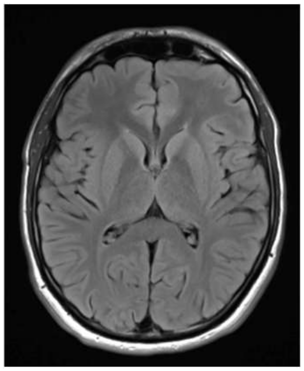


# NEUROIMAGING

*What's in there anyway?*

*Jason Massa DO, FAAN*

# *Contents*

# *Educational Objectives*

This symbol means high yield topic!

- Understand differences between CT and MRI, and when to use which.
- Learn general appearance of acute stroke and hemorrhage on MRI and CT scan.
- Learn to differentiate between different types of edema on MRI and CT scan.
- Understand anatomy of the brain with CT and MRI.
- Differentiate ischemic from hemorrhagic stroke on CT.
- Understand utility of ultrasound in evaluation of a patient at risk for stroke.
- Become familiar with high yield MRI sequences.

You will be getting a lot of more specific neuroradiology throughout your lectures on clinical topics. The goal here is to familiarize you with most of the common neuroimaging techniques so that you have a clear foundation for the images used to present pathology in later lectures.

# *History*

- The pre-CT era was barbaric!
- Pneumoencephalogram was one of the only imaging techniques available.
- CSF was drained and replaced with **AIR.**
- Poor resolving quality, abandoned in late 70s with advent of CT.
- Can be proposed as plan on rounds to see if the attending is paying attention.

Very poorly tolerated
- Patient had a spinal needle inserted, and CSF drained
- They were strapped to chair and rotated around to get the fluid replaced with air
- This took days-weeks to resolve
- Complications included high rates of infection, hemorrhage.

## *Indications*

- Neurologic deficits localizing to the brain
- Useful in workup of suspected:
  - Stroke
  - Tumor
  - Infection
  - Secondary Headaches
- Specific indications are discussed in Clinical Lectures
- Should be used judiciously

We will discuss specific situations today, but otherwise please refer to the clinical materials provided in other lectures for diagnostic algorithms.
It would be great to do an MRI on every patient with even the vaguest of neurologic complaints, but this isn’t feasible, and potentially could lead to worsened outcomes.

- ”normal” MRI reports are rare, most radiologist reports will indicate some level of benign changes that can be very scary for patients such as ischemic white matter disease or benign vascular abnormalities.
- I get at least a few referrals a month for patients that had inappropriately ordered head imaging that came to discuss benign findings (often waiting months and doing a lot of googling.)

*When viewing cross-sectional scans, imagine that you are sitting at the patient's feet and looking up*
*Right and left are swapped*

# *Brain Imaging Techniques*

- Plain X-ray
- Computed Tomography (**CT, CTA**, PET, SPECT)
- Magnetic Resonance (**MRI, MRA**, MR SPECT)
- Ultrasound
- Catheter Angiography (**DSA**, a type of fluoroscopy)

These are the basic breakdowns of the different modalities. There is no one imaging technique that is best for everything. There are pros/cons to each which we will discuss today. Similarly, the underlying technologies can be used in unique ways to gain very different information. For instance an MRI scanner can be used to run spectroscopy (remember this from premed chemistry?) on a defined region of the brain to help determine if the normal expected chemical makeup of the tissue is seen. This has limited usefulness.

# *Plain X-Ray*

Rarely useful in Adults

Can see significant skull fractures

Pineal Calcification can be used as landmark for midline shift

The pineal glad is a midline structure and is often calcified to some extent in adulthood. If visible and significantly shifted off the midline, can indicate that there is some mass effect pushing it off the midline such as from hemorrhage or edema. (This skull x0ray was taken from a case where a pt had a pituitary neoplasm).

# *COMPUTED TOMOGRAPHY*

- Tomography – technique for producing cross-sectional images using a penetrating wave (such as X-ray in the case of the standard CT scan.)
- Other types include Positron Emission Tomography (PET) and Single-Photon Emission Computed Tomography (SPECT.)
- CT scan can utilize **IV iodine contrast** to highlight the vasculature and certain pathologies.
- CT signals are referred to by their **density**

## *Computed Tomography*

CT – Density
MRI – Intensity

Your radiology attendings will correct you if you swap these. I swap them all the time on accident.

# *CT Scan*

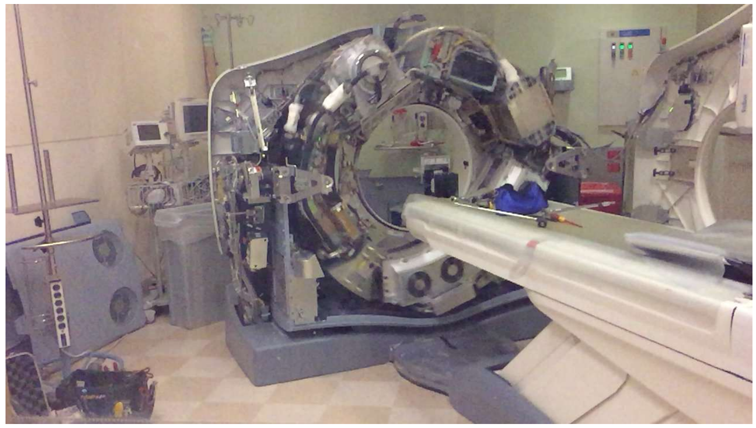
*Advantages*

- **Fast**
- Boney structures imaged well
- Acute hemorrhage appears bright

*Disadvantages*

- Lower spatial resolution than MRI
- Radiation exposure
- Less sensitive to parenchymal changes within the brain
  - i.e. acute ischemic stroke

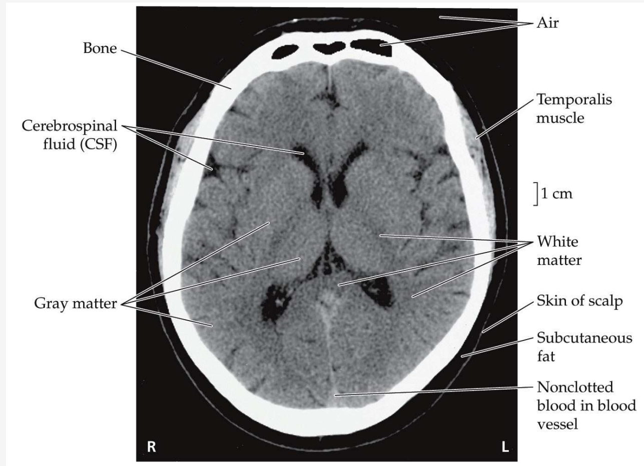
CT Scan in action



# NORMAL CT HEAD

# *Non-contrast CT Head*

- Bone is high density
- Air very low density
- CSF is low density
- Grey matter more dense than white matter
- Grey/white differentiation is subtle but visible
- Let's look at an actual CT scan




