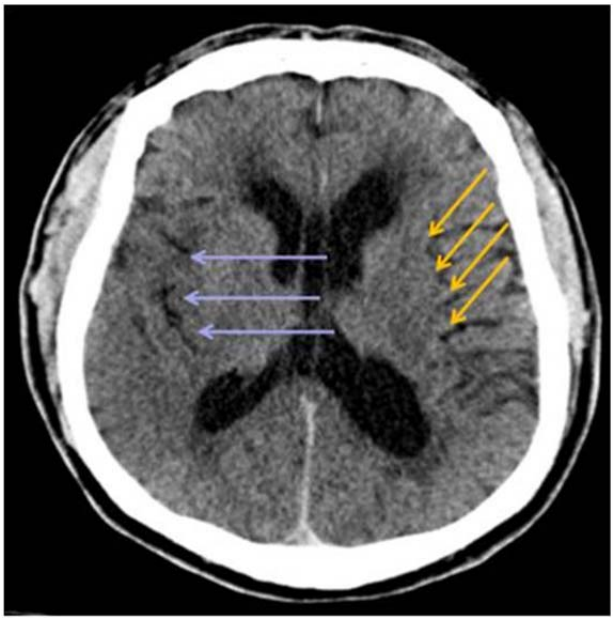


Figure 23: Loss of insular ribbon and obscuration of the sylvian fissure on the patient's right (blue arrows). Orange arrows represent the insular ribbon (fine white area directly medial to the sylvian fissure) on the non-affected side.

ES-Effacement of Cortical Sulci

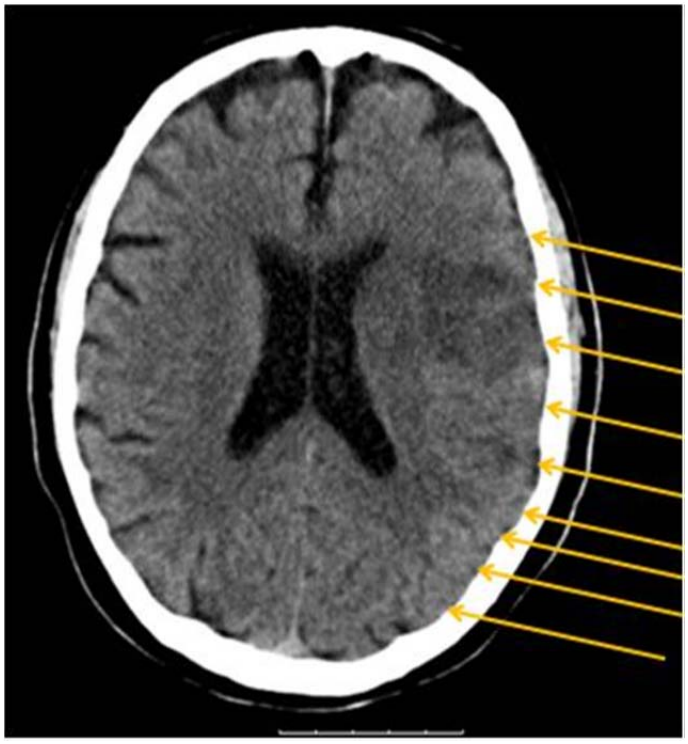


Figure 24: Effacement of cortical sulci (orange arrows)

Effacement of cortical sulci can ultimately lead to ventricular compression (Figure 25). Within the NINDS trial, evidence of edema or mass effect by CT was associated with an 8-fold increase risk of symptomatic hemorrhage.[27]

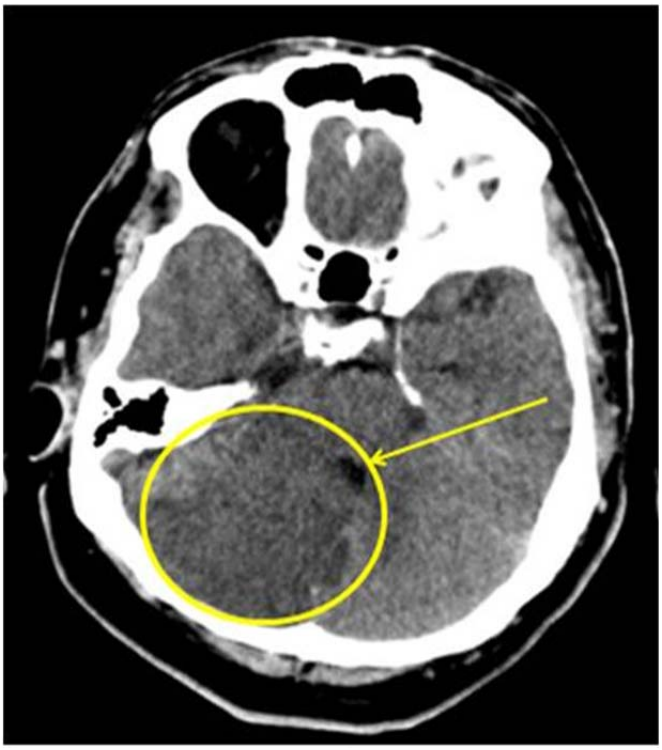


Figure 25: Cerebellar Infarct with right to left midline shift and partial effacement of the 4th ventricle.

