Cardiac PET-CT Imaging

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Perspective

- PET-CT Focus has been on Oncology
  - (Session titled: “PET/CT Applications in Oncology”)
- Cardiac PET imaging is well-established
- Cardiac PET-CT imaging is relatively new
  - Many unanswered questions
- I’m a physicist
Overview

- Cardiac PET applications
- Hardware differences
  - “PET–CT” vs. “PET+CT” vs. “PET&CT”
- Cardiac PET: CT-based attenuation correction
- Potential artifacts in PET–CT
- Summary PET-CT vs. PET
- Image fusion with CTA
- Open issues…
Cardiac PET procedures

Applications:

- Myocardial viability
  - $^{18}$F-FDG ($t_{1/2} = 110$ min)
- Myocardial perfusion (Rest / Stress)
  - $^{82}$RbCl ($t_{1/2} = 1.3$ min)
  - $^{13}$NH$_3$ ($t_{1/2} = 10$ min)
- Left Ventricular function (ECG gating)

Procedure Guidelines (ASNC):

Cardiac PET procedures

Myocardial viability

- $^{18}$F-Fluorodeoxyglucose (FDG)

FDG 5-15 mCi

$t = 0$

Preview

Emission 10 - 30 min

Transmission

$t = 45-60$ min
Cardiac PET procedures

Myocardial perfusion

- $^{82}\text{RbCl}$ (from $^{82}\text{Sr}/^{82}\text{Rb}$ generator)

![Diagram of cardiac PET procedures]

- **Preview**: 10-20 mCi, 3 min
- **Rest**: 10-60 mCi, 5 min
- **Transmission**: Pharma. Stress ~8 min, Trans?
- **Stress**: 10-60 mCi, 5 min
Cardiac PET procedures

Myocardial perfusion

- $^{13}\text{NH}_3$ (from cyclotron)

- $\text{NH}_3$ 10-20 mCi
- Rest 5-15 min
- Pharma. Stress ~10 min
- Trans. 10-20 mCi
- Stress 5-15 min

$t = 0$

$t > 50\text{ min}$
FDG viability images

Example – 16-frame gated images
82Rb Rest/Stress perfusion images

Female, Age 67
130kg (286 lbs)
157cm (5’2”)

Acquisition:
Biograph16 PET-CT
70cm bore diameter
40 mCi 82RbCl
5 min duration
3D mode

Patient could not fit in 56cm bore diameter (EXACT HR+ PET)
Instrumentation

Compared to SPECT cameras, there are large differences between PET systems

- Acquisition geometry (2D, 3D, or both)
- Attenuation correction (transmission sources ($^{68}$Ge or $^{137}$Cs) or x-ray CT)
- Scintillation crystals (BGO, LSO, GSO)
- Count sensitivity
- Count rate capacity

→ Clinical protocols must account for differences
Instrumentation

Terminology used in this presentation:

- "PET" scanners
  - Use transmission sources (no x-ray CT)
- "PET–CT" scanners
  - CT replaces PET transmission sources
- "PET+CT" scanners
  - Can use either CT or transmission sources
- "PET&CT"
  - Software fusion, independent PET and CT
PET Attenuation Correction

Transmission sources ("PET" and "PET+CT")
- Rotating $^{68}$Ge or $^{137}$Cs sources
- Contamination (emission, scatter, randoms)

CT-based ("PET−CT" and "PET+CT")
- X-ray source
- Fast
- “Noiseless”
- Higher dose
- Metal artifact
PET Attenuation Correction

Matched geometries for emission data and transmission data needed to avoid artifacts

- Avoid patient motion between scans
- Avoid breathing misregistration

In Cardiac PET, lateral wall borders the lung and is most susceptible to artifacts

- Mispositioning of heart (of emission data) within the lung region (of transmission data) causes under-correction
Cardiac motion

MR cine images
Respiratory motion

Respiration causes significant heart displacement:

Fused images at end-inspiration and end-expiration
PET Attenuation Correction

Transmission source-based attenuation correction

PET emission scan
- Free-breathing protocol, long acquisition time

Transmission scan
- Free-breathing protocol, long acquisition time

Breathing motion is time-averaged similarly for both scans
CT for Attenuation Correction?

Conventional cardiac PET and CT protocols:

PET emission scan
- Free-breathing protocol, long acquisition time

Cardiac CT scan
- Breath-hold protocol, short acquisition time

→ Respiratory status is different
Respiratory phase (PET-CT fusion)

Fused images with CT and CT-AC at end inspiration and at end expiration

CT-AC at end inspiration

CT-AC at end expiration
Respiratory phase (PET-CT fusion)

Polar maps with CT and CT-AC at end inspiration and at end expiration

Transmission source  CT-AC at end inspiration  CT-AC at end expiration
“Fast” CT-AC

- Can be done quickly (~3 sec for 16 det row CT)

- Attempt to match PET respiratory status
  - At or near end-expiration
  - Shallow free-breathing

- Potential artifact, if CT scan done at incorrect respiratory phase
“Fast” CT-AC

Clinical validation (thus far)

- Keofpli et. al., *JNM* 2004 April; 45: 537-542.
  - $N = 7$ patients: Comparison of CT-AC at low vs. high mAs and vs. $^{68}$Ge-AC. Visual assessment of segments showed 90-94% consistency.
  - $N = 3$ patients: Consistency of $^{13}$NH$_3$ MBF over 8 repeat CT scans used for CT-AC (Avg COV = 7%)
  - $N = 4$ patients: Comparison of FBP vs. iterative reconstruction using CT