NEUROANATOMY 2e, Figure 4.3



Go to horos to view scan

# CT with contrast

- Iodine based contrast helps to visualize blood vessels and some types of pathology such as tumors or infection.
- When something is brighter after contrast administration, it is referred to as "enhanced."
- Ex: The area of hypodensity in the frontal lobe demonstrates enhancement with IV contrast.
- CT head with and without contrast is not frequently used except in certain clinical scenarios (unable to obtain MRI due to pacemaker for example.)
- When contrast is used for vascular imaging, it is called a CT Angiogram and uses a specific technique (see next slide.)

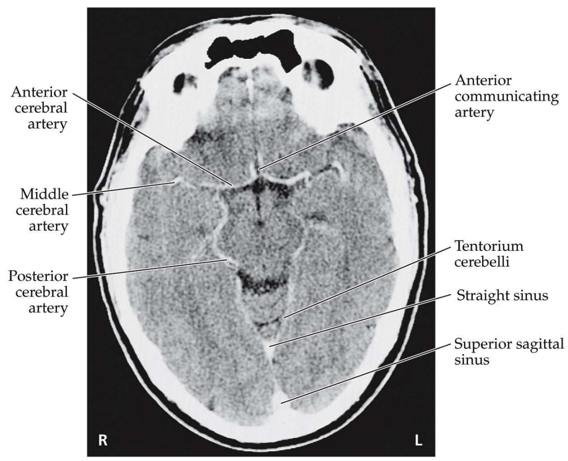
Almost everything that you might want to image with a post-contrast CT is better imaged on MRI (except vasculature)

# CT Angiography

- Utilizes a bolus of IV contrast to selectively enhance vascular structures.
- With the patient in the scanner, a small IV push of contrast is administered while the technician views a fast-updating slice through the intracranial vasculature.
- The time it takes for the contrast to reach the vessels is determined.
- Then a more detailed image through the brain is taken which is timed with the full administration of contrast.
- This helps to ensure that the contrast is mostly within the arteries of the brain before it has had a chance to enter the venous structures or cause any other pathological enhancement.

Timing bolus is important to avoid imaging both the artieries and venous structures at the same time, making differentiation difficult especially in the posterior fossa.

## *ENHANCEMENT OF CEREBRAL VASCULATURE ON CT WITH CONTRAST*



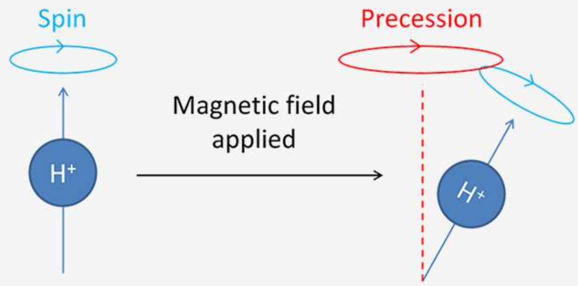

*NEUROANATOMY 2e*, Figure 4.4



Circle of willis visible
Superior sagittal and straight sinus are visible as well
If CT Angiography was performed, ideally only the arterial side of the vasculature would enhance.
In CT Venography, the timing of the bolus would be delayed to highlight the venous structures.

# *MAGNETIC RESONANCE IMAGING*

# *MRI Basics: Highly simplified*




- Technique which uses a strong magnetic field and radiofrequency detectors to produce excellent images of soft tissues.
- There are many ways of utilizing this technology to image the brain.
- A strong static magnetic field exists within the scanner which causes the spin of hydrogen nuclei to align.
- A second magnetic field is generated which causes the spinning hydrogen nuclei to move and relax back to the original alignment, they emit a radiofrequency signal through a process called **precession**.
- The signal emitted is determined by the tissue's **susceptibility**.
- See "Introduction to MRI" article in canvas for more details. This article is written for clinicians and explores some of the physics of MRI.

# *Recovery Time (T)*

- T1 weighted images
  - Longitudinal component of the magnetization vector.
  - Relaxation time for a tissue determines its intensity on T1 sequences – short T1 is bright and long T1 is dark.
  - **White matter is brighter than grey matter.**
  - Blood has different intensity depending on its status (discussed in another slide).
  - **This sequence is generally best for looking at structure of the brain parenchyma rather than for pathology.**

- T2 weighted images
  - Transverse component of the magnetization vector.
  - Relaxation or recovery time determines signal intensity, but is reversed – short T2 is dark, long T2 is bright.
  - In contrast to T1, on a T2 sequence **grey matter is brighter than white matter.**
  - Blood has different intensity depending on its status (discussed in another slide).
  - **This sequence is generally best for looking for pathology within the brain structure (edema, necrosis, demyelinating lesions)**

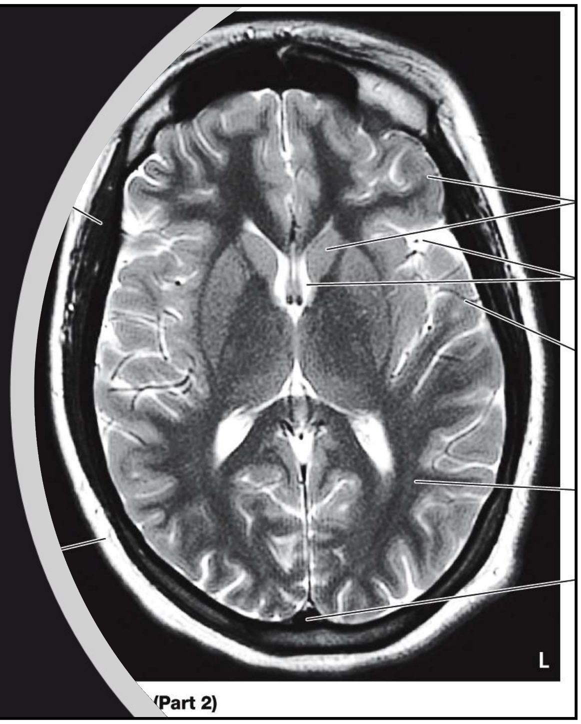

# *T1 weighted*

- Grey matter is **Dark**
- White matter is **Bright**
- CSF is **Dark**
- Bone is **Dark**
- Fatty scalp is **bright**