EIC changes within 3 hours of symptom onset do not preclude the use of t-PA. Other findings of stroke syndrome on NCCT include lacunar infarcts (Figure 26).

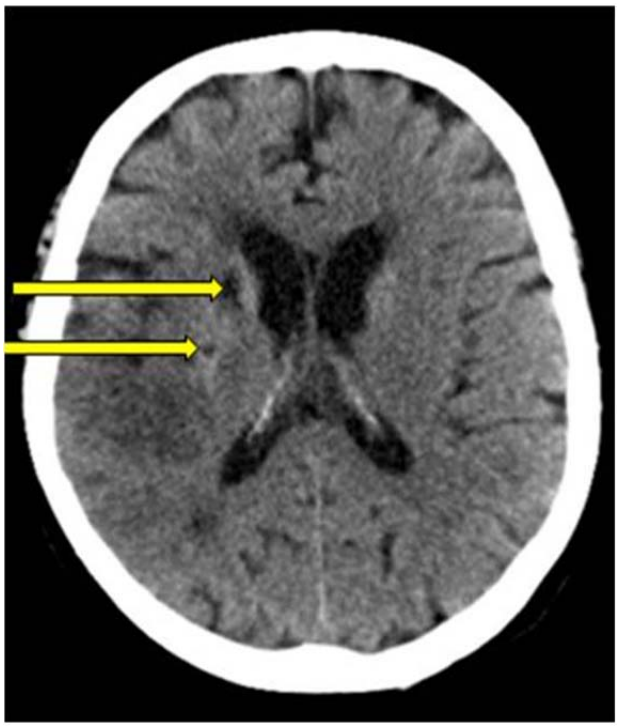


Figure 26: Lacunar infarcts of the caudate nucleus and putamen.

The role of MRI

MR provides an excellent means to evaluate the cerebral parenchyma and its efficacy continues to be demonstrated within the literature regarding stroke syndromes. MR Diffusion Weighted Imaging (MR-DWI) has been shown to be very sensitive for demonstrating acute infarction within minutes after insult.[6, 7, 28, 29] DWI can also be useful in the detection of brain parenchymal lesions likely to reflect completed infarction[12] and those that are difficult to detect on NCCT scan - including posterior fossa ischemia (20% of ischemic strokes),[6, 14] lacunar strokes, small deep white matter and/or cortical lesions.[7] In order to differentiate viable tissue from nonviable tissue for the purpose of thrombolytic therapy, DWI can be combined with perfusion weighted MR (PWI).[6, 30] The reported sensitivities/specificities in detecting the presence and extent of infarcted tissue range from 88-100% and 86-100%, respectively.[8] The aforementioned effectiveness of DWI has led to its emergence as the most sensitive and specific imaging technique for acute infarction and the gold standard for evaluation and discrimination of the infarct core.[1]

Given the importance of the exclusion of hemorrhage in the evaluation of the suspected stroke patient, MR evaluation of hemorrhage - both acute and chronic - is an important area of study. Sensitivity for hemorrhage detection correlates with the age of hemorrhage and which MR sequences are utilized (e.g. FLAIR, gradient recalled echo (GRE)).[1, 8] MR with GRE excludes ICH and has similar accuracy to NCCT in accomplishing this. MR with FLAIR can detect abnormal collections of fluid - including hemorrhages.[1, 12, 31] However, their appearance on FLAIR is radiographically similar to other pathologic (e.g. meningitis) and nonpathologic conditions (e.g. propofol administration)[32, 33] which limits the absolute exclusion of acute hemorrhage based on MR imaging as a standalone test.[8] In patients whom there is a strong suspicion of subarachnoid hemorrhage, NCCT should be performed.[1, 9] Chronic hemorrhages can be detected on MR sequencing with GRE and conceptually, appear to be a contraindication to the use of t-PA. However, when evaluated in the setting of acute stroke intervention with t-PA, there is no increased risk of hemorrhagic transformation in those patients with up to 10 microhemorrhages.[34, 35]

MR may also play a critical role in the evaluation of those ED patients with "wake up stroke" who are excluded from the current guidelines for administration of thrombolytic therapy given the unknown duration of infarct.[9] Using a combination of findings from both DWI (infarct detected)and

FLAIR (no or minimal hyperintense signal), prediction of time of onset is becoming possible and further study will elucidate effectiveness.[8]

The main limitations of MR are described in Table 1. Despite increasing availability in some ED's, the time to obtain images that could result in a delay to therapeutic intervention remains a practical concern. Results reveal that these MR sequences can be performed in as little as 20 minutes in experienced centers.[36] Some of these centers that are able to have equivocal efficiency with imaging times and no contraindications to MR, have implemented a MR strategy for imaging[9] wherein MR is performed prior to or following NCCT.[37, 38]

