2010 Spring Clinical MRI Education Seminar

Applications of MRI in Neurological Diagnostic Imaging

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Objectives

- Review fundamental clinical cases that illustrate the wide array and utility of available neuroradiology MR imaging techniques / applications
- Gain insight into the rationale behind MR imaging protocols
- Develop a greater understanding of potential points of patient care impact
Outline

- Review fundamental clinical cases that illustrate the wide array and utility of available neuroradiology MR imaging techniques:
  - Gradient echo / SWI
  - Diffusion
  - FLAIR
  - IR-SPGR / MP-RAGE
  - MRA / MRV
  - Spectroscopy
  - Perfusion

- Review potential points of patient care impact:
  - Additional patient history?
  - Would an additional study or different protocol be better?
  - Would intravenous contrast be helpful?
  - Are the referring physician and/or neuroradiologist aware of critical findings?
Brain – Screen

• Indications
  – Screen, Altered mental status, Dementia, Psychiatric disorder, Headaches

• Sequences
  – 3 PL LOC
  – Sag T1 SE
  – Ax T2 FLAIR
  – Sag T2 FLAIR
  – Ax T1 SE
  – Ax T2 TSE FS
  – Ax DWI EPI
  – Cor T2 TSE

• Comments
  – Axial scans should be parallel to the AC-PC line
25 year-old pregnant female with mental status change
Potential Points of Impact

- **Patient history?**
  - Do we know more than “mental status change”?
  - Onset of symptoms?
  - Hypertension? Pregnancy? Steroids?

- **Sequences to consider anticipating?**
  - MRI brain without contrast => evaluate for acute ischemia
  - Avoid contrast with pregnancy!
Posterior Reversible Encephalopathy Syndrome (PRES)

- Associated with diverse clinical entities:
  - acute glomerulonephritis, preeclampsia / eclampsia, SLE, TTP, hemolytic-uremic syndrome, drug toxicity (e.g. cyclosporine, tacrolimus, cisplatin, and erythropoietin)

- Most cases manifest with acute to subacute hypertension, and seizures are also frequent

- Two pathophysiologic mechanisms:
  - Cerebral vasospasm and resulting ischemia
  - Breakdown in cerebrovascular autoregulation with ensuing interstitial extravasation of fluid

- Diffusion MR imaging - used to discriminate
  - Cytotoxic edema - cerebral ischemia - decreased water mobility
  - Vasogenic edema - cerebrovascular autoregulatory dysfunction - increased water mobility
Middle-aged female with new onset parasthesias
Potential Points of Impact

• Patient history?
  – Do we know more than “parasthesias”?
  – Onset of symptoms? Prior history?
  – Neurologic deficits?

• Sequences to consider anticipating?
  – Sagittal FLAIR imaging (eg. multiple sclerosis)
  – Post-contrast images
Multiple Sclerosis

- Demyelinating condition of the central nervous system - generally considered to be autoimmune

- White matter tracts are affected, including those of the cerebral hemispheres, infratentorium, and spinal cord

- Clinical diagnosis supported by radiologic findings
3 month-old male with obtundation
Potential Points of Impact

- Patient history?
  - Do we know more than “obtundation”?
  - Onset of symptoms?
  - History of cardiopulmonary arrest?

- Are the referring physician and/or neuroradiologist aware?

- Other studies to consider anticipating?
  - MRI => confirm suspected acute ischemia
Diffuse hypoxic-ischemic cerebral injury

• Major cause of morbidity in children
  – Clinical discrepancies raise possibility of nonaccidental trauma

• Several possible reasons for anoxic injury:
  – Anoxic anoxia - not enough oxygen – uncommon
  – Anemic anoxia - not enough blood or hemoglobin
    • acute hemorrhage
    • chronic anemia
    • carbon monoxide poisoning
  – Stagnant (ischemic) anoxia (hypoxic-ischemic injury) - not enough blood flow – most common
    • localized (such as ischemic strokes)
    • generalized (circulatory collapse / arrhythmias / cardiac arrest)
Headache
Potential Points of Impact

• Patient history?
  – Do we know more than “headache”?
  – Onset of symptoms? Recent trauma?
  – Neurologic deficits?