NTCC2e-Fig-04-06-1.jpg

# T2 weighted

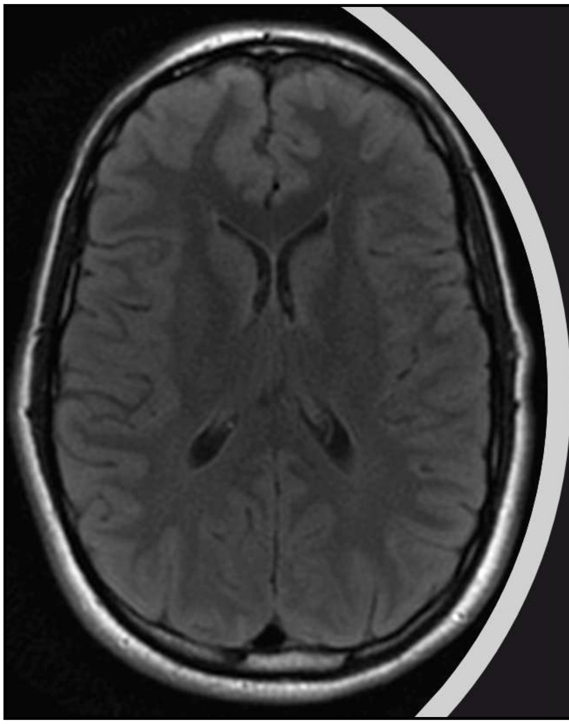
- Grey matter is **Bright**
- White matter is **Dark**
- CSF is **Bright**
- Bone and air remain **Dark**



# *Special Sequences*

- T2 FLAIR – "Fluid level attenuation inversion recovery" – effectively removes the bright CSF signal so that periventricular structures can be visualized.
- Gradient Echo or SWAN/SWIM – sequences which are very sensitive to metals such as iron, which show up as very dark spots, useful for identifying areas of **old or chronic** hemorrhage.
- DWI/ADC -- "Diffusion weighted imaging" and "Apparent Diffusion Coefficient" – useful for imaging of cytotoxic edema such as seen in acute stroke.

Some of these sequences have different names depending on the manufacturer of the scanner or the software used.



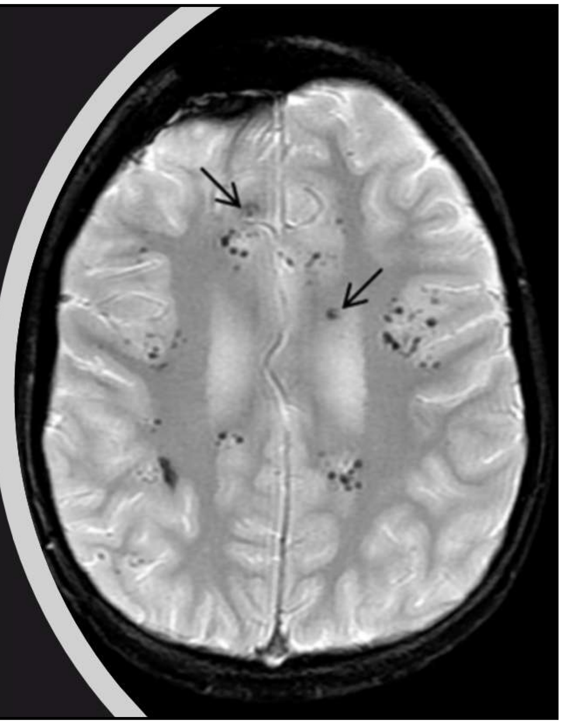
# *T2 Flair*

- Grey matter is **Bright**
- White matter is **Dark**
- CSF is **Dark**
- Bone and air remain **Dark**
- **The subtraction of the bright CSF signal allows for better visualization of CSF-adjacent structures like periventricular areas.**

NTCC2e-Fig-04-06-1.jpg

# *Gradient Echo or GRE*

- T2 weighted image.
- **Old blood products cause dephasing, resulting in very dark, low signal intensity lesions.**
- In this case these represent microhemorrhages, potentially from amyloid angiopathy.



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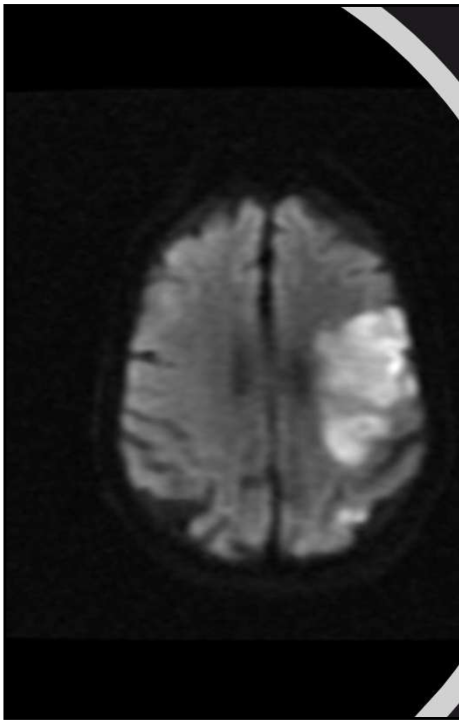


# *Diffusion Weighted Imaging*

- Areas of cytotoxic edema show up as **bright on DWI**, with a corresponding **dark area on the ADC** sequence.
- Useful in acute stroke, as DWI can become positive in <30 minutes.
- Must compare to the ADC sequence, as hyperintensity on both sequences suggests “T2 shine-through.”
- Like a measurement of Brownian motion.

Left MCA acute infarct.

