PRINCIPLES OF IMAGING IN VASCULAR DISEASE

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ACKNOWLEDGMENTS

• SIEMENS MEDICAL
• GE MEDICAL SYSTEMS
• PHILIPS MEDICAL SYSTEMS
• TOSHIBA
• MEDICAL MEDIA SYSTEMS-M2S
• VITAL IMAGES
• TERARECON

• No financial disclosures
IMAGING MODALITIES

- DOPPLER ULTRASOUND
- DIGITAL SUBTRACTION ANGIOGRAPHY (DSA)
- MR ANGIOGRAPHY
- CT ANGIOGRAPHY
DIGITAL SUBTRACTION ANGIOGRAPHY
CONVENTIONAL ANGIOGRAPHY (DSA)

• “GOLD STANDARD”
  – High Resolution
  – Rapid Acquisition
  – Arterial and Venous Imaging
  – Diagnostic Angiography and Intervention Same Sitting
  – May Repeat Injections
CONVENTIONAL ANGIOGRAPHY

• DISADVANTAGES
  – Invasive
    • Patient Monitoring
  – Ionizing Radiation
  – Iodinated Contrast Media Nephrotoxicity
  – Multiple Injections for Multiple Views
ROTATIONAL ANGIOGRAPHY
3D Rotational Angio Process

Acquisition:
- Propeller – 4 sec.
- Roll – 6 sec.

Rotational Angio Run on Console:

Initial Reconstruction: 45-75 sec.
Radiation Safety

- Portable C-arm
  - Comparable power output to fixed suites
  - Less shielding
    - Greater exposure from scatter/leakage radiation
- FDA mandate all flouro machines report dose metrics
Radiation Safety

• Rad = radiation absorbed dose (.01 joules/kg)
  • 1 Gray = 100 rads

• Dose area product (DAP) = absorbed dose x area irradiated (Gy/cm²)

• Kerma - kinetic energy released in matter/unit mass (air)
Radiation Dosimetry

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<tr>
<th>Report status:</th>
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<tbody>
<tr>
<td>Cumulative fluoroscopy time:</td>
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<tr>
<td>Cumulative DAP (fluoroscopy):</td>
<td>234270 mGycm²</td>
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<td>Cumulative DAP (exposure):</td>
<td>356475 mGycm²</td>
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<tr>
<td>Total DAP:</td>
<td>590745 mGycm²</td>
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<td>Cumulative Air Kerma:</td>
<td>1,734.66 mGy</td>
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<tr>
<td>Total number of acquired runs:</td>
<td>18</td>
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<td>Total number of acquired images:</td>
<td>844</td>
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<tr>
<td>Total number of acquired exposure images:</td>
<td>799</td>
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</table>
Radiation Safety

Deterministic skin effects:
Patients receiving cumulative air kerma $> 3000$ mGy at risk for skin injury

Patient A - 8 weeks post angio
Patient B - post multiple procedures
CTA AND MRA

• DIFFERENT TECHNOLOGIES
• Non Invasive
• Volume Acquisition
  – Image Post Processing
    • MIP
    • MPR
    • 3D Volume Rendering
(MRI) MAGNETIC RESONANCE IMAGING

• Images generated based on behavior of hydrogen nuclei
  – when exposed to Magnetic Field Gradients
  – and Radiofrequency Waves

• 1.5 TESLA       3 TESLA
MR ANGIOGRAPHY

- PULSE SEQUENCE S

- Non-Contrast:
  - Time of flight angiography (2D OR 3D)
  - Phase contrast angiography

- Gd enhanced 3D TOF angiography (CE-MRA)
3D CE-MRA

• ADVANTAGES
  – Non Invasive
  – No Ionizing Radiation
  – Contrast “Less Nephrotoxic”
  – Post Processing Fast
    • Rapid Subtraction
    • Good Bone Removal
CE-MRA SUBTRACTION PROCESS

Contrast

Pre contrast
MAXIMUM INTENSITY PROJECTION ALGORITHM
MIP
MIP PROJECTION

Angle 5.0°
CE-MRA

• LIMITATIONS
  – Study Time
  – Patient Cooperation
    • Motion Artifact Degrades Image
  – Post Processing Times
  – Calcifications Not Well Seen
  – Resolution Less Than Angiography
MR CONTRAST AGENTS