• Are the referring physician and/or neuroradiologist aware?
Subarachnoid hemorrhage

- Differential diagnosis of hyperintense FLAIR signal within subarachnoid space:
  - Subarachnoid hemorrhage
  - Meningitis / pus
  - Carcinomatosis
  - Supplemental oxygen
    - Caution: Most sedated / general anesthesia patients will have this finding
Brain – Tumor or Infection

• Indications
  – Tumor, Infection, Meningitis, Encephalitis

• Sequences
  – 3PL LOC
  – SAG T1 SE
  – SAG T2 FLAIR
  – AX T2 FLAIR
  – AX T1 SE
  – _Inject_
  – AX T2 TSE FS
  – AX DW EPI
  – SAG T1 IRSPGR 3D +C
  – AX T1 IRSPGR 3D +C MPR
  – COR T1 SE FS +C
  – SAG T1 SE +C OPT
  – AX T1 SE +C OPT

• Optional
  – SPECT – Single Voxel
  – SPECT – Multi Voxel
Mechanisms of contrast enhancement

- Combination of two primary processes in the central nervous system:
  1. intravascular (vascular) enhancement
  2. interstitial (extravascular) enhancement
Intravascular enhancement

• Proportional to increases in blood flow or blood volume

• Related to different pathologic / physiologic processes:
  – Neovascularity
  – Vasodilation or hyperemia
  – Shortened transit time or shunting
Interstitial enhancement

• Alterations in permeability of **blood-brain-barrier (BBB)**
  – Semi-permeable capillary membranes within brain, spinal cord, and proximal nerves - protect from plasma proteins and inflammatory cells
  
  – Result of endothelial cell specialization – requires close relationship of the foot process of the perivascular astrocytes
  
  – Neural capillaries have a continuous basement membrane, narrow intercellular gaps, junctional complexes, and a paucity of pinocytotic vesicles
  
  – Blocks lipophobic compounds and creates a unique interstitial fluid environment for neural tissues
Blood-Brain Barrier (BBB)
Interstitial enhancement

- Alterations in BBB permeability related to different pathologic / physiologic processes:
  - New blood vessels (angiogenesis)
  - Active inflammation (infectious and noninfectious)
  - Cerebral ischemia
  - Pressure overload (eclampsia and hypertension)
Extraaxial enhancement

- **Pachymeningeal**
  - **Dura mater**
    - Comprises two fused membranes derived from embryonic meninx primativa: (1) periosteum of inner table of skull and (2) meningeal layer.
    - May be adjacent to bone, or involve dural reflections of falx cerebri, tentorium cerebelli, falx cerebelli, and cavernous sinus.
    - Also described as *dura-arachnoid enhancement*.
      - Normal, thin arachnoid membrane is attached to inner surface of dura.
  
- **Leptomeningeal**
  - **Pia mater and arachnoid**
    - May occur on surface of brain or in subarachnoid space.
    - Also described as pial or *pia-arachnoid enhancement*.
      - Follows along pial surface of brain and fills subarachnoid spaces of sulci and cisterns.
      - Usually described as having a "gyriform" or "serpentine" appearance."
Anatomy - meninges
Pachymeningeal or Dura-Arachnoid Enhancement

- May arise from various benign or malignant processes
  - Transient postoperative changes
    - May be dura-arachnoid and/or pia-arachnoid
  - Intracranial hypotension
  - Neoplasm
    - Meningioma
    - Metastatic disease (e.g. breast and prostate cancer)
    - Secondary CNS lymphoma
  - Granulomatous disease
Dura-arachnoid pachymeningeal enhancement