# *T1 Post Contrast*

- Grey matter is **Dark**
- White matter is **Bright**
- CSF is **Dark**
- Bone is **Dark**
- Fatty scalp is **bright**
- Can see enhancement within some of the vascular structures and choroid plexus

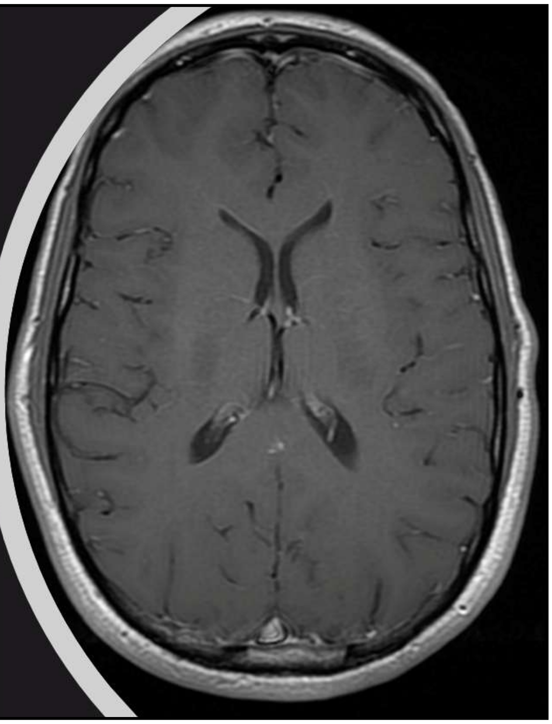


**TABLE 4.3 MRI Appearance of Commonly Scanned Tissues**

| TISSUE | T1-WEIGHTED | T2-WEIGHTED | FLAIR |
|---|---|---|---|
| Gray matter | Gray | Light gray | Light gray |
| White matter | White | Dark gray | Gray |
| CSF or water | Black | White | Dark gray |
| Fat | White | White[a] | White[a] |
| Air | Black | Black | Black |
| Bone or calcification | Black | Black | Black |
| Edema | Gray | White | White |
| Demyelination or gliosis | Gray | White | White |
| Ferritin deposits (e.g., in basal ganglia) | Dark gray | Black | Black |
| $Ca^{2+}$ bound to protein | White | Dark gray | Dark gray |
| Proteinaceous fluid | White | Variable | Variable |

[a]Although fat appears dark on T2-weighted images on spin echo (SE) imaging, with fast spin echo (FSE) sequences used in most clinical scans, subcutaneous and epidural fat appears bright due to "J-coupling" (unless fat saturation is also applied). The same holds true for FLAIR.

*OANATOMY 2e*, Table 4.3



# *MRI APPEARANCE OF TISSUE TYPES*

# *CT VS MRI*

| *CT* | *MRI* |
|---|---|
| • Ionizing radiation | • No radiation |
| • Cheap | • Expensive |
| • Soft tissue contrast poor | • Excellent soft tissue contrast |
| • Great for acute hemorrhage and trauma | • Not great for acute hemorrhage or trauma |
| | • Able to show acute ischemic stroke quickly* |
| • **Density** | • **Intensity** |

MRI not routinely used urgently in acute stroke due to time constraints. Stroke is a clinical diagnosis, which can be made at the bedside with a proper history and examination.

## CT

- Iodine contrast
- Short Exam Times
  - 10 seconds for actual patient stay still time for scanning
- CT angiography (requires contrast)

## MRI

- Gadolinium contrast
- Long exam times
  - Full brain w standard sequences ~30 min
- Claustrophobia
- MRA (angiography, does not require contrast)
- Patient cooperation needed
- Magnetic fields (caution)
  - Pacemakers
  - Aneurysm clips **in brain**
  - Nerve stimulators
  - Metallic foreign bodies in eyes

Gad – nephrogenic systemic sclerosis – check bun/cr before administering. This has become so rare with newer formulations of gad that some institutions do not require checking renal function before administration in otherwise healthy patients anymore.

Most recent (5 years or so) pacemakers are MRI ”conditional” but may need to be placed into an MRI mode. This is similar for deep brain stimulators and nerve stimulators as well. Most aneurysm clips manufactured in this century are MRI compatibility, but caution is advised.

In most cases the radiology team will coordinate to determine the safey of the study, but you should be screening your patients before ordering these studies for contra-indications mentioned above.

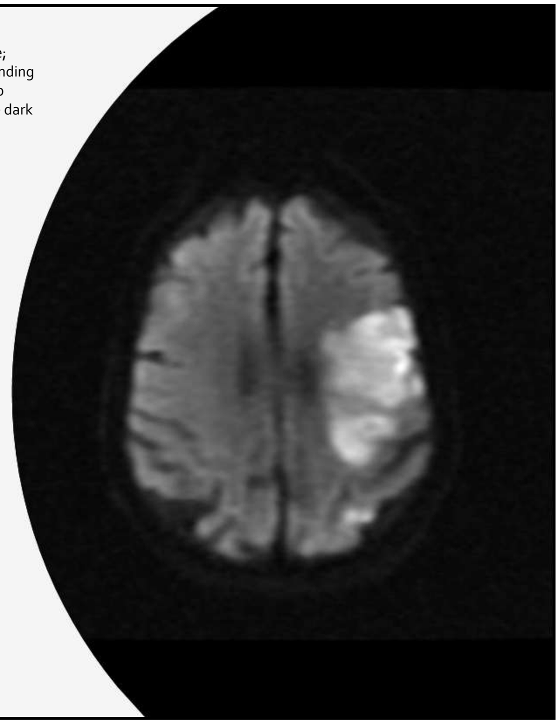
# *IMAGING OF EDEMA AND BLOOD*

# Types of Cerebral Edema

- **Cytotoxic** – failure of the Na/K ATPase leads to intracellular swelling. This is the main type of edema seen in acute stroke and is responsible for the MRI changes.
- **Vasogenic** – breakdown of the blood/brain barrier leads to extracellular swelling. This is commonly seen around tumors and demyelinating plaques.
- **Transependymal** – increased CSF pressures cause signal change in the periventricular regions. Seen in hydrocephalus.

# *Cytotoxic Edema*

DWI sequence; corresponding ADC map would be dark

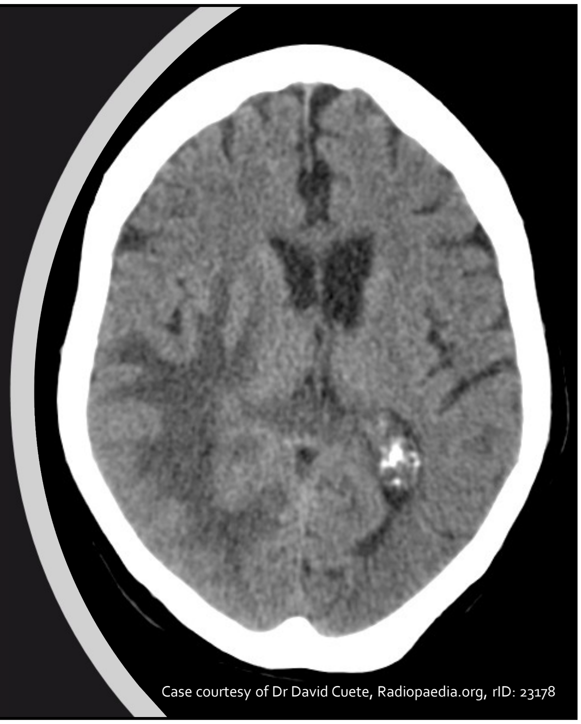


- This patient would be expected to have symptoms of left MCA syndrome
  - Eyes deviated left
  - Right sided arm>leg weakness and sensory changes
  - Right facial weakness
  - Aphasia
- **A corresponding CT may look normal or show subtle loss of grey/white differentiation.**

Left MCA acute infarct.

