SKELETAL IMAGING WITH
\(^{18}\text{F-Fluoride PET}\)

Frederick D. Grant, M.D.
Children’s Hospital, Boston
Harvard Joint Program in Nuclear Medicine
## Bone Imaging Agents

<table>
<thead>
<tr>
<th></th>
<th>keV</th>
<th>$T_{1/2}$</th>
<th>Imaging Delay</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sr-85</td>
<td>514</td>
<td>65 d</td>
<td>3-7 d</td>
<td>1961</td>
</tr>
<tr>
<td>Sr-87m</td>
<td>388</td>
<td>2.8 h</td>
<td>(1-3 h)</td>
<td>1969</td>
</tr>
<tr>
<td>F-18</td>
<td>(511)</td>
<td>1.8 h</td>
<td>0.5 – 1 h</td>
<td>1962</td>
</tr>
<tr>
<td>sodium fluoride</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tc-99m phosphates</td>
<td>140</td>
<td>6 h</td>
<td>4-6 h</td>
<td>1971</td>
</tr>
<tr>
<td>Tc-99m diphosphonates</td>
<td>140</td>
<td>6 h</td>
<td>3 h</td>
<td>1973</td>
</tr>
</tbody>
</table>
BLOOD CLEARANCE OF SKELETAL IMAGING AGENTS

Strontium ($t_{1/2}$ 18-24 h)
Polyphosphate ($t_{1/2}$ 8.1 h)
Pyrophosphate ($t_{1/2}$ 10.5 h)
Diphosphonate ($t_{1/2}$ 3.2 h)
Fluoride ($t_{1/2}$ 1.3 h)

Skeletal Imaging with $^{18}$F-NaF PET

- $^{18}$F-sodium fluoride approved by FDA in 1972
  - Gamma camera imaging of 511 keV photons
- Rapidly replaced by $^{99m}$Tc-diphosphonates
  - Anger camera optimized for 140 keV
  - generator production of $^{99m}$Tc
  - availability of $^{99m}$Tc bone agent kits
- With clinical adoption of PET imaging
  - PET cameras now widely available
  - $^{18}$F shipping logistics improved
- Re-visit use of $^{18}$F-NaF for bone imaging
Skeletal Imaging: Utility of $^{18}$F-NaF PET

- Primary osseus tumors
- Skeletal metastases
- Benign skeletal disease
  - Sports Medicine
  - Fractures
- Other indications?
- Concerns and Issues
8 year-old boy with Ewing’s sarcoma

18F-NaF

99mTc-MDP

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Imaging skeletal metastases

- $^{99m}$Tc-MDP planar scintigraphy
- $^{99m}$Tc-MDP SPECT
- $^{18}$F-NaF PET

COURTESY Abass Alavi, M.D.
Detecting Skeletal Metastases with $^{18}$F-NaF PET

- $^{99m}$Tc-MDP SPECT is more sensitive than planar SPECT, not planar, $^{99m}$Tc-MDP imaging is the appropriate comparison for $^{18}$F-NaF PET
- $^{18}$F-NaF PET vs. $^{99m}$Tc-MDP SPECT
  - $^{18}$F-NaF PET is more sensitive
  - $^{18}$F-NaF PET has higher image quality
  - $^{18}$F-NaF PET and $^{99m}$Tc-MDP SPECT have similar specificities
- Both $^{18}$F-NaF PET and $^{99m}$Tc-MDP SPECT need correlative imaging
Bone Imaging with PET

Imaging Skeletal Metastases:
$^{18}$F-NaF and $^{18}$F-FDG PET

- $^{18}$F-NaF and $^{18}$F-FDG both have higher sensitivity than $^{99m}$Tc-MDP
- $^{18}$F-FDG more likely to detect:
  - non-osseous disease
  - bone marrow metastases
  - small lytic lesions
- $^{18}$F-NaF is specific for cortical bone involvement
- $^{18}$F-NaF more likely to detect:
  - tumors with low FDG avidity
27 year-old woman receiving chemotherapy for metastatic breast carcinoma

18F-NaF PET

18F-FDG PET
Flare response in vertebra T7 after 4 cycles of chemotherapy for breast cancer.

18F-NaF PET

18F-FDG PET

Initial 12 weeks later
2 year-old girl with neuroblastoma
18F-NaF Bone Imaging: Sports Medicine

18 year-old female runner
Training for a marathon
Severe lower leg and foot pain
18F-NaF Bone Imaging: Sports Medicine

18 year-old female runner
Training for a marathon
Severe lower leg and foot pain

Scan completed ~1 hour after arrival in Nuclear Medicine

Widespread stress injury in both tibiae, right fibula, both feet
18F-NaF Bone Imaging: Sports Medicine

12 year-old gymnast with lower back pain
18F-NaF Bone Imaging: Sports Medicine

12 year-old gymnast with lower back pain
Left pars stress in vertebra L5
21 year-old runner with lower back pain
21 year-old runner with lower back pain
Increased uptake left sacro-iliac joint, likely stress injury
17 year-old male athlete with lower back pain that worsens with hyperextension

Increased F-18 uptake suggests right pars stress in vertebra L5

Corresponds to a non-displaced pars fracture
18F-NaF Bone PET: CT co-registration

15 year-old female athlete with back pain after landing from a high jump

Increased F-18 uptake corresponds to a wedge compression fracture of vertebra L3
Detecting Skeletal Metastases with $^{18}$F-NaF PET/CT

- Specificity of $^{18}$F-NaF PET improved by CT
- $^{18}$F-NaF PET/CT has higher specificity than $^{99m}$Tc-MDP SPECT

BUT:

- $^{99m}$Tc-MDP SPECT is changing
  - improved image processing (software)
  - how will $^{99m}$Tc-MDP SPECT/CT perform?