MR v. NCCT

In an effort to determine whether MR is a useful and effective imaging method within the ED setting, Chalela et al. performed a prospective comparison study of NCCT and MR in patients presenting with suspected stroke.[39] The sample size included 356 consecutive patients where the decision to perform neuroimaging was initiated by the emergency physician. Of the patients in whom the final discharge diagnosis was acute ischemic stroke (n=190), the detection rate for MR was 46% compared with 10% for NCCT.[39] At the time of publication of this study, the therapeutic window for administration of tPA was 3 hours. Looking at the data within this timeframe to symptom onset <3 hours, MR detected acute ischemic stroke in 41 of 90 patients (45.6%; p=<0.0001) while NCCT detection rate was 6.7% (6 of 90). Within the subgroup of patients who underwent imaging with symptom onset 3-12 hours, MR had a greater overall sensitivity for acute ischemic stroke - 81% (v. 20% NCCT). This is important to note given the increase in the time to treat with thrombolytic therapy (4.5 hours). NCCT would be expected to have sensitivity greater than 20% for ischemic stroke on NCCT scan due to the accumulation of edema and resultant ischemic changes.

In an analysis for the use of diffusion weighted imaging, the new evidence based guideline of the American Academy of Neurology (AAN) in 2010 supports the superiority of DWI over NCCT scan for the diagnosis of acute ischemic stroke patients presenting within 12 hours of symptom onset (Level A recommendation).[40]

Multimodal Imaging

Due to advancing technology, information can now be obtained about structure, function, and hemodynamic parameters in the evaluation of patients with suspected stroke syndromes. Multimodal CT includes NCCT, CT angiography, and CT perfusion while MR includes conventional sequences coupled with MR angiography (MRA), diffusion weighted imaging (DWI), and perfusion weighted imaging (PWI). Multimodal imaging by CT or MR may provide a plausible means to identify those patients who may benefit from acute reperfusion therapy by extending the therapeutic window for t-PA since many patients presenting to the ED do not often arrive immediately following onset of symptoms.[6, 41] However, selecting candidates for reperfusion on the basis of penumbral imaging (MR/CT perfusion) requires further diagnostic study and is not current standard of care.[4] As a result of the potential benefits of multimodal imaging, the most recent guidelines of the AHA/ASA have added the recommendation from their previous guidelines to include that these imaging modalities "will improve diagnosis of ischemic stroke" (Class 1, Level of Evidence A).[9]

Computed tomography angiography (CTA) & Magnetic resonance angiography (MRA)

CTA & MRA are the most common vascular imaging techniques used in the evaluation of stroke syndromes. In contrast to the reference standard - digital subtraction angiography - CTA/MRA are noninvasive and carry less risk to the patient.[8] Through evaluation of both the intracranial and extracranial circulation by image acquisition from the aortic arch to the cranial vertex, information can be obtained on vessel patency (identification of occlusion, dissection, grading collateral blood flow, vascular malformations, and early recanalization)[6, 7] and guide therapeutic decision making as well as obtain information on the cause of the stroke (e.g. dissection) to be used in consult with neurology. For example, when evaluating the intracranial circulation, vascular lesions identified within the proximal aspect of large vessels result in larger infarcts and have a greater risk of hemorrhagic transformation and benefit from neurovascular intervention. Similarly, a diseased vessel segment identified on extracranial evaluation (used in identifying if an occlusion is thrombotic or embolic in nature) causing occlusion is typically treated medically, whereas stenosis (>70%) in a symptomatic patient would necessitate carotid endarterectomy or stent placement.[8]

The advantages and limitations of CTA can be found within Table 1. For the practicing EP, the ability to perform CTA immediately following a negative NCCT (average completion time approximately 10 minutes) and initiate thrombolytic therapy is a significant advantage in maximizing the "time is brain" axiom. As a general rule, coupling CTA with NCCT in the diagnostic workup of patients with stroke syndromes can increase the sensitivity for EIC not seen on NCCT scans and improve the contrast between perfused and underperfused areas of the brain.[23] Another advantage of CTA is the obtaining of source images of the brain (CTA-SI). These can increase detection of acute ischemia and potentially identify the infarct core[8] by reflecting cerebral blood volume. CTA-SI has shown effectiveness in the detection of large ischemic regions approaching DWI (although less effective for smaller ones or those in the posterior fossa).[1] The practical benefit of performing CTA in addition to those factors noted above is reflected in those patients where NCCT is "normal" and the patient has an occlusion on CTA - these patients would potentially benefit from reperfusion. In contrast, those without occlusion on CTA and/or areas of hypoperfusion on CTA-SI may have no appreciable benefit to reperfusion.

When compared to the accepted gold standard of DSA in evaluating the intracranial circulation, CTA was 98.4% sensitive and 98.1% specific in the detection of proximal occlusion.[42] CTA with maximum intensity projection images is regarded as the most accurate technique to delineate the degree of collateral circulation[43] - which has an inverse relationship to the final infarct volume.