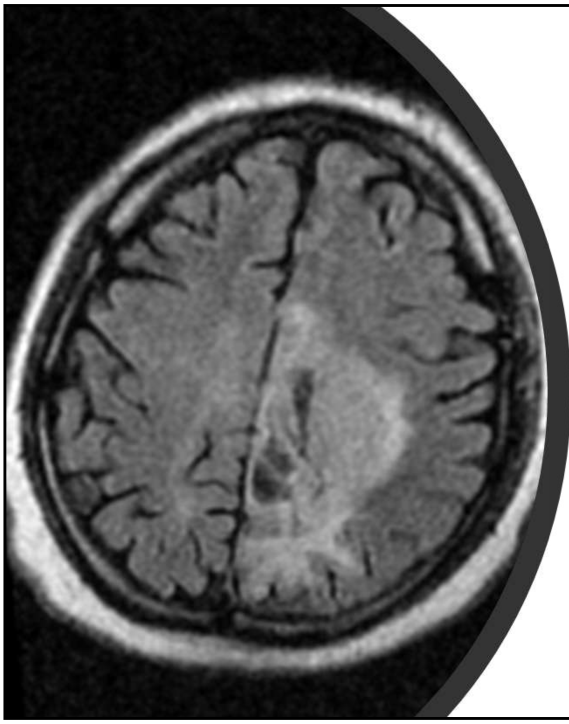
# *Vasogenic Edema*

- **Grey/white differentiation preserved.**
- Visible as hypodensity on CT.
- Visible as hyperintensity on T2 MRI.
- Associated with BBB breakdown.
- This patient has a metastatic lesion in the right temporal/parietal region.



Case courtesy of Dr David Cuete, Radiopaedia.org, rID: 23178

What type of imaging is this?
Substantial hypodensity in the right temporal and occipital lobes.
Metastases tend to cause more edema than primary brain tumors.



# *Vasogenic Edema*

- Grey/white differentiation preserved.
- Visible as hypodensity on CT.
- **Visible as hyperintensity on T2 MRI.**
- Associated with BBB breakdown.
- This patient had CNS lymphoma vs demyelinating lesion.

What type of imaging is this?
CNS lymphoma and demyelinating lesions are notoriously difficult to differentiate based on imaging characteristics alone.

# *Transependymal Edema*

- Hypodensity is seen in the periventricular regions due to hydrocephalus, caused by a ventricular shunt failure.

Case courtesy of Dr Ian Bickle, Radiopaedia.org, rID: 55488

Hydrostatic pressure on the ventricles

# *Aging of Blood on MRI*

- As blood products breakdown within the brain parenchyma, their susceptibility changes with time.
- A rough estimate of blood age can be determined by comparing the signal intensity on T1 and T2 sequences.
- **CT is the preferred modality when acute hemorrhage is suspected.**
- Breakdown of blood proceeds as follows
  - Intracellular oxyhemoglobin
  - Intracellular deoxyhemoglobin
  - Intracellular methemoglobin
  - Extracellular methemoglobin
  - Hemosiderin (this is what causes dephasing on GRE)

# AGING OF BLOOD ON MRI

**TABLE 4.4 MRI Appearance of Intracranial Hemorrhage**

| TIME SINCE HEMORRHAGE | T1-WEIGHTED | T2-WEIGHTED |
|---|---|---|
| Acute: first 6–24 hours (intracellular oxyhemoglobin) | Gray | Light gray |
| Early subacute: 1–5 days (intracellular deoxyhemoglobin) | Gray | Dark gray |
| Middle subacute: 3–7 days (intracellular methemoglobin) | White | Dark gray |
| Late subacute: 3–30 days (extracellular methemoglobin) | White | White |
| Chronic: >14 days (hemosiderin, mainly on outer rim) | Dark gray | Black |

*Note*: The actual sequence of changes in the appearance of hemorrhage on MRI scans can be fairly complicated and variable, depending on individual scanners.

***NEUROANATOMY 2e*, Table 4.4**



As you can see, the grey and light grey signal intensities might be difficult to distinguish from normal structures in acute hemorrhage.
Most important take away is that prior to 6 hours, acute hemorrhage might not be visible on an MRI.

# *END OF PART 1*

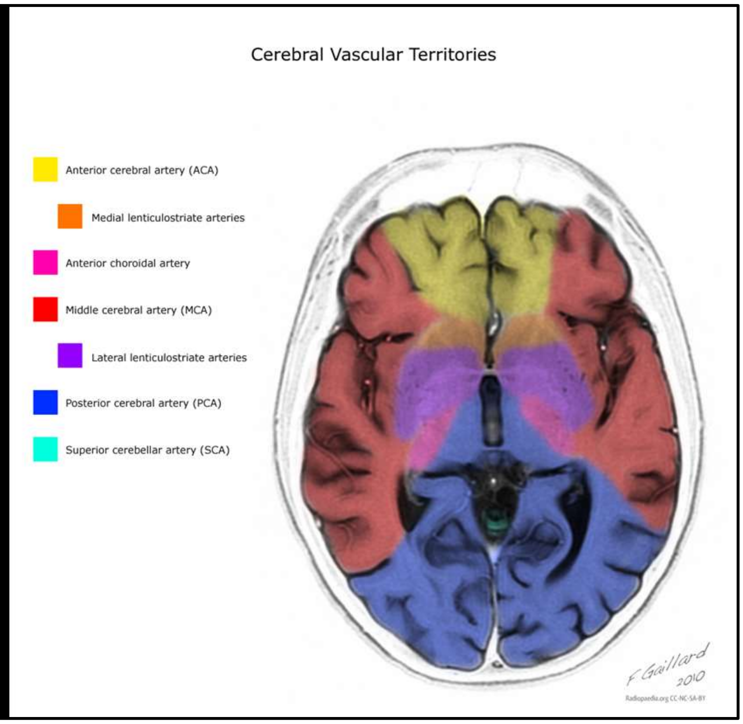
# PART 2: NORMAL MRI

# *VASCULAR TERRITORIES*

# *Large Vessel Territories*

Try to predict deficits from your knowledge of neuroanatomy from the affected territories:

- MCA
- ACA
- PCA




Case courtesy of Assoc Prof Frank Gaillard, Radiopaedia.org, rID: 10814

# *ANGIOGRAPHY*

# *Catheter Angiography*

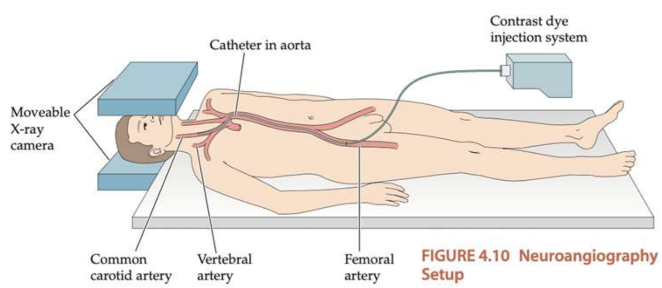


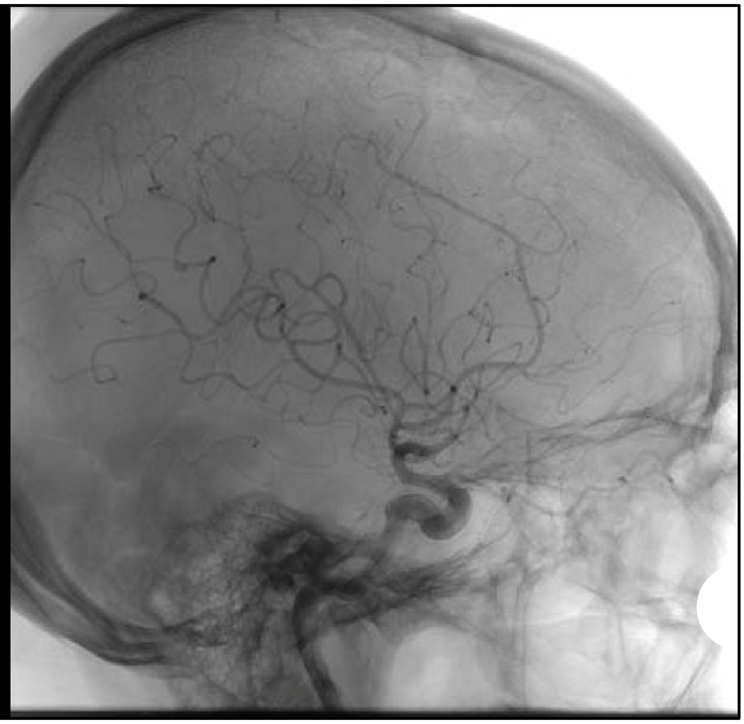
FIGURE 4.10 Neuroangiography Setup

- A catheter is inserted into the femoral artery.
- Threaded up into the common carotid or more distally.
- Digital Subtraction Angiography (a type of fluoroscopy) is used to capture images of the intracerebral vasculature with high fidelity.
- This often used in conjunction with procedures such as thrombectomy or aneurysm coiling/stenting.

Usually performed by an interventional radiologist, though many institutions have interventional neurologists and neurosurgeons who can do this.

# *Sagittal view ICA*

- Can see the internal carotid leading into the intracerebral portion.
- Then branching into the MCA and ACA along with more distal branches.
- The X-ray camera is on a gantry and can be moved around a central axis to visualize the vasculature at different angles.



**Case courtesy of Mr Brendan James Erskine, Radiopaedia.org, rID: 46308**


## CT ANGIOGRAM

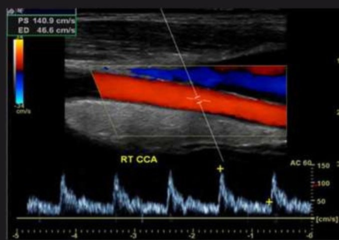
Colorized

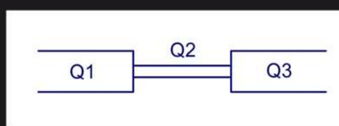
Color renderings such as seen on the right are rarely used clinically but look pretty cool. Both of these images are 3d reconstructions of source images from a CT Angiogram.