Smirniotopoulos, J. G. et al. Radiographics 2007;27:525-551
Pia-arachnoid leptomeningeal enhancement

Smirniotopoulos, J. G. et al. Radiographics 2007;27:525-551
Leptomeningeal or Pia-Arachnoid Enhancement

- Enhancement of pia mater; enhancement extends into subarachnoid spaces of sulci and cisterns
- Primary mechanism of enhancement is via breakdown of blood-brain barrier without angiogenesis
- Usually associated with meningitis
  - Bacterial
    - Typically thin and linear enhancement
  - Viral
    - Typically thin and linear enhancement
    - May also produce enhancement along cranial nerves
  - Fungal
    - May produce thicker, lumpy, or nodular enhancement
Leptomeningeal or Pia-Arachnoid Enhancement

• **“Carcinomatous meningitis”**
  – Neoplasms may produce enhancement of brain surface and subarachnoid space
    • May produce thicker, lumpy, or nodular enhancement, similar to that of fungal meningitis

  – Primary tumors
    • Medulloblastoma, ependymoma, glioblastoma, and oligodendroglioma

  – Secondary tumors
    • Lymphoma, breast cancer
Cortical gyral enhancement

Smirniotopoulos, J. G. et al. Radiographics 2007;27:525-551
Cortical Gyral Enhancement

• Superficial intraaxial enhancement
  – usually caused by vascular or inflammatory / infectious processes
  – rarely neoplastic

• Vascular causes:
  – Reperfusion of ischemic brain / subacute infarction
  – Migraine headache
  – Posterior reversible encephalopathy syndrome (PRES)
  – Seizures

• Inflammatory / infectious causes:
  – Meningoencephalitis
Subcortical nodular enhancement

Smirniotopoulos, J. G. et al. Radiographics 2007;27:525-551
Nodular Cortical and Subcortical Enhancement

- Typical for hematogenous dissemination of metastatic disease and clot emboli

- Metastatic disease usually travels into brain through arteries and less commonly via venous system - majority are supratentorial

- Metastatic lesions are typically subcortical, occurring in or near the gray matter–white matter (corticomedullary) junction

- Angiogenesis allows metastases to grow larger but also produces BBB abnormality, which results in contrast enhancement and considerable perilesional vasogenic edema

- Because of location, cortical and subcortical metastases, even as small lesions, are likely to cause noticeable neurologic symptoms, including seizures
Deep white matter ring-enhancing lesions, especially those with mass effect and surrounding vasogenic edema, are most often either primary neoplasms (e.g., glioblastoma multiforme) or abscesses.

Metastatic deposits are often solid nodular lesions that may become ring-enhancing because of necrosis (e.g., after chemotherapy or irradiation).

Consider infectious etiology (brain abscess) in patients with subacute bacterial endocarditis, indwelling catheters, or other implanted devices (e.g., cardiac valves).
Smooth ring-enhancing pattern in late cerebritis and subsequent cerebral abscess

Smirniotopoulos, J. G. et al. Radiographics 2007;27:525-551
Necrotic ring pattern of high-grade neoplasms

Smirniotopoulos, J. G. et al. Radiographics 2007;27:525-551
37 year-old male with mental status change
Potential Points of Impact

• Patient history?
  – Do we know more than “mental status change”?
  – Onset of symptoms?
  – Neurologic deficits? Fever? Elevated WBC?

• Other studies to consider anticipating?
  – MRI brain => include post-contrast images
  – Include ADC map to assess diffusion restriction
Cerebral abscess

- **Key characteristics:** central diffusion restriction; rim enhancement; vasogenic edema

- **Differential diagnosis:**
  - Non-Hodgkin’s lymphoma
    - Can have rim enhancement and restricted diffusion, but usually iso-to low T2 signal
  - GBM
    - Usually more heterogeneous, without large fluid center or diffusion restriction
  - Tumefactive MS (multiple sclerosis)
  - Metastasis
  - Resolving hematoma
  - Infarct
65 year-old female with altered mental status
Potential Points of Impact

- Patient history?
  - Do we know more than “altered mental status”?
  - Onset of symptoms?
  - Neurologic deficits? Fever? Elevated WBC?