For the evaluation of the extracranial circulation, CTA is preferred to MRA as it has similar sensitivities to DSA[8]. A meta-analysis from 28 studies comparing CTA to DSA revealed 85% sensitivity (95% CI, 79% to 89%) and 93% specificity (95% CI, 89% to 96%) in detection of 70-99% stenosis; and (95% CI, 93% to 99%) and 99% (95% CI, 98% to 100%) for occlusion.[44] In addition to the enhanced sensitivity, certain limitations of MR and MRA are overcome by CTA (see Table 1). While MRA may not be comparable to CTA for the evaluation of the intracranial circulation, it performs comparably in the evaluationof carotid and vertebral artery dissection.[8] For the practicing EP in the evaluation of acute stroke syndromes, MRA is best applied to those patients who have contraindications to the performance of CTA (e.g. allergy to contrast, renal insufficiency).

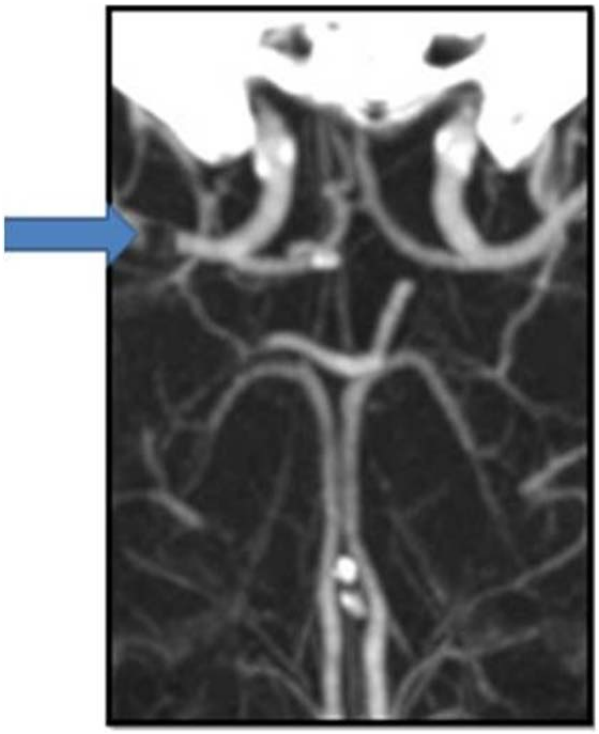


Figure 27: CTA demonstrating right MCA occlusion.

Computed tomography perfusion (CTP) & Magnetic Resonance Perfusion (MRP)

The perfusion techniques of CTP & MRP evaluate capillary and circulation at the tissue level. After injection of contrast, perfusion maps of cerebral blood volume/flow are obtained in order to differentiate infarcted from oligemic but probably salvageable tissue (see Figure 27).[4, 6, 23]

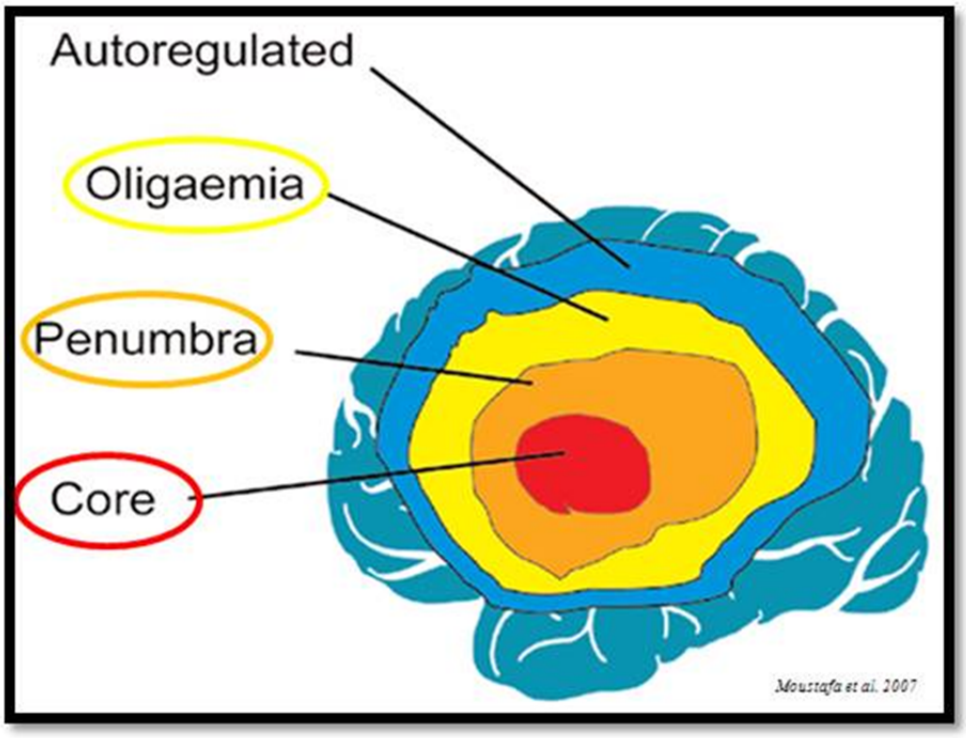


Figure 28: Core - infarcted tissue; Penumbra - functionally impaired but salvageable (target of reperfusion therapy); Oligemic - not at risk unless secondary insults occur that transition oligemic tissue to penumbra (e.g. hyperglycemia).[6]

