PET/CT and MRI in Radiation Oncology
Part III: Program Considerations

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Objectives

- Understand clinical use cases and justification for sole-use PET/CT and MRI systems for radiation oncology
- Consider emerging use cases for PET/CT and MRI
- Examine imaging suite designs from perspective of RO needs
- Understand typical workflows and RO-specific staffing requirements
PET/CT
PET/CT in RO: Justification and Use Cases

Value of PET has been established in several oncologic sites

- Diagnostic & cost effective
  - Differential diagnosis of solitary pulmonary nodules
  - Staging/re-staging of NSCLC
  - Restaging of lymphoma and colorectal cancer

- Diagnostic & partially cost effective
  - Staging/re-staging for
    - GI tract tumors
    - Breast
    - Melanoma
    - HN

- Cost effectiveness not yet demonstrated for:
  - Tumor response
  - Detection of relapse
  - Treatment planning

PET/CT in RO: Justification and Use Cases

Tumor response

- PET/CT non-invasive
- Standard imaging evaluates morphological changes only, PET allows earlier response assessment in many sites
- Potential value of PET for response assessment demonstrated in:
  - Breast
  - Lymphoma
  - GI tract (esophagus, rectal)
  - HN
  - Lung
- Lack of prospective evidence indicating clinical impact from the changes in therapy based on PET response data
PET/CT: Prognosis and Response Assessment

- Lung Cancer
  - Intensity of FDG PET as independent prognostic marker
    - e.g. Pottgen et al, 2005, Mac Manus et al, 2003
  - Time trends in FDG uptake in NSCLC patients to adapt treatment based on early response, Baardwijk et al, 2007
  - Correlation of NSCLC tumor texture on FDG PET with response and survival, Cook et al, 2013

- Prostate
  - [F18] Dihydro-testosterone to evaluate androgen receptor status during prostate radiotherapy, Osbourne et al
    - Feasibility of FDHT imaging in non-metastatic disease
    - Monitoring of AR status before and during radiotherapy

- HN
  - [F18] Misonidazole to detect hypoxia
  - Changes to F-MISO avid areas 5-10 days into radiotherapy as guide for dose de-escalation in selected patients
PET/CT in RO: Justification and Use Cases

PET/CT for treatment planning

- Target size may increase or decrease
  - Target increase due to identification of gross disease not detected by other imaging modalities
  - Target decrease due to differentiation of reliably non-malignant disease (e.g. atelectasis) or to improved definition of GTV

Erdi et al, Radiotherapy and Oncology, 2002
## Impact of PET/CT in Target Definition

<table>
<thead>
<tr>
<th>Study</th>
<th># Patients</th>
<th>Seg. Method</th>
<th>% GTV (or PTV) Increase %pts (% change)</th>
<th>% GTV (or PTV) Decrease %pts (% change)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Erdi, 2002</td>
<td>11 (Lung)</td>
<td>Thresh (42%)</td>
<td>64% (5%-46%)</td>
<td>36% (2%-48%)</td>
</tr>
<tr>
<td>Messa, 2005</td>
<td>18 (Lung)</td>
<td>Thresh (40-50%)</td>
<td>39% (33%-279%)</td>
<td>17% (26%-34%)</td>
</tr>
<tr>
<td>Deniaud-Alexandre, 2005</td>
<td>92 (Lung)</td>
<td>Thresh (50%)</td>
<td>23% (1.5%-78%)</td>
<td>26% (2.5%-143%)</td>
</tr>
<tr>
<td>Hanna, 2010</td>
<td>28 (Lung)</td>
<td>Thresh (50%)</td>
<td>54% (~0%--225%)</td>
<td>46% (~0%--30%)</td>
</tr>
<tr>
<td>Leclerc, 2015</td>
<td>31 (HN)</td>
<td>Gradient Method</td>
<td>3% (NS)</td>
<td>97% (Avg ~40%)</td>
</tr>
<tr>
<td>Scarfone, 2004</td>
<td>6 (HN)</td>
<td>Thresh (~50%)</td>
<td>83% (Avg 15%)</td>
<td>0%</td>
</tr>
</tbody>
</table>
PET/CT in RO: Justification and Use Cases

- Target definition using PET is challenging
  - Visual interpretation is subject to inter-observer variability
  - \textit{PET/CT done in treatment position decreases registration inaccuracies but} ....
  - No clear quantitative standardization for using SUV for tumor segmentation
  - Motion effects may confound PTV segmentation

Riegel et al, JACMP, 2014
# Impact of PET/CT on Inter-Observer Variability

<table>
<thead>
<tr>
<th>Study</th>
<th># Patients</th>
<th>Seg. Method</th>
<th>Structure</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ashmalla, 2005</td>
<td>19 (Lung)</td>
<td>Thresh (42%)</td>
<td>GTV</td>
<td>Mean Volume Difference</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>28.3 cm$^3$ (CT)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>9.1 cm$^3$ (PET/CT)</td>
</tr>
<tr>
<td>Hanna, 2010</td>
<td>28 (Lung)</td>
<td>Thresh (50%)</td>
<td>GTV</td>
<td>Median Concordance Index</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.57 (CT)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.64 (PET/CT)</td>
</tr>
<tr>
<td>Steenbakkers, 2006</td>
<td>22 (Lung)</td>
<td>NS</td>
<td>GTV</td>
<td>Overall Standard Dev.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.02 cm (CT)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.42 cm (PET/CT)</td>
</tr>
</tbody>
</table>

Steenbakkers, IJROBP, 64, no.2, p. 435, 2006
PET/CT Suite Design and Construction

Multi-disciplinary team
- Basic layout similar to NM but consider both RO & NM workflow
- Radiology input essential

Workload
- Number/types of cases
- PET/CT versus CT-only mix
- Isotopes
- Remember growth is likely!