- Other studies to consider anticipating?
  - MRI brain => include post-contrast images, particularly if infectious process is suspected
Meningitis / Ventriculitis

- Debris in ventricles with ependymal enhancement → ventriculitis

- Can have ependymal enhancement with NHL, spread of GBM, etc. but usually more nodular/focal and w/o debris

- Often associated with abscess rupture or indwelling shunt catheter

- 40-80% mortality but often indolent
45 year-old female who presented with severe headache; recent lumbar puncture performed for suspected meningitis
Potential Points of Impact

• Patient history?
  – Do we know more than “severe headache”?
  – Any neurologic symptoms?
  – Recent surgery?

• Other studies to consider anticipating?
  – MRI brain WITH contrast – concern for meningitis
Intracranial Hypotension

- Result of low CSF volume caused by:
  - Head trauma
  - Tear in spinal nerve root sheath, perineural cyst, or spinal arachnoid diverticulum
  - Iatrogenic causes
    - Lumbar puncture
    - Overdraining ventricular or spinal shunts
  - Spontaneous
    - Results from rupture of spinal arachnoid membrane, which allows CSF passage into subdural or epidural space
Brain – Trauma / Hemorrhage

• Indications
  – Trauma, Hemorrhage

• Sequences
  – 3 PL LOC
  – Sag T1 SE
  – Sag T2 FLAIR
  – Ax T2 FLAIR
  – Ax T1 SE
  – Ax T2 TSE FS
  – Ax DWI EPI
  – Cor T2 TSE
  – **Ax GRE or SWI**

• Comments
  – Axial GRE should have TE > 25 ms
7-month old male with scalp swelling
Potential Points of Impact

- **Patient history?**
  - Do we know more than “scalp swelling”?
  - History of trauma or fall?

- **Are the referring physician and/or neuroradiologist aware?**
  - Must exclude non-accidental trauma

- **Other studies to consider anticipating?**
  - CT => characterize suspected fracture and evaluate for potential associated intracranial hemorrhage
    - Soft tissue and bone algorithms
  - MRI => assess for additional parenchymal injuries and potentially assist with injury / hemorrhage dating
Non-accidental trauma

- CT - recommended in initial evaluation of non-accidental trauma
  - High sensitivity in detecting acute intracranial bleed, fractures, cerebral edema and hypoxic-ischemic injury
  - Attenuation of subdural / epidural hematoma varies by chronicity:
    - Acute - hyperdense
    - Subacute – isodense
    - Chronic – hypodense

- MRI - essential second investigation
  - Best performed 5-10 days after insult
  - Reliably differentiate between acute and chronic subdural hematoma
  - Most sensitive modality for detecting early ischemic changes
  - Clearly delineates anatomic locations difficult to image with CT
    - posterior fossa, anterior part of middle cranial fossa, close to inner table of skull
80 year-old male with dementia that has progressed over the past 4 years
Potential Points of Impact

• Patient history?
  – Do we know more than “dementia”?
  – Previous CVA symptoms? Risk factors?
  – Neurologic deficits?

• Other studies to consider anticipating?
  – GRE imaging – evaluate for previous hemorrhage associated with infarcts
Figure 3b. Sensitivity of GRE imaging for hemosiderin in an 80-year-old man with dementia that has progressed over the past 4 years.

Chao C P et al. Radiographics 2006;26:1517-1531

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Figure 3a. Sensitivity of GRE imaging for hemosiderin in an 80-year-old man with dementia that has progressed over the past 4 years.