CTP has good sensitivity in the detection of large hemispheric strokes[45] but does not perform equally as well in strokes not caused by proximal occlusions.[46] CTA/CTP has been shown to perform nearly equivocal when compared to MR in the selection of patients for thrombolysis who presented with stroke syndromes and when eligible for repurfusion.[47] However, there are no large, successfully completed clinical trials using only CTP to select patients for reperfusion therapy beyond the current recommended time window that have been successfully completed.[8] With the performance of CTA with CTP, there is the potential additional concern regarding the amount of contrast utilized in these patients. A study evaluating the incidence of contrast induced nephropathy (CIN) was conducted in 108 patients who underwent CTA/CTP imaging. Only 2.9% of patients had a significant increase in baseline creatinine and none of the patients developed chronic kidney disease or required dialysis.[48]

MRP when combined with DWI roughly identifies the ischemic penumbra through a mismatch in diffusion-perfusion.[9] Given that the target of effective reperfusion therapy is the penumbra, the clinical relevance of this mismatch lies in the potential extension of the window for those patients most likely to benefit from thrombolytic therapy even further since this mismatch is reflective of the existence of salvageable at-risk tissue. This mismatch is found in 70% of patients with anterior circulation stroke within 6 hours of symptom onset; (2) strongly

associated with proximal MCA occlusion; and (3) resolution on reperfusion is associated with neurological recovery.[6] Efficacy and validation has been established in multiple clinical trials (e.g. Dose Escalation of Desmoteplase for Acute Ischemic Stroke - DEDAS; Desmoteplase in Acute Ischemic Stroke - DIAS; Diffusion Weighted Imaging Evaluation for Understanding Stroke - DEFUSE; and Echoplanar Imaging Thrombolytic Evaluation Trial - EPITHET).[8] For additional pros/cons of MRP, refer to Table 1.