- Contain gadolinium (Gd)
  - Highly paramagnetic

- Free Gd toxic
  - Metal bound to chelate $\rightarrow$ ligand (e.g. DTPA)
Gd BASED CONTRAST AGENTS

• Used since 1985
• Numerous safety studies
  – Dose : 0.1mmol/kg (0.2ml/kg)
• Moderately severe bronchospasm, facial edema, tachycardia, arrhythmias, urticaria 1 in 5,000
• Severe Anaphylactoid reactions 1 in 400,000

Goldstein et al. Radiology 1990;174:17-23
NEW DISEASE: NEPHROGENIC SYSTEMIC FIBROSIS

- Described 1999
- Fibrosis of skin, connective tissue, organs, contractures
- Potentially fatal
- Relationship to Gd contrast agents suggested in 2006

Cowper SE. Nephrogenic Fibrosing Dermopathy [NFED/NSF] Website
NEPHROGENIC SYSTEMIC FIBROSIS

- Increased risk NSF in patients
  - with acute or chronic severe renal insufficiency (GFR <30ml/min/1.73m²)

- FDA alert 2006, updated 5/23/07
- Boxed warning all agents: Magnevist, Multihance, Omniscan, OptiMARK, ProHance
NEPHROGENIC SYSTEMIC FIBROSIS FDA 9/9/10

- Magnevist, Omniscan, Optimark contraindicated in patients with AKI or chronic severe kidney disease
- Screen all patients for renal dysfunction: Hx and/or lab tests
- Avoid use in patients with known risk
- Do not exceed dose in product labeling
- Monitor for signs and symptoms in at risk patients
- Hemodialysis patients: consider prompt hemodialysis post administration
NSF

• Occurs weeks to months following exposure

• Associated with “Pro-inflammatory conditions”

• Risk in patients with mild to moderate renal insufficiency unknown

• NSF has not been reported in patients with normal renal function
INCIDENCE

• RARE

• Registries:
  – Cowper (ICNSFR): 380 patients
  – FAERS : 1395
  – Legal data set: 382

• Mortality 4/13 = 31%

CE-MRA

- APPLICATIONS
  - Carotid vessels
  - Thoracic aorta
  - Abdominal aorta and pelvic vessels
  - Renal arteries
  - Mesenteric vessels
  - Peripheral vessels
  - Venous system
Accuracy of MRA for internal carotid artery disease: meta-analysis

<table>
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<th>&gt;70% Stenosis</th>
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<tr>
<td></td>
<td>sens</td>
<td>spec</td>
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<tr>
<td>TOF MRA</td>
<td>91.2%</td>
<td>88.3%</td>
</tr>
<tr>
<td>CE MRA</td>
<td>94.6%</td>
<td>91.9%</td>
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</tbody>
</table>

Debrey SM. Stroke 2008:39;2237
Accuracy of MRA for internal carotid artery disease: meta-analysis

Moderately severe stenosis (50-69%)

<table>
<thead>
<tr>
<th>Method</th>
<th>Sens</th>
<th>Spec</th>
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</thead>
<tbody>
<tr>
<td>TOF MRA</td>
<td>37.9%</td>
<td>92.1%</td>
</tr>
<tr>
<td>CE MRA</td>
<td>65.9%</td>
<td>93.5%</td>
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</tbody>
</table>

Debrey SM. Stroke 2008;39:2237
CE-MRA AORTA

Arterial phase
CE-MRA ABDOMINAL AORTA

• ANEURYSMS
  – Monitoring Size
  – Considerations:
    • Renal Function
    • Patient Ability to Cooperate
CE-MRA
CHRONIC AORTIC DISSECTION

• MRA ADVANTAGES:
  • No Ionizing Radiation
  • Serial Follow-up
  • Multiplanar Viewing
CHRONIC AORTIC DISSECTION WITH GRAFT
CHRONIC AORTIC DISSECTION WITH GRAFT
RENAL ARTERY STENOSIS

- MRA widely used for screening
- Detect presence or absence of stenosis
- If abnormal, arteriography recommended
CE-MRA RENAL ARTERY STENOSIS

• LIMITATIONS
  – Assessment stenosis severity may be difficult
  – Fibromuscular dysplasia problematic
  – Stents produce signal dropout
MRA RENAL ARTERY
STENOSIS