Chao C P et al. Radiographics 2006;26:1517-1531

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Cerebral Amyloid Angiopathy

• Cerebrovascular disorder characterized by deposition of β-amyloid protein in the media and adventitia of small and medium-sized vessels

• Both sporadic and hereditary forms may occur

• Manifests radiologically as part or all of a constellation of findings including acute or chronic ICHs in a distinctive cortical-subcortical distribution, leukoencephalopathy, and atrophy
Susceptibility-Weighted Imaging

- 3D high-resolution velocity-compensated gradient-echo sequence that exploits magnetic properties of tissues

- Refers to use of resultant magnitude and phase images, or a combination thereof

- Can provide detailed assessment of venous architecture
**T2* Technique**

**T₂* relaxation**

- dephasing of transverse magnetization due to both:
  - microscopic molecular interactions (T₂)
  - spatial variations of the external main field ΔB

(tissue/air, tissue/bone interfaces) – susceptibility differences

- **SWI** => T₂* technique that enhances local contrast by utilizing relatively long TE

- **Long TE**
  - ~40 ms at 1.5 T
  - ~25 ms at 3.0 T

- **Scan Time ~ 7 minutes**

*Source: Jorge Jovicich*
High-Frequency Phase Image

- Use 2D Hanning filter (in k-space) to smooth original image
- Divide original image by the smoothed image
  - Phase unwrapped image
  - Image with high frequency phase information

Phasemap of original Image
Phasemap of 2D Hanning filtered image
High pass phase Image

Adapted from Magnetic Resonance Systems Research Lab – Stanford University
Phase Mask

- Produce phase mask:
  - If phase >= 0, resulting phase mask value = 1
  - If phase < 0, resulting mask value = \( \frac{\text{ph}(x) + \pi}{\pi} \)

- Normalize phase mask (range: 0 to 1)
  - Using triangle function

Adapted from Magnetic Resonance Systems Research Lab – Stanford University
Enhanced Magnitude Image

- Multiply phase mask by original magnitude image
- can be multiplied 3 - 8 times

Phase mask ^4 X Magnitude → SWI Processed Image

Adapted from Magnetic Resonance Systems Research Lab – Stanford University
Traumatic Brain Injury

Routine GRE

SWI

Thomas, Bejoy, et. al. Neuroradiology (2008) v50
Amyloid Angiopathy

Imaging Cerebral Amyloid Angiopathy using Susceptibility-Weighted Imaging
Haacke et al, AJNR February 2007
Brain – Seizure / Dysplasia

- **Indications**
  - Seizure, Dysplasia, Mesial temporal sclerosis

- **Sequences**
  - 3 PL LOC
  - Sag T1 SE
  - Ax T2 FLAIR
  - Ax T1 SE
  - Ax T2 TSE FS
  - Ax DWI EPI
  - **Cor T2 TSE** (angled perpendicular to temporal lobes)
  - **Cor FLAIR** (angled perpendicular to temporal lobes)
  - **Ax IR-SPGR / MP-RAGE** or **Cor IR-SPGR / MP-RAGE**

- **Comments**
  - Coronal sequences should be thin section perpendicular to the long axis of the hippocampus
2 year-old female with seizures
Potential Points of Impact

• Patient history?
  – Do we know more than “seizures”?
  – Onset of symptoms?
  – Prior studies / previous surgery / trauma?

• Pulse sequences to consider anticipating?
  – Axial IR-SPGR / MP-RAGE
  – Coronal T2 and FLAIR through hippocampi
Periventricular Nodular Heterotopia

- In a normal brain, much of the gray matter (consisting mostly of nerve cells) appears on the brain surface, while white matter (consisting mostly of nerve fibers interconnecting areas of gray matter) runs deeper.

- In PNH, a migrational abnormality occurs during development - portions of gray matter sit deep in the brain core, within the white matter, having failed to migrate out to the surface.
  - May serve as elliptogenic foci.
Brain – Advanced Protocols

- Dural venous sinus thrombosis
  - Cor 2D TOF SPGR
  - Sag 2D TOF SPGR (slight oblique angle)

- Stroke, TIA, Vertebrobasilar infarct, Aneurysm
  - Ax 3D TOF SPGR
  - Ax Perfusion

- Tumor, Metabolic abnormality
  - Single voxel spectroscopy (short and long echo; eg. TE 35 and 144) on all new mass lesions
  - Multi voxel spectroscopy - suspected gliomas
  - Perfusion
    - Gd – 20 ml @ 3-5 ml/s
30 year-old female with mental status changes
Potential Points of Impact

• Patient history?
  – Do we know more than “mental status changes”?
  – Any neurologic symptoms?
  – Recent surgery? Dehydration?

• Are the referring physician and/or neuroradiologist aware?

• Other studies to consider anticipating?
  – CTV head + contrast; reconstructions / MIP images
  – MRI brain – evaluation for ischemia / hemorrhage
Dural Venous Thrombosis

- **MRI**
  - Main sign is lack of expected signal flow void on standard T1- and T2-weighted images
  - Challenging diagnosis in acute stage
    - Hypointense signal of acute thrombus mimics normal flow void on T2-weighted images
    - Absence of flow void on T1-weighted images must be carefully sought because thrombus may be isointense / mildly hyperintense to brain tissue
69 year-old female with chronic headache
Potential Points of Impact

- **Patient history?**
  - Do we know more than “headaches”?  
  - Any neurologic symptoms?

- **Concern for cerebral aneurysm?**

- **Other studies to consider anticipating?**
  - CTA head - reconstructions / MIP images  
  - Cerebral angiogram – if warranted
Basilar Tip Aneurysm

- Occurs at distal bifurcation of basilar artery, between origin of two posterior cerebral arteries

- Intracranial aneurysm distribution:
  - 30-35% => anterior communicating artery
  - 30-35% => posterior communicating artery origin
  - 20% => middle cerebral artery bifurcation
  - 5% => basilar artery bifurcation or tip
  - 1-5% => other posterior fossa vessels

- Conventional angiography – remains gold standard for detection and characterization of cerebral aneurysms

- CTA can detect more than 95% of aneurysms identified on conventional angiography
50 year-old male with brain tumor found on an outside hospital MRI study
Potential Points of Impact

• Patient history?
  – Do we know more than “tumor”?
  – Previous surgery?
  – Neurologic deficits?
  – Outside images available for radiologist review?

• Other studies to consider anticipating?
  – MR spectroscopy
  – MR perfusion
  – Post-contrast IR-SPGR (for radiation therapy)
MR Spectroscopy

- Useful in tumor evaluation and surgical / biopsy planning

- Although water and fat contribute virtually all of the signal in proton MR imaging, it is possible to suppress these signals and assess the signal from other metabolites including choline, creatine, and NAA

- Metabolic mapping of spectra allows rapid assessment of spectral peaks and choline map also demonstrates the most malignant site to biopsy

- Elevated choline probably represents the cell membrane breakdown secondary to the tumor, while NAA is a metabolite of normal neuronal tissue and creatine reflects energy stores
Middle-aged female with a brain tumor
Potential Points of Impact

• Patient history?
  – Do we know more than “tumor”?
  – Previous surgery and/or biopsy results?
  – Neurologic deficits?
  – Outside images available for radiologist review?

• Other studies to consider anticipating?
  – MR spectroscopy
  – MR perfusion
  – Post-contrast IR-SPGR (for radiation therapy)
MR Perfusion

- Useful in brain tumor evaluation and surgical / biopsy planning
- Uses contrast which has slightly different magnetic characteristics from blood - causes a disturbance in the localized magnetic field
- Signals are analyzed mathematically and expressed as an image (e.g. CBF, CBV, MTT maps). By offsetting the changes in shape in the flow of the contrast bolus against time, it is possible to calculate how much blood is reaching the area of concern within the brain.
THANK YOU!

HAVE A GREAT DAY!