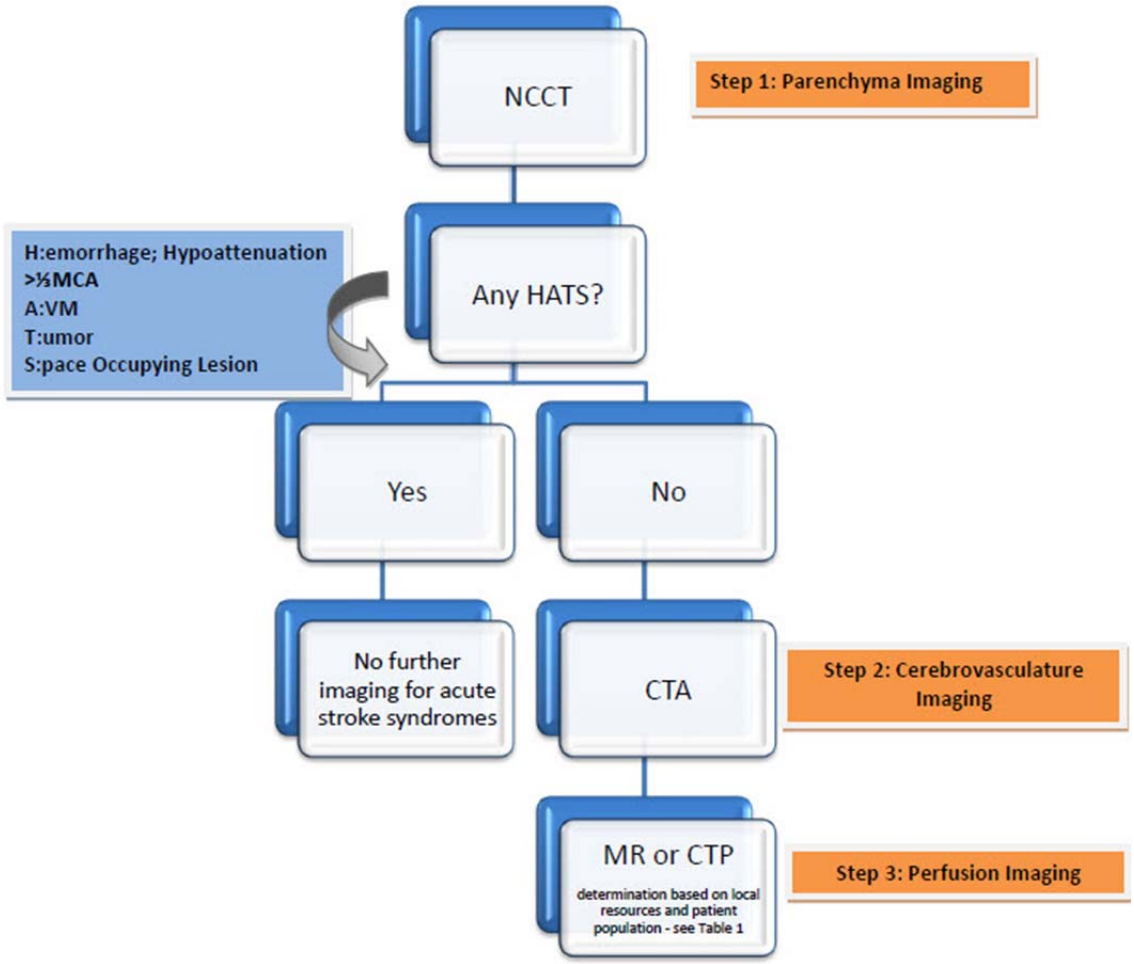
Conclusion

NCCT scan continues to be an acceptable initial imaging modality in the diagnostic workup of stroke syndromes. While other more comprehensive imaging studies provide greater information regarding vessel patency and tissue viability, treatment should not be delayed in order to obtain more advanced studies.[9] Given the continuing advancement in stroke diagnosis and management, the guidelines for imaging analysis and imaged based treatment protocols will evolve as further studies are conducted comparing these modalities.

Table 1: Comparison of Neuroimaging techniques used in Stroke Syndromes

	Pros	Cons	Key Point
NCCT	• Availability • Cost • Monitoring of unstable patient • Speed	• Specificity • Insensitive for small cortical/subcortical infarcts (e.g. posterior fossa – brainstem, cerebellum)[49]	• Excellent sensitivity for exclusion of ICH
CTA	• Availability • Less vessel narrowing artifact (v. MRA) • Short acquisition time • Ease of monitoring • Greater spatial resolution (v. MRA)	• Contrast allergy (incidence →0.15% with low osmolar non-ionic contrast)[50] • Renal function • Radiation exposure (Head- 2.5 mSv; Head-Neck 9.5 mSv)[51] • Pseudo-dissection or pseudo-occlusion (reader dependent)	• Can occur immediately after NCCT • Excellent evaluation of collateral circulation
CTP	• See CT • Combined with CTA, can roughly estimate infarct and ischemic penumbra	• Contrast allergy • Renal function • Radiation exposure (3.35-6.7 mSv)[51] • Not as sensitive as DWI for acute ischemia[8] • Incomplete visualization of circulation	• Alternative for patients in whom MR is contraindicated
MR (DWI, PWI, GRE, FLAIR)	• Detection of ischemia • Detection of small cortical/subcortical lesions • Differentiation of acute from chronic ischemia	• Metallic equipment contraindication (e.g. patient & monitoring equipment) • Limited availability in most ED's • Image acquisition time	• DWI → Most sensitive & accurate means to determine acute infarction and infarct core
	• Increased spatial resolution • Lack of radiation, exposure to contrast		
MRA	• Imaging alternative	• See MR • Inability to assess the collateral circulation and distal/branch occlusions[9] • Gadolinium associated nephrogenic systemic fibrosis	• Consider in contrast allergic/renal insufficiency patients
MRP	• Whole brain coverage • Lack of radiation (compared with CTP)	• Studies regarding the diagnostic/clinical utility of MRP are underpowered • Variable definitions for infarct core, penumbra, etc.[8]	• Determination of diffusion-perfusion mismatch when combined with DWI (important for therapeutic decision making)

Figure 29: Algorithm for Radiologic Evaluation of Stroke Syndromes



1. Latchaw RE, Alberts MJ, Lev MH, et al. Recommendations for imaging of acute ischemic stroke: a scientific statement from the American Heart Association. *Stroke.* Nov 2009;40(11):3646-3678.
2. Albers GW, Amarenco P, Easton JD, et al. Antithrombotic and thrombolytic therapy for ischemic stroke: American College of Chest Physicians Evidence-Based Clinical Practice Guidelines (8th Edition). *Chest.* Jun 2008;133(6 Suppl):630S-669S.
3. Felberg RA, Naidech AM. The 5 Ps of acute ischemic stroke treatment: parenchyma, pipes, perfusion, penumbra, and prevention of complications. *South Med J.* Apr 2003;96(4):336-342.
4. Fugate JE, Giraldo EA, Rabinstein AA. Thrombolysis for cerebral ischemia. *Front Neurol.*1:139.
5. Hacke W, Kaste M, Bluhmki E, et al. Thrombolysis with alteplase 3 to 4.5 hours after acute ischemic stroke. *N Engl J Med.* Sep 25 2008;359(13):1317-1329.
6. Moustafa RR, Baron JC. Clinical review: Imaging in ischaemic stroke--implications for acute management. *Crit Care.* 2007;11(5):227.
7. Wintermark M, Rowley HA, Lev MH. Acute stroke triage to intravenous thrombolysis and other therapies with advanced CT or MR imaging: pro CT. *Radiology.* Jun 2009;251(3):619-626.
8. Kunst MM, Schaefer PW. Ischemic stroke. *Radiol Clin North Am.* Jan;49(1):1-26.
9. Adams HP, Jr., del Zoppo G, Alberts MJ, et al. Guidelines for the early management of adults with ischemic stroke: a guideline from the American Heart Association/American Stroke Association Stroke Council, Clinical Cardiology Council, Cardiovascular Radiology and Intervention Council, and the Atherosclerotic Peripheral Vascular Disease and Quality of Care Outcomes in Research Interdisciplinary Working Groups: the American Academy of Neurology affirms the value of this guideline as an educational tool for neurologists. *Stroke.* May 2007;38(5):1655-1711.
10. Hacke W, Kaste M, Fieschi C, et al. Intravenous thrombolysis with recombinant tissue plasminogen activator for acute hemispheric stroke. The European Cooperative Acute Stroke Study (ECASS). *JAMA.* Oct 4 1995;274(13):1017-1025.
11. Barber PA, Demchuk AM, Zhang J, et al. Validity and reliability of a quantitative computed tomography score in predicting outcome of hyperacute stroke before thrombolytic therapy. ASPECTS Study Group. Alberta Stroke Programme Early CT Score. *Lancet.* May 13 2000;355(9216):1670-1674.
12. Aronovich BD, Reider G, II, Segev Y, et al. Early CT changes and outcome of ischemic stroke. *Eur J Neurol.* Jan 2004;11(1):63-65.
13. Wardlaw JM, Mielke O. Early signs of brain infarction at CT: observer reliability and outcome after thrombolytic treatment--systematic review. *Radiology.* May 2005;235(2):444-453.
14. De Keyser J, Gdovinova Z, Uyttenboogaart M, et al. Intravenous alteplase for stroke: beyond the guidelines and in particular clinical situations. *Stroke.* Sep 2007;38(9):2612-2618.

