Imaging of Pediatric MSK Tumors

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Tumor Imaging Goals

**Diagnosis**
- Lesion characterization
- Benign vs malignant
- DDX
- Extent of disease

**Treatment**
- Size, extent
- Treatment response
  - Tissue characterization (necrosis vs growth)
  - RECIST guidelines
- Surgical planning
  - Relationship to neurovascular structures
  - Measurements for custom reconstruction

**Surveillance**
- Local recurrence
- Metastatic search
Current MR Imaging Goals

• Highest resolution
  – even at small FOV
  – reduce motion artifact

• Tissue characterization
  – Functional imaging
  – Metabolic imaging

• Decrease sedation

• Increase acquisition speed
At Diagnosis

Normal RM

Stress fx

EWS

Leukemia
Tumor Mimics/Pitfalls

- Inflamatory lesions
  - Osteoid osteoma
  - Chondroblastoma
  - Infection
  - Myositis ossificans
  - Histiocytosis
  - CRMO (CNO)

- Trauma/stress fracture

19 y.o. right elbow mass
Two 15 year olds with rt knee pain

D. Femur stress fx, p. tibia stress reaction

Primary bone lymphoma
Primary Osseous Lymphoma

- 6% of 1° bone tumors, <10% of pediatric NHL
- B-cell NHL
- Commonly involves epiphyses and equivalents
- MR - “Infarct-like” appearance, sequestra
- 10-15% metastases at dx
Epidemiology: 90% of malign. pediatric bone tumors

**Osteosarcoma**

- ~ 400 new cases/yr in U.S.
- #1 primary malignant bone tumor < 18 y.o.
- Peak: 13-16 y.o., boys > girls
- Sites: d. femur (75%), p. tibia, p. humerus
- Risk factors: prior xrt, genetic predisposition (retinoblastoma, Li-Fraumeni, Rothmund-Thomson)

**ES family of tumors**

- ~ 200 new cases/yr
- Caucasian predominance
- Peak: 10-15 y.o, 30% < 10 y.o., 30% > 20 y.o.
- Sites: axial (54%), appendicular (42%)
- Translocation of chromosomes 22 + 11 involving ESWR1 gene
# COG* imaging guidelines for Osteosarcoma

<table>
<thead>
<tr>
<th>Site</th>
<th>Presentation / Pre-op</th>
<th>Post-op, On ChemoRx</th>
<th>Surveillance off Rx</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary tumor</td>
<td>AP, lat XR MR + contrast</td>
<td>XR q 16 wks MR (unless precluded by hardware)</td>
<td>XR q3 mo x4, q6 mo x4, q12 mo x2 MR for sx</td>
</tr>
<tr>
<td>Bone Mets</td>
<td>AP, lat XR MR + contrast</td>
<td>MR if sx</td>
<td>XR q3 mo x4, q6 mo x4, q12 mo x2 MR for sx</td>
</tr>
<tr>
<td>Whole body</td>
<td>MDP bone scan PET?</td>
<td>MDP bone scan q16 wks PET?</td>
<td>MDP bone scan q3 mo x4, q6 mo x4, q12 mo x2 PET to evaluate abnormal imaging</td>
</tr>
<tr>
<td>Chest</td>
<td>PA, lat XR CT</td>
<td>XR q 2 mo. CT q 16 wks if abnormal in past</td>
<td>XR q6 mo x 6 CT q3 mo x 4, q6 mo x 2</td>
</tr>
</tbody>
</table>
COG* imaging guidelines for Ewing Family of Tumors

<table>
<thead>
<tr>
<th>Site</th>
<th>Presentation + prior to local control</th>
<th>On ChemoRx, post local control</th>
<th>Surveillance off Rx</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary tumor</td>
<td>AP, lat XR MR + contrast</td>
<td>XR – ½ way thru and at end of rx MR/CT – 3/4 months after local control</td>
<td>XR q3 mo x8, q6 mo x6, q12 mo x5 MR for sxs</td>
</tr>
<tr>
<td>Whole body</td>
<td>MDP bone scan FDG-PET</td>
<td>MDP bone scan at end of rx PET at end of rx</td>
<td>MDP bone scan if sxs PET if sxs or abnormal imaging</td>
</tr>
<tr>
<td>Chest</td>
<td>PA, lat XR – dx only CT</td>
<td>CT – ½ way thru and at end of rx</td>
<td>XR q3 mo x 8, q6 mo x 6, q12 mo x 5 CT if abnormal CXR</td>
</tr>
</tbody>
</table>

18 m.o. with Ewing Sarcoma

- Ewing family (EFT)
- Chromosome 22
  - EWS gene translocation
  - Mesenchymal cell origin
- PET – all pts (BS deemphasized)
Response Evaluation Criteria in Solid Tumors (RECIST)*

- Applies to primary and mets together
  - size-based assessment of tumor burden
- Sum of longest dimension of each lesion
- Requires measurable soft tissue
- Lesions must be $\geq 10$ mm
- Response:
  - Progression = $\geq 20\%$ increase in sum (or new lesions)
  - Partial response = $> 30\%$ decrease in sum
  - Complete response = disappearance of all lesions
- Unreliable for osteosarcoma
  - $> 20\%$ show increased size despite rx response

Treatment Response MR Evaluation

- Diffusion weighted imaging (DWI)
- Dynamic contrast-enhanced MRI
- Whole body MR (FSE, DW)
- Spectroscopy
- Chemical shift (for marrow)
Comprehensive Bone Tumor Protocol

