Reducing Sedation & Anesthesia in PET/CT & PET/MR

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OUTLINE: Approaches to Reducing Sedation & Anesthesia

- Rationale
- Image Quality, Sedation/Duration Reduction
- PET-CT, PET-MR and Dedicated PET Scanners
- Discussion
RATIONALITY: Reducing Sedation & Anesthesia

Effects of Anesthesia and Sedation on Pediatric Patients

- Significant risks associated with anesthesia on the developing brain [1]
- Visit durations significantly longer for anesthetized (4h) and sedated (3.5h) patients (vs 2.3h) [2]
- Require presence of Nurse & Anesthesia team
- Double the number of sedations/anesthesia for PET/MR
- Anesthetized patients incur the highest costs, followed by sedated patients

[1] Mastro et al., J of PeriAnesthesia Nursing 2019

OUTLINE: Approaches to Reducing Sedation & Anesthesia

- Rationale
- Image Quality, Sedation/Duration Reduction
  - SPECT, SPECT-CT and Dedicated SPECT Scanners
  - PET-CT, TOF-PET, PET-MR and Dedicated PET Scanners
- Discussion

METHODS: Approaches to Reducing Sedation/Anesthesia

Bases for Approaches to Reducing Sedation/Anesthesia:

- Assess image quality objectively by signal-to-noise ratio (SNR) for a clinical task (e.g., lesion detection, activity estimation)
- Assume Poisson statistics, a doubling of counts (halve time) yields 41% (√2) improvement in SNR (and image quality)
- Conversely, if a physics or instrumentation approach yields an improvement of SNR of 41%, this gain could be used to halve the imaging time without changing image quality.
METHODS: Approaches to Reducing Sedation & Anesthesia

In summary, any method that improves image quality (SNR) can be used to reduce imaging time and hence help move from anesthesia to sedation (or obviate sedation) while keeping image quality constant.

Mission: Impossible

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  • Imaging Time Reduction by using iterative reconstruction and 3D geometry
• Discussion
Assessment of Time Reduction with 3D vs. 2D PET

- 3 sphere sizes were acquired in 10 different locations (e.g., lungs, soft tissue, bone) to avoid errors associated with lesion simulation
- Each sphere was acquired separately in 2D and 3D and scaled to ensure marginal detectability in each patient

Generation of synthetic lesion-present WB studies

Lesion-present patient studies

El Fakhri et al., JNM 2007 (48): 1951-1960
Lesion-present patient studies (2)

- 2D WB scan (BMI = 33)
- 3D WB scan (BMI = 33)

Lesion-present patient studies (3)

- 2D WB scan (BMI = 50)
- 3D WB scan (BMI = 50)

Assessment of Time Reduction with 2D/3D and Processing

- 2D AWOSEM vs. 2D FBP: Time reduction 36%
- 3D AWOSEM vs. 3D FBP: Time reduction 77%

Typical BMI of 26
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Image quality depends on patient size

1 min/bed  Light patient (BMI=23)  3 min/bed

How can TOF improve image quality (reduce time)?

\[ \Delta t = t_1 - t_2 \]
\[ \Delta x = c \cdot \Delta t / 2 \]

TOF information reduces coupling, thus improves SNR

Signals from different vessels are coupled

\[ \text{SNR} = \frac{N}{\sqrt{N}} \]

Image reconstruction from projections

\[ \Delta x = \text{Reduction in variance} = \text{gain in sensitivity} \] (NEC) = Reduction Imaging Time

\[ \text{SNR} = \text{Reduction in time} / \text{Reduction in time} \]

<table>
<thead>
<tr>
<th>TOF</th>
<th>( \Delta t )</th>
<th>( \Delta x )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 s</td>
<td>1 s</td>
<td>7.8</td>
</tr>
<tr>
<td>3 s</td>
<td>3 s</td>
<td>7.8</td>
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Time Reduction with TOF-PET: how much can we gain?

5 min Non-TOF PET

3 min TOF PET

6:1 sphere to background contrast; 35-cm diam. cyl.; 1-cm spheres

5 min TOF PET

Time Reduction with TOF-PET

Normal patient list data

1. Fully-corrected reconstructed lesion absent volume
2. Scatter estimate
3. Background activity level, C_B

Sphere in air list data

Lesion uptake ratio + C_B

Extracted sphere list data

Fused list data

Fused list data

CT image

Fully-corrected reconstructed lesion present volume

RESULTS: Representative lesion-present studies

Non-TOF 1 min/bed position

TOF 1 min/bed position

Non-TOF 3 min/bed position

TOF 3 min/bed position

Patient BMI=24.6; 4:1 uptake 1-cm lesion in lung
RESULTS: Representative lesion-present studies (2)

<table>
<thead>
<tr>
<th>Non-TOF 1 min/bed position</th>
<th>TOF 1 min/bed position</th>
<th>Non-TOF 3 min/bed position</th>
<th>TOF 3 min/bed position</th>
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Patient BMI=24.6; 4:1 uptake 1-cm lesion in lung

METHODS: Time Reduction with TOF-PET

Non-TOF PET TOF-PET

Patient with a lung lesion (4:1) and BMI=19

Non-TOF PET TOF-PET

Patient with a liver lesion (6:1) and BMI=42

**SNR improvement of 8% in liver, 14% in lung**

**time reduction of 30%**
RESULTS: Time Reduction with TOF-PET

• Similar SNR with TOF-PET for 33% less TBR, 76% shorter imaging time

• Time reduction of 34% in the liver and 70% in the lungs
• Time reduction of 40% for BMI<30 and 49% for BMI>30