15. Dzialowski I, Hill MD, Coutts SB, et al. Extent of early ischemic changes on computed tomography (CT) before thrombolysis: prognostic value of the Alberta Stroke Program Early CT Score in ECASS II. *Stroke.* Apr 2006;37(4):973-978.
16. Grotta JC CD, Lu M, Patel S, Levine SR, Tilley BC, Brott TG, Haley EC, Jr, Lyden PD, Kothari R, et al. Agreement and variability in the intepretation of early CT changes in stroke patients qualifying for intravenous rtPA therapy. *Stroke.* 1999;30:1528-1533.
17. Patel SC, Levine SR, Tilley BC, et al. Lack of clinical significance of early ischemic changes on computed tomography in acute stroke. *JAMA.* Dec 12 2001;286(22):2830-2838.
18. Sims JR, Gharai LR, Schaefer PW, et al. ABC/2 for rapid clinical estimate of infarct, perfusion, and mismatch volumes. *Neurology.* Jun 16 2009;72(24):2104-2110.
19. Qureshi AI, Ezzeddine MA, Nasar A, et al. Is IV tissue plasminogen activator beneficial in patients with hyperdense artery sign? *Neurology.* Apr 25 2006;66(8):1171-1174.
20. von Kummer R, Meyding-Lamade U, Forsting M, et al. Sensitivity and prognostic value of early CT in occlusion of the middle cerebral artery trunk. *AJNR Am J Neuroradiol.* Jan 1994;15(1):9-15; discussion 16-18.
21. Derex L, Hermier M, Adeleine P, et al. Clinical and imaging predictors of intracerebral haemorrhage in stroke patients treated with intravenous tissue plasminogen activator. *J Neurol Neurosurg Psychiatry.* Jan 2005;76(1):70-75.
22. Leary MC, Kidwell CS, Villablanca JP, et al. Validation of computed tomographic middle cerebral artery "dot"sign: an angiographic correlation study. *Stroke.* Nov 2003;34(11):2636-2640.
23. Schellinger PD, Fiebach JB, Hacke W. Imaging-based decision making in thrombolytic therapy for ischemic stroke: present status. *Stroke.* Feb 2003;34(2):575-583.
24. von Kummer R, Allen KL, Holle R, et al. Acute stroke: usefulness of early CT findings before thrombolytic therapy. *Radiology.* Nov 1997;205(2):327-333.
25. Larrue V, von Kummer RR, Muller A, et al. Risk factors for severe hemorrhagic transformation in ischemic stroke patients treated with recombinant tissue plasminogen activator: a secondary analysis of the European-Australasian Acute Stroke Study (ECASS II). *Stroke.* Feb 2001;32(2):438-441.
26. Von kummer R, Hacke, W. Safety and efficacy of intravenous tissue plasminogen activator and heparin in acute middle cerebral artery stroke. *Stroke.* 1992(23):646-652.
27. Tissue plasminogen activator for acute ischemic stroke. The National Institute of Neurological Disorders and Stroke rt-PA Stroke Study Group. *N Engl J Med.* Dec 14 1995;333(24):1581-1587.
28. Fiebach JB, Schellinger PD, Jansen O, et al. CT and diffusion-weighted MR imaging in randomized order: diffusion-weighted imaging results in higher accuracy and lower interrater variability in the diagnosis of hyperacute ischemic stroke. *Stroke.* Sep 2002;33(9):2206-2210.
29. Hjort N, Christensen S, Solling C, et al. Ischemic injury detected by diffusion imaging 11 minutes after stroke. *Ann Neurol.* Sep 2005;58(3):462-465.