- Cor T1, FSEIR – entire bone
- Sag T2 fat sat
- Ax PD, T2 fat sat
- DWI/ADC – axial
- Spectroscopy- single voxel
- 3D GRE DCE – pre + post C
- C+ T1 fs short and long axis
DWI - Principle

• Brownian motion of water in extracellular tissues
• Tissue structure/ cellularity
  – Qualitative and Quantitative
• Restricted diffusion
  – Decrease in extracellular space (edema)
  – Increase in cell #, size (tumors, fibrosis)
• Increased diffusion
  – ↓ cell # (necrosis, cysts, fluid)
  – ↑ cell membrane permeability (ischemia)
DWI in MSK Tumors

• **Diagnosis: general rules**
  - Malignant = restricted diffusion
  - Benign tumors ~ “less restricted” diffusion
  - Myxoid content = ↑ diffusion

• **Response to therapy**
  - Necrosis → ↑ diffusion
  - Ischemia → ↑ diffusion
  - Recurrence/ metastases → ↓ diffusion
  - Post op change/hematoma → ↑ diffusion
18 m.o. boy with left thigh pain, swelling

Dx = Ewing Sarcoma
Same pt after 2 cycles chemo rx

**DWI = bright, suggests restricted diff**

**ADC = bright → increased diff, thus T2 effect**

**Path: “No viable tumor”**
9 y.o. with left thigh pain

Dx: telangiectatic osteosarcoma
Telangiectatic Osteosarcoma: pre and post rx

@ Dx

s/p Rx

FSE T2 fs  DWI  ADC
DWI Quantitative Assessment

- ADC value (apparent diffusion coefficient)
  - Calculated from all b values in data set
  - $\leq 1.5 \times 10^{-3} \text{ mm}^2/\text{sec}$ – high cellularity
  - Contaminated by capillary perfusion at low b
- PIDC (perfusion independent diff coef)
  - Higher b value data only (slow diffusion)
  - Eliminates perfusion effect
  - $\leq 1.1 \times 10^{-3} \text{ mm}^2/\text{sec}$ – high cellularity
- Correlation with % necrosis would be ideal
13 y.o. with proximal tibial osteosarcoma

DX:

FSEIR

DWI

ADC=2.5

3 cycles Rx:

ADC=1.1
12 y.o. with radiation induced, refractory OSA prox tibia

T2 fs:

DWI: (outside hospital exam, no DWI)

ADC:

@ dx  s/p 2 cycles rx  s/p change in rx
9 y.o. with limited ROM left hip: Synovial sarcoma

@ Dx

s/p 3 cycles rx

T2 fs  T1 + gad  DWI, b 500  ADC

0.6 – 0.9  0.8 – 1.9
Dynamic Contrast Enhanced MR

- Perfusion
  - Diagnosis
  - Response to therapy
- Pre-op angiography
- High temporal/ spatial resolution
- 3T – $\uparrow$T1 relax blood vs tissue → CNR
- Parallel imaging + faster sequences
  - TRICKS/ TWIST MRA
  - 3D LAVA/ VIBE – perfusion
  - $\uparrow$ small vessel visualization
DCE: Qualitative Assessment

- Tumor margin delineation
- First pass - simplified
  - Intense enhancement = residual/recurrent tumor
  - Intermediate enhancement = post rx fibrosis
  - Minimal enhancement = necrosis, edema, hemorrhage
- Guide bx @ dx or recurrence
7 y.o. boy with osteosarcoma s/p 2 cycles chemorx, pre-op eval

3D GRE VIBE/LAVA

Time Intensity Curves

Fem artery

Intramedullary tumor

Soft tissue mass
Surveillance Imaging

- Metastasis detection
- Problem-solving
- Local recurrence
  - Hardware artifact mitigation
    - MR techniques
    - Dual energy CT
- FDG-PET and WB MR complimentary
12 y.o. with EWS rt humerus, staging studies
Ewing Sarcoma – PET vs MRI in Response Assessment

Pre-ChemoRx
FSE-T2/FS

Post-ChemoRx
Post-Gd T1/FS

18F-FDG-PET

Courtesy of Stephan Voss, M.D.
Whole Body MR

- Metastatic survey
- Cancer predisposition surveillance
- Assessment of cortical bone, marrow, soft tissues

13 y.o. boy with NF1
19 y.o. with NF1, prior MPNST

BCH: SUV \geq 4.5 \text{ g/mL}, \text{surgical sampling/rxn}
NF-1 and $^{18}$F-FDG-PET: SUV and final histology:
*Benign plexiform* -> *atypical NF* -> *MPNST*

Courtesey of Stephan Voss, M.D.

Tsai et al. (2012) J. NeuroOnc 108:469
NF-1 and MPNST

$SUV_{\text{max}} = 5$
Atyp NF

$SUV_{\text{max}} = 4.2$
Benign NF

$SUV_{\text{max}} = 4.9$
Atyp NF

$SUV_{\text{max}} = 9.3$
MPNST

Courtesy of Stephan Voss, M.D.
Molecular tissue characterization

- Choline level (peak)
  - Increased cell membrane turnover
  - Correlates with malignancy

- Single voxel techniques most useful

- Susceptibility issues

Hardware Imaging: Artifact Reduction

- General: high BW, ↓ slice thick, ↑ matrix, ↑ ETL, ↓ TE
- SEMAC - optimized sequences – STIR, TSE (WARP)
- 1.5 T preferred
Summary

• Conventional and functional imaging techniques are complimentary.
• Together they improve our confidence
  – Dx
  – Response to therapy
  – Long term surveillance
• Size alone (RECIST) insufficient to assess rx response for OSA, EFT