Thin MIP
RENAL TRANSPLANT
MRA
MESENTERIC ISCHEMIA
TAKAYASU’S AORTITIS
CE-MRA PERIPHERAL VESSELS

- 1.5T OR 3T SYSTEM
- STATIONARY TABLE
- MOVING TABLE
3D TOF Gd ENHANCED MRA

- MOVING TABLE - COMBINATION
  - SINGLE STATION CALF (7CC - 21CC VOL)
  - STEPPING TABLE
    - Aortoiliac-Pelvis, Thighs (11CC - 31CC VOL)
Meta-analysis: Accuracy of CE-MRA for Assessing steno-occlusions in PAD

- 32 studies compared CE-MRA to DSA
- N= 1,022 patients
- For diagnosis stenosis < 50% vs ≥ 50% or occlusion
- Pooled sensitivity CE-MRA 94.7%
  specificity CE-MRA 95.6%

Meta-analysis: Accuracy of CE-MRA for Assessing Steno-occlusions in PAD

- **CE-MRA:**
  Correctly classified 95.3% steno-occlusions
  Overstaged 3.1%
  Understaged 1.6%

- **Conclusion:** MRA high accuracy for identifying or excluding clinically relevant lesions in patients with PAD symptoms.

MR IMAGING
VASCULAR MALFORMATIONS

• MRI important in diagnosis and follow-up
• MRI: delineates size lesion, extent of soft tissue involvement
• MRA shows vascular supply
VENOUS MALFORMATION
CENTRAL VEIN OBSTRUCTION
NEWER APPLICATIONS:

Total Body MRA
Time resolved MRA
3D Turbo spin echo MR angiography
TOTAL BODY MRA
TOTAL BODY MRA
Time Resolved MRA
3cc Magnevist

AVM
Left Distal Thigh
Newer MR contrast agent

- Feraheme (ferumoxytol)
  - Ultrasmall superparamagnetic iron oxide nanoparticle (USPIO)
5 y.o. ESRD. Non-Gd CE-MRA: Feraheme
CT ANGIOGRAPHY
CT BREAKTHROUGH: CTA MULTIDETECTOR-ROW ARRAY

• Combined HELICAL (SPIRAL) CT
  – Continuous CT Gantry Rotation
  – With continuous movement of table through scanner

• Multiple - Row Detector Array
MULTIDETECTOR-ROW CT

- Fast Gantry Rotation Time
- Powerful X-Ray Tubes
- Improved reconstruction algorithms
- Increased data collection with each rotation
- Rapid data acquisition
MULTIDETECTOR-ROW CT

- Shorter scanning time
- Greater longitudinal coverage
- Thinner Sections Large Territories
MULTIDETECTOR CTA

• ADVANTAGES
  – Fast
  – High Resolution

• DISADVANTAGES
  – Iodinated Contrast Agent
  – Ionizing Radiation
  – First Pass Technique – Single Bolus Injection
CTA AORTIC DISSECTION

- ACUTE DISSECTION
  - HIGH RESOLUTION
  - FAST
  - AVAILABILITY
ABDOMINAL AORTA

- ANEURYSMS
  - Monitoring Of Size
  - CTA or MRA
  - Considerations:
    - Patient ability to cooperate
    - Renal function
AORTIC ENDOGRAFTS

• CTA

  – Advantages:

    • Size Measurement for Endograft Selection
ENDOGRAFT FOLLOW-UP

• CTA
  – Less artifact from metallic components
  – Endoleaks better seen
  – Specialized software M2S, Terarecon, Vitrea
THORACIC ENDOGRAFT
CTA RENAL ARTERIES

- CTA or MRA
- Choice determined by clinical question
- Patient renal function
RENAL ARTERY CTA

- Renal Donors
  - CTA Resolution better for accessory arteries

- Renal Artery Stenosis
  - Useful for renal stent evaluation
CTA RENAL ARTERY ANEURYSM
MESENTERIC ISCHEMIA

- CTA: Acute Ischemia
- MRA: Chronic Ischemia
  - Elderly patient screening
CTA MESENTERIC STENT
Stent Migration - 3D Reconstruction