30. Hjort N, Butcher K, Davis SM, et al. Magnetic resonance imaging criteria for thrombolysis in acute cerebral infarct. *Stroke.* Feb 2005;36(2):388-397.
31. Noguchi K, Ogawa T, Inugami A, et al. Acute subarachnoid hemorrhage: MR imaging with fluid-attenuated inversion recovery pulse sequences. *Radiology.* Sep 1995;196(3):773-777.
32. Tha KK TS, Kudo K, et al. Differential diagnosis of hyperintense cerebrospinal fluid on fluid attenuation inversion recovery images of the brain. Part I: pathologic conditions. . *Br J Radiol.* 2009;82(977):426-434.
33. Tha KK TS, Kudo K, et al. Differential diagnosis of hyperintense cerebrospinal fluid on fluid attenuation inversion recovery images of the brain. Part II: non-pathologic conditions. . *Br J Radiol.* 2009;82(979):610-614.
34. Boulanger JM, Coutts SB, Eliasziw M, et al. Cerebral microhemorrhages predict new disabling or fatal strokes in patients with acute ischemic stroke or transient ischemic attack. *Stroke.* Mar 2006;37(3):911-914.
35. Kim HS, Lee DH, Ryu CW, et al. Multiple cerebral microbleeds in hyperacute ischemic stroke: impact on prevalence and severity of early hemorrhagic transformation after thrombolytic treatment. *AJR Am J Roentgenol.* May 2006;186(5):1443-1449.
36. Kang DW, Chalela JA, Dunn W, et al. MRI screening before standard tissue plasminogen activator therapy is feasible and safe. *Stroke.* Sep 2005;36(9):1939-1943.37. Kidwell CS, Chalela JA, Saver JL, et al. Comparison of MRI and CT for detection of acute intracerebral hemorrhage. *JAMA.* Oct 20 2004;292(15):1823-1830.
38. Schellinger PD, Jansen O, Fiebach JB, et al. Feasibility and practicality of MR imaging of stroke in the management of hyperacute cerebral ischemia. *AJNR Am J Neuroradiol.* Aug 2000;21(7):1184-1189.
39. Chalela JA, Kidwell CS, Nentwich LM, et al. Magnetic resonance imaging and computed tomography in emergency assessment of patients with suspected acute stroke: a prospective comparison. *Lancet.* Jan 27 2007;369(9558):293-298.
40. Schellinger PD, Bryan RN, Caplan LR, et al. Evidence-based guideline: The role of diffusion and perfusion MRI for the diagnosis of acute ischemic stroke: report of the Therapeutics and Technology Assessment Subcommittee of the American Academy of Neurology. *Neurology.* Jul 13;75(2):177-185.
41. Katzan IL, Hammer MD, Hixson ED, et al. Utilization of intravenous tissue plasminogen activator for acute ischemic stroke. *Arch Neurol.* Mar 2004;61(3):346-350.
42. Lev MH, Farkas J, Rodriguez VR, et al. CT angiography in the rapid triage of patients with hyperacute stroke to intraarterial thrombolysis: accuracy in the detection of large vessel thrombus. *J Comput Assist Tomogr.* Jul-Aug 2001;25(4):520-528.
43. Tan JC, Dillon WP, Liu S, et al. Systematic comparison of perfusion-CT and CT-angiography in acute stroke patients. *Ann Neurol.* Jun 2007;61(6):533-543.
44. Koelemay MJ, Nederkoorn PJ, Reitsma JB, et al. Systematic review of computed tomographic angiography for assessment of carotid artery disease. *Stroke.* Oct

2004;35(10):2306-2312.
45. Wintermark M, Fischbein NJ, Smith WS, et al. Accuracy of dynamic perfusion CT with deconvolution in detecting acute hemispheric stroke. *AJNR Am J Neuroradiol.* Jan 2005;26(1):104-112.
46. Maruya J, Yamamoto K, Ozawa T, et al. Simultaneous multi-section perfusion CT and CT angiography for the assessment of acute ischemic stroke. *Acta Neurochir (Wien).* Apr 2005;147(4):383-391; discussion 391-382.
47. Wintermark M, Meuli R, Browaeys P, et al. Comparison of CT perfusion and angiography and MRI in selecting stroke patients for acute treatment. *Neurology.* Feb 27 2007;68(9):694-697.
48. Hopyan JJ, Gladstone DJ, Mallia G, et al. Renal safety of CT angiography and perfusion imaging in the emergency evaluation of acute stroke. *AJNR Am J Neuroradiol.* Nov 2008;29(10):1826-1830.
49. Mullins ME, Schaefer PW, Sorensen AG, et al. CT and conventional and diffusion-weighted MR imaging in acute stroke: study in 691 patients at presentation to the emergency department. *Radiology.* Aug 2002;224(2):353-360.
50. Hunt CH, Hartman RP, Hesley GK. Frequency and severity of adverse effects of iodinated and gadolinium contrast materials: retrospective review of 456,930 doses. *AJR Am J Roentgenol.* Oct 2009;193(4):1124-1127.
51. Almandoz JD ea. CT Angiography of the carotid and cerebral circulation. *Radiol Clin North Am.* 2010;48(2):265-281. Â