$^{18}$F-NaF PET/CT typically not head-to-toe
3 month old boy brought to ED by his mother; she reports that the child is not using his right arm after an older sibling pushed him off a bed
Non-accidental Trauma / Child Abuse

Multiple sites of uptake corresponding to fractures on skeletal survey. $^{18}$F-NaF bone PET improves sensitivity and specificity of skeletal survey.
18F-NaF Bone PET: Other Indications

• Femoral head osteonecrosis
• Bone graft viability
• Quantitative bone turnover studies
• Three-phase bone scan??
$^{18}$F-NaF Skeletal PET: Concerns and Issues

- Dosimetry
- Departmental Workflow
- Reimbursement
$^{18}$F-NaF Skeletal PET: Dosimetry compared to $^{99m}$Tc-MDP

- **Radiation**
  - $^{18}$F: positron (local) + 511keV gamma
  - $^{99m}$Tc: 140 keV gamma
- **Physical Half-life**
  - $^{18}$F: 110 minutes
  - $^{99m}$Tc: 6 hours
- **Bone Uptake and Soft Tissue Clearance**
  - Both have ~50% uptake in bone
  - $^{18}$F soft tissue clearance faster than $^{99m}$Tc-MDP
# $^{18}$F-NaF Skeletal PET: Dosimetry compared to $^{99m}$Tc-MDP

<table>
<thead>
<tr>
<th>70 kg Adult</th>
<th>$^{99m}$Tc-MDP</th>
<th>$^{18}$F-NaF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Administered Dose (mCi)</td>
<td>14</td>
<td>4</td>
</tr>
<tr>
<td>(MBq)</td>
<td>518</td>
<td>148</td>
</tr>
<tr>
<td>Effective Dose (mSv)</td>
<td>3.0</td>
<td>4.0</td>
</tr>
<tr>
<td>Bladder Wall (mGy)</td>
<td>24.9</td>
<td>32.6</td>
</tr>
<tr>
<td>Bone surfaces (mGy)</td>
<td>32.6</td>
<td>5.9</td>
</tr>
<tr>
<td>Red Marrow (mGy)</td>
<td>4.8</td>
<td>5.9</td>
</tr>
</tbody>
</table>

F. Fahey IN Grant, et al. JNM 2008
### $^{18}$F-NaF PET vs. $^{99m}$Tc-MDP: Age-Dependent Effective Dose (mSv)

<table>
<thead>
<tr>
<th>Age (y)</th>
<th>Weight (kg)</th>
<th>$^{99m}$Tc-MDP (0.2 mCi/kg)</th>
<th>$^{18}$F-NaF (0.06 mCi/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adult</td>
<td>70</td>
<td>3.0</td>
<td>4.0</td>
</tr>
<tr>
<td>15</td>
<td>55</td>
<td>2.8</td>
<td>3.9</td>
</tr>
<tr>
<td>10</td>
<td>32</td>
<td>2.6</td>
<td>3.5</td>
</tr>
<tr>
<td>5</td>
<td>19</td>
<td>2.0</td>
<td>3.4</td>
</tr>
<tr>
<td>1</td>
<td>9.8</td>
<td>2.0</td>
<td>3.6</td>
</tr>
</tbody>
</table>

$^{18}$F-NaF Skeletal PET: Concerns and Issues

- Dosimetry
- Departmental Workflow
- Reimbursement
- Imaging Workflow with $^{18}$F-NaF
  - faster turnaround than $^{99m}$Tc-MDP
  - facilitates same day follow-up
  - requires PET scanner availability
- Image Acquisition with $^{18}$F-NaF
  - less patient motion with faster PET scan
  - no motion correction with PET
  - sedation of very young children
18F-NaF Skeletal PET: Concerns and Issues

• Dosimetry
• Departmental Workflow
• Reimbursement
  – Depends on insurance company
  – Very difficult if SPECT is a struggle
  – Separate CPT code might facilitate
  – Probably the biggest hurdle to the routine use of 18F-NaF bone scans
Indications for $^{18}$F-Fluoride Skeletal PET

- Oncology
  - Skeletal metastatic disease
    - Identification
    - Assessing response to therapy
  - Bone pain in cancer patients
  - Primary bone tumors

- Benign Bone Disease
  - Sports Medicine (back, extremities)
  - Fractures

- Others?
Bone Imaging with $^{18}$F-NaF Skeletal PET

• Higher quality images than $^{99m}$Tc-MDP SPECT, with similar radiation dose
• Potential for improved workflow
• More accurate than $^{99m}$Tc-MDP SPECT in detecting both benign and metastatic skeletal disease
• Unresolved Questions:
  – How will $^{99m}$Tc-MDP SPECT/CT compare?
  – Will reimbursement issues be resolved?