# *MRA: NECK VESSELS*

Switch to Horos for real MRA

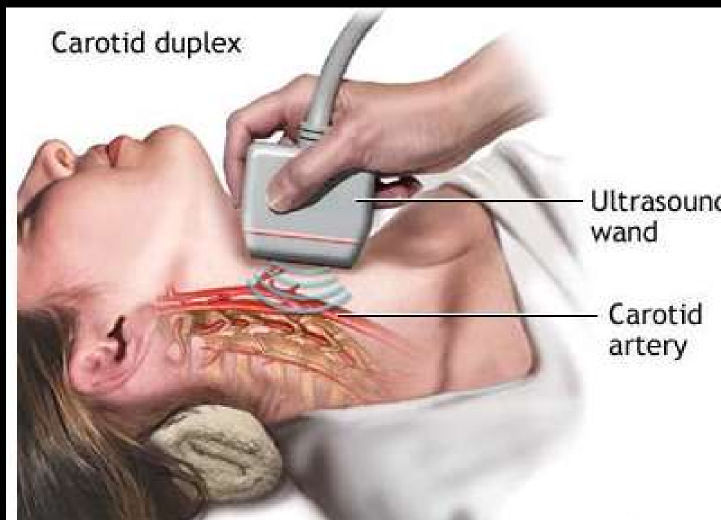
# *ULTRASOUND*




# *Carotid Doppler Ultrasound*

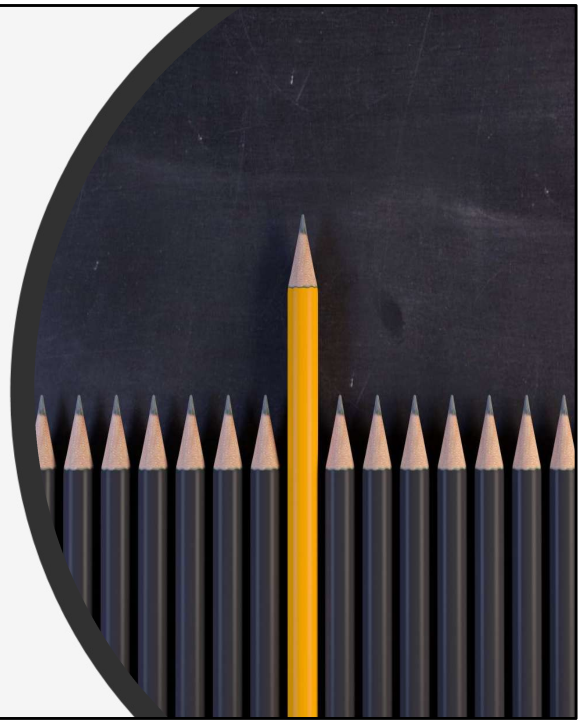
- **Bernoulli's principle**
- Flow through a vessel will remain constant.
- If there is a narrowed area, then the velocity will increase to maintain constant flow rate.
- Velocity difference will directly correlate to the percentage of stenosis.




# *CAROTID DOPPLER ULTRASOUND*

- Mostly used to for assessment of carotid stenosis.
- This is important in secondary stroke prevention.
- Can identify patients that might benefit from carotid endarterectomy or stenting

# *SELECTED CASES*



# *Acute Ischemic Stroke*

- 56 year old woman with a history of paroxysmal atrial fibrillation presented to the emergency department with right sided weakness and difficulty speaking. Her son is with her and reports that symptom onset was sudden, occurring about 60 minutes prior to arrival.

- Her examination shows right facial droop, arm and leg weakness.
- When attempting to answer questions, she produces only meaningless sounds, and is not following directions.
- Her eyes seem deviated toward the left.

# *First Move?*

- In terms of imaging, which is the best first modality in this case?
  - CT Head non-contrast
  - CT Head with contrast
  - MRI Brain without contrast
  - CT Angiography
  - Carotid Doppler

## *CT Head Non-contrast*

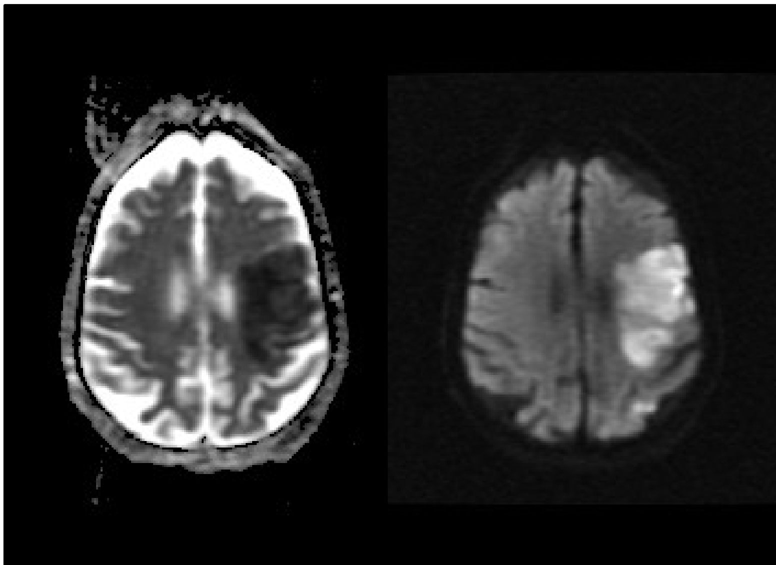
- Looking for subtle grey-white differentiation loss.
- Any hyperdensity within the parenchyma.
- Considering the signs and symptoms, which part of this image are you most focused on?

This CT scan is normal.

# *CT Head is normal, now what?*

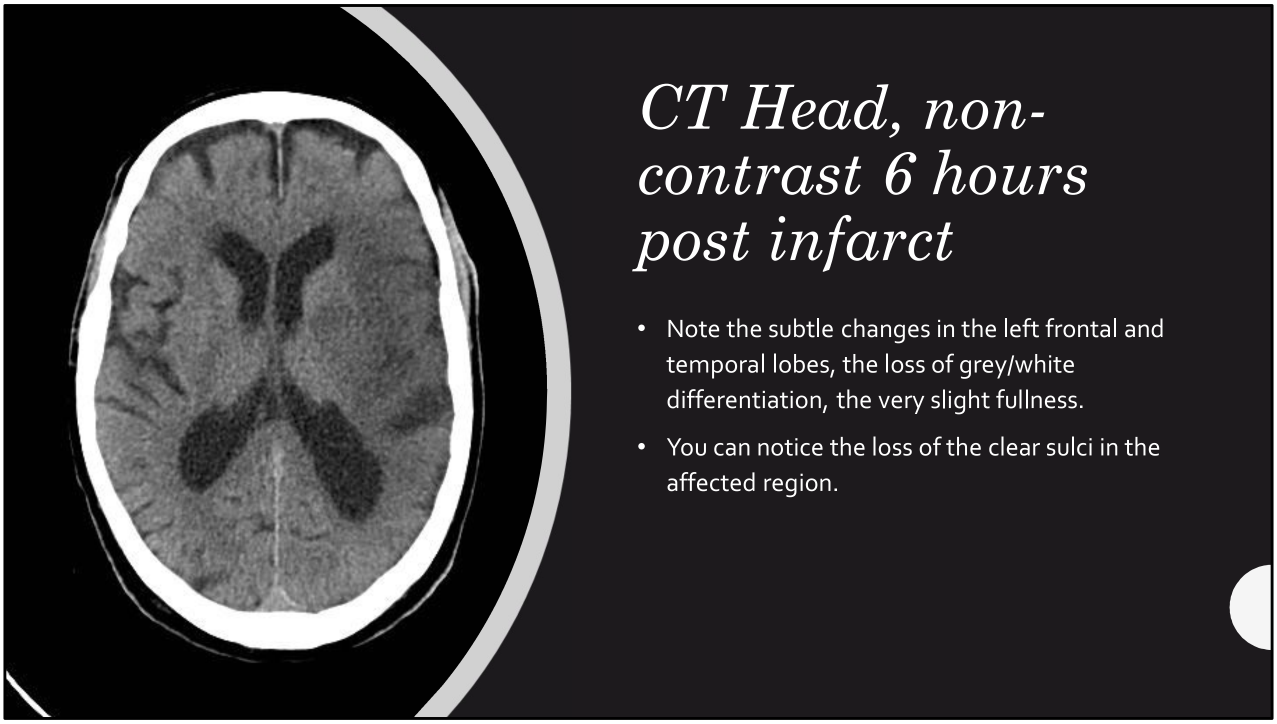
- In the workup of an acute neurologic deficit, an initial non-contrast CT Head is gold standard first imaging modality.
- The CT of the brain is frequently **normal** in acute ischemic stroke.
- Acute ischemic stroke can be clinically indistinguishable from acute hemorrhagic stroke, and a normal CT of the brain effectively rules out hemorrhage.
- The details of acute ischemic stroke management will be discussed later.
- If we want to show evidence of an ischemic stroke, which would be the best modality to use?