RO Considerations
- Bore size, Tabletop
- IV Contrast
- Respiratory Motion Management

MSK PET/CT Simulations 2013-2015
PET/CT Suite Design and Construction

Shielding
- ¼ inch Pb typical for scanner room
- PET lead equivalent glass for console room window
- 1-2 inches Pb for injection rooms
- Consider workflow in suite layout
- AAPM TG108

Uncontrolled Areas
- Reception, Waiting, Exam Room: shared with other sim patients

Controlled Areas
- Radiopharmacy, Injection Rooms, Nursing Area, Toilet, Waste Area
- Scanner and console
PET/CT Radiation Protection

Staffing
- RO nurse trained in NM
- Nuc Med technicians, RTTs
- Physicist qualified to do QA

Staff radiation protection
- Dose preparation/admin
- Time spent with patient:
  - during uptake & procedure
    - Immobilization
    - Patient marking
  - Typical RTT exposure: 30-50 mrem/month

Quinn et al, Med Phys (39); 2012
PET/CT in RO: Workflow

Patient Arrival → Glucose Testing → Injection (RN) → Uptake (45 min) → PET/CT (NM techs) (RO Scan) → PET/CT (NM techs) (Diagnostic)

0 → 30 → 75 → 175 min

IV Started → Immob → Planning CT + contrast → Isocenter Placement

Total Procedure time: 4-6 hours

Toilet | Nursing

Injection Rm1 | Injection Rm2

Console
MRI in RO: Justification and Use Cases

- MRI Justification in RO is focused on clinical effectiveness
  - Imaging variety
    - Anatomic with superior soft tissue contrast
    - Physiologic/functional information
  - Motion assessment
  - Prognostic potential
  - Response assessment
  - Use in adaptive therapy
- Sites
  - CNS
  - HN
  - GYN & GI
  - Lung
  - Brachy

MR Patients by Site

CT vs T1 Post Contrast
MRI in RO: Justification and Use Cases

- Superiority of imaging tumor/normal tissues well established for many sites (e.g. CNS, HN, prostate, GYN)
- Incorporation of DWI, DCE-MRI, fMRI, MRS for initial planning and response assessment
  - Multi-parametric approaches increase sensitivity and specificity for target delineation
  - May be particularly valuable for focal and adaptive therapy

- Weekly DWI for HN response assessment
- ADC change precedes volume change by 1-2 weeks

Tyagi et al, submitted for publication
MRI in RO: Challenges

Scanner
- Bore size (~70 cm)
- Lack of virtual simulation workflow
- System & patient distortions
  - System distortions usually < 3 mm
  - Patient distortions $\propto$ field strength and may exceed 3mm

Courtesy of N. Tyagi
MRI in RO: Challenges

• Sequences, coils optimized for RO simulation slow in coming
  – Most patients require diagnostic + RO sequences
• Difficult to directly translate sequences from diagnostic studies or other scanners due to patient position, vendor or field strength differences

Courtesy of N. Tyagi and K. Zakian
MRI in RO: Challenges

• Methods for MR-only simulation still evolving
  – Creation of synthetic-CT images for dose calculation and generation of references images for IGRT
• Atlas based approaches (e.g. Dowling et al, IJROBP, 2012)
• Image based approaches (e.g. Kim et al, IJROBP, 2015)
MR in RO: Facility Design

- Same considerations as Radiology installation +
  - Surrounding RO shielding and potentially sensitive equipment
  - Placement in RO clinic/simulation suite
    - Clearance and weight bearing support during installation
    - Ability to control access to facility and magnet particularly during anesthesia and brachytherapy
  - MR compatibility and separation of RO equipment & immobilization devices

Philips Healthcare
MRI Safety Zones

- **Zone 1:**
  - Freely accessible to public without supervision
  - Fringe field < 5 Gauss
- **Zone 2:**
  - Interface between Zone 1 and controlled areas
  - Area where screening takes place
- **Zone 3:**
  - Area where magnetic field strong enough to present physical hazard
  - Control access to Zone 4
- **Zone 4:**
  - Magnet room
  - All ferromagnetic material excluded

ACR Guidance Document on MR Safe Practices
JMRI, 37, 2013
MRI in RO: Workflow

Staffing Requirements
2 MR Technologists, 2 RTTs
MR physicist, RO Physicist

Total Procedure time: 2-3 hours or more
Summary

• Technological value of multi-modality in RO has been demonstrated or is evolving for PET/CT and MR for:
  – Target delineation
  – Response Assessment
• Most common sites include:
  – PET/CT: Lung, HN, Lymphoma, GI
  – MRI: CNS, HN, GI/GYN, Brachytherapy
• Design, staff and workflow considerations are similar to those of diagnostic installations but also include unique considerations
  – RO simulation procedures include clinical steps and concerns that are not routinely encountered in diagnostic exams
  – Staff expertise in both imaging and RO