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• Imaging Time Reduction in PET-MRI vs. PET-CT
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Rationale for Integrated PET-MR

<table>
<thead>
<tr>
<th>PET</th>
<th>MR</th>
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<tbody>
<tr>
<td>High sensitivity</td>
<td>Exquisite high resolution, excellent soft tissue contrast</td>
</tr>
<tr>
<td>Absolute quantitation</td>
<td>Non ionizing</td>
</tr>
<tr>
<td>Good Time resolution</td>
<td>Excellent time resolution</td>
</tr>
<tr>
<td>Poor spatial resolution</td>
<td>Poor sensitivity</td>
</tr>
<tr>
<td>Limited anatomic information</td>
<td>Absolute quantitation challenging</td>
</tr>
</tbody>
</table>

Integrated Whole-Body PET-MR

Sequential PET-CT vs Simultaneous PET–MR

25 cm axial coverage

Rationale: Motion deterioration vs Gating

- Blurring
- Lower Noise

- Using all PET data at all motion phases without motion correction

- Using some PET data only at one motion phase

- Freezing Motion
- Higher Noise

Using all PET data with MR-based motion correction
Methods: Motion Corrected OSEM

- List-mode MLEM reconstruction algorithm with motion modeled in the system matrix:

\[ a_{m}(f) = \sum_{i} a_{m}(f) \]

Motion transmission maps in a convolution of prior with the right frame to yield an updated frame

- Attenuation map in the reference frame
- Attenuation maps in the deformed frames
- Attenuation correction using deformed attenuation maps at each frame:


Primate Results: Acquisition

- Motion Correction with Primate in simultaneous PET-MR

Gated tagged MR
gated PET


Nonhuman Primate Results


6x shorter scan
Measure Motion Fields and Track Motion Phases

Motion correction for PET reconstruction

Cardiac PET/MR: pig studies ($^{18}$F-Flurpiridaz)

No MoCo (standard)  ECG-gating  MoCo (proposed)

Cardiac PET/MR: human studies ($^{18}$F-FDG)

Impact of MoCo on estimation of kinetic parameters ($K_t$, Patlak)
Hepatic Cancer Study


[18F]T807 and tractography in TBI

MNormandin, D Wooten, W. Wedeen, R. Zafonte, G. El Fakhri

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Time Reduction with Dedicated PET Scanners

**Dedicated brain PET**

- FOV 35 cm x 24 cm long

**Imaging Time ≥ 260%**

**ECAT EXACT HR+**

- Injected dose: 200 MBq of 18FDG.
- HR+ scan: 54 min post injection, 30 min acquisition.
- NeuroPET scan: 90 min post injection, 30 min acquisition.

**NeuroPET**

- Injected dose: 1840 MBq of 11C-PiB.
- HR+ scan: 45 min post injection, 15 min acquisition.
- NeuroPET scan: 70 min post injection, 15 min acquisition.

Same concept applies to other Hi-sensitivity scanners, for example:

- If axial FOV = 21.6 instead of 16.2, sensitivity ↑ 75% and Time ≥ 260%
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SCIENCE TRANSLATIONAL MEDICINE | FOCUS

Total-body imaging: Transforming the role of positron emission tomography
Simon R. Cherry,"*" Ramsey D. Bednar,* Joel S. Kang,* William W. Maack,* Paal Prins,* Terry Jones*"†

The first total-body positron emission tomography (TR-WF) scanner represents a radical change for experimental medicine and diagnostic health care.


All PET studies are limited by statistics, radiation dose, or both

Current scanners do not maximize the sensitivity for whole-body imaging (<1% of the available signal collected)

T. Jones
<1% of the potential return on the investment in:

- Cyclotron operation
- Labelled tracer production
- PET scanning facilities and resources
- The radiation dose to the patient
- Imaging Time

Total-Body PET: Maximizing sensitivity and simultaneously imaging the whole body

T. Jones

EXPLORER Team

UCDavIs
Simon Cherry
Terry Jones

Srialan Krishnamoorthy
United Imaging Healthcare
Total-Body PET: Maximizing Sensitivity

- 40x gain in effective sensitivity for total-body imaging!
- Can translate into 40x faster imaging time obviating the need for sedation
- 4-5x gain in sensitivity for single organ imaging

Image Gently

- 40-fold reduction in Imaging time
  - Whole-body PET at ~0.15 mSv
  - Annual natural background is ~2.4 mSv
  - Return flight (SFO-LHR) is ~0.11 mSv
  - PET can be used with minimal risk – new populations
  - Very fast imaging obviates the need for sedation

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DISCUSSION: Physics Approaches to Reducing Sedation

- **Achievable Time reduction today:**
  - 70% in WB with iterative reconstruction
  - 34% in liver with TOF-PET
  - 70% in lungs with TOF-PET

- **Achievable Time reduction with PET/MR today:**
  - PET-MR reduces by half the number of sedations and shortens the PET duration by 600% (still need to reduce MR duration)

- **Potential imaging time reduction with Total Body in the future:**
  - Total Body PET can reduce imaging time by 4000%, obviates the need for sedation

Thank You!