# *DIFFUSION WEIGHTED MRI*



ADC Map DWI

DWI bright, ADC dark – cytotoxic edema. These sequences are very sensitive to ischemic stroke and can become abnormal within 30 minutes of the onset of stroke, unlike CT which can take hours.




Note the subtle changes in the left frontal and temporal lobes, the loss of grey/white differentiation, the very slight fullness. You can notice the loss of the clear sulci in the affected region.

# *Acute Hemorrhagic Stroke*

- An 83 year old man presented to the emergency department with complaints of left sided weakness, numbness associated with severe headache, nausea and vomiting.

- His examination showed left facial droop, left arm and leg weakness, hemibody numbness.
- He had neglect and extinction for left sided stimuli.
- His speech was slurred.

# *First Move?*

- In terms of imaging, which is the best first modality in this case?
  - CT Head non-contrast
  - CT Head with contrast
  - MRI Brain without contrast
  - CT Angiography
  - Carotid Doppler

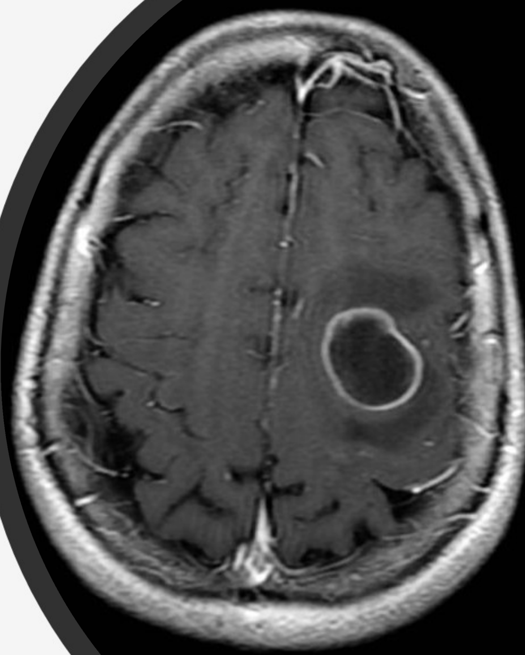
# *CT Head Non-contrast*

- Large hyperdensity in the right deep white matter
- Midline shift
- Some extension into the right lateral ventricle can be seen in the frontal horn.

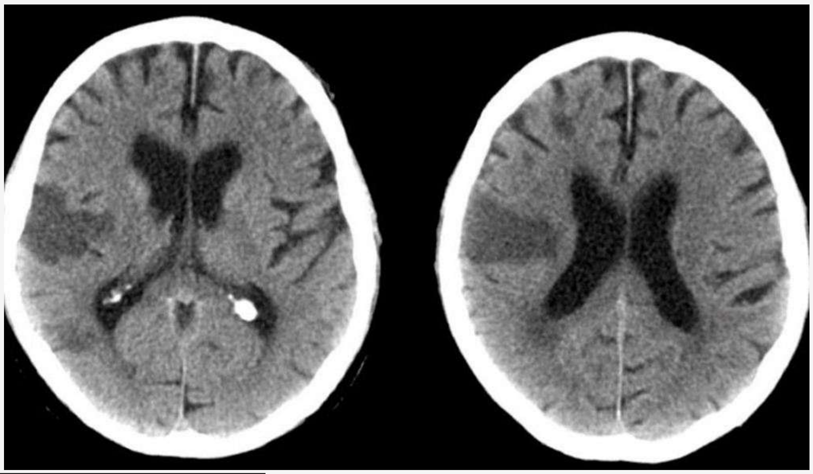
https://www.researchgate.net/figure/Brain-CT-of-case-1-indicating-a-massive-intracerebral-hemorrhage-on-the-right-basal_fig1_223958831

# *RING ENHANCING LESION*

- Very broad differential
- Breakdown of the blood brain barrier at the surrounding areas causes contrast enhancement
- Possible etiologies include:
  - Demyelinating lesions (though usually incomplete ring)
  - Infection
  - Tumor

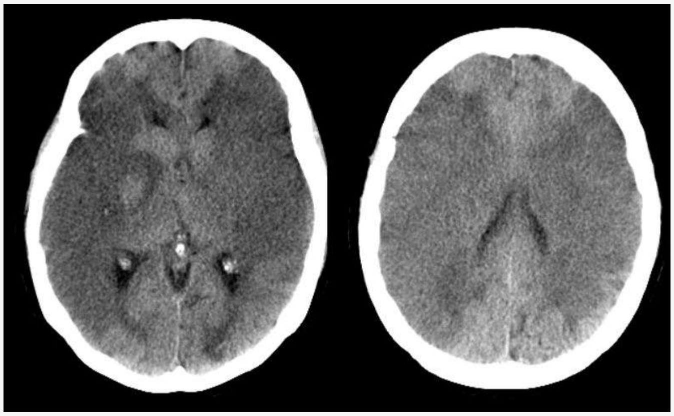


# *MCA Ischemic Stroke (Cortical branch)*



http://www.neuroradiologycases.com/2012/09/ischemic-stroke-and-vascular.html

*BILATERAL MCA INFARCT*



# Neuroradiology Resources

- There's nothing like scrolling through the images yourself, try www.Radiopaedia.org for real cases, frequently annotated very well by talented radiologists and radiology residents.
- *Caveat – Radiopaedia is a user generated content website and as such is not an acceptable reference for clinical decision making. If you find something on the site that is confusing or inconsistent with what you have been taught you will need to find another reference for it.
- The Blumenfeld's text contains great images for correlating the structural material.
- The Duane Haines Neuroanatomy Atlas also contains imaging correlates.
- You will receive more abnormal imaging as we go through the specific pathologies of the nervous system.