CTA

MRA
CTA PERIPHERAL VESSELS
CTA PERIPHERAL VESSELS REQUIREMENTS

• Need to cover large volume
  – 100cm
  – Aortic bifurcation to feet

• Image acquisition during arterial phase
16 ROW MDCT CTA

• Advantages:
  • Large Volume Coverage In Shorter Time
    – 100cm In 21.4 Sec
    – 5x Faster Than 4 Row MDCT
  • Same Resolution And Slice Thickness
  • Comparable Or Lower Dose Than 4 Row MDCT
16 ROW OR HIGHER MDCT SCANNER:

TOTAL BODY SCAN
MULTDETECTOR- ROW HELICAL CT

• ISSUES:
  – Large Number Transverse Images
    Produced: 908-2,131
  – Workstation viewing

• POST PROCESSING REQUIRED
  – Bone and soft tissue removal
IMAGE POST PROCESSING

• MPR
• MIP
• 3D VOLUME RENDERING
• TRANSPARENCIES
• EDITING AND SEGMENTATION
IMAGE POST PROCESSING

- Critical for accurate diagnosis
- Time consuming
- Dedicated personnel
MULTIDETECTOR-ROW CT

ACCURACY OF TECHNIQUE?
CTA in PAD Meta-analysis 2009

- 909 studies: 20 met inclusion criteria (2.2%)
- 957 patients
- CTA
  - Sensitivity > 50% stenosis or occlusion = 95%
  - Specificity = 96%

Met R, et al. JAMA 2009;301:415
CTA in PAD: Meta-analysis 2009

- Occlusions correctly identified in 94% segments
- >50% stenosis in 87%
- Absence stenosis in 96% segments
- Overstaging in 8%
- Understaging 15%

Met R, et al. JAMA 2009; 301:415
MDCT-CTA VS ANGIOGRAPHY

- DSA Higher Resolution
- Both require large volume contrast
- CTA One Injection
- CTA - Timing Critical:
  - Venous Contamination
  - Small Vessels e.g. Foot
RADIATION EXPOSURE

• CALCULATED EFFECTIVE DOSE INDEXES
  – 0.93 cSV 4 Row MDCT
  – 3.62 cSV Conventional angiography

• Radiation exposure 3.9x greater with angiography

• 16 Row, 64 Row dose modulation techniques
Diagnostic Performance CTA and CE-MRA in CLI and IC
Systematic Review and Meta-analysis

- 1995-2013
- 12 CTA articles 673 patients
- 30 CE-MRA articles 1404 subjects

Diagnostic Performance CTA and CE-MRA in CLI and IC
Systematic Review and Meta-analysis

<table>
<thead>
<tr>
<th>Aortotibial</th>
<th>Sensitivity</th>
<th>Specificity</th>
</tr>
</thead>
<tbody>
<tr>
<td>CTA</td>
<td>96%</td>
<td>95%</td>
</tr>
<tr>
<td>CE-MRA</td>
<td>93%</td>
<td>94%</td>
</tr>
</tbody>
</table>

Diagnostic Performance CTA and CE-MRA in CLI and IC
Systematic Review and Meta-analysis

- CTA CE-MRA both accurate for diagnosis PAD
- Performance not different in CLI or IC
- Separate imaging of tibial arteries by CE-MRA preferred

NEWER DEVELOPMENTS

DSA-CT COMBINATION

DUAL SOURCE CT
CT-DSA COMBINATION
XperCT
DUAL SOURCE CT

Lv, P. et al. AJNR 2014
CONCLUSION

- VARIETY OF IMAGING TECHNIQUES AVAILABLE
- SELECTION DETERMINED BY CLINICAL QUESTION AND CLINICAL STATUS OF THE PATIENT
- TECHNICAL RESOURCES
THANK YOU
QUESTIONS

Nephrogenic systemic fibrosis is:

1) A common disease  True  False
2) Associated with iodine containing contrast agents  True  False
3) Seen in patients with normal renal function  True  False
The imaging modality most helpful for initial imaging in patients with suspected acute aortic dissection is:

1) MR/MRA  True  False
2) CT/CTA  True  False
QUESTION

Which of the following are true:

1) MRA and CTA are equally good for assessing stent patency

2) Calcifications are better seen on MR imaging

3) CT imaging is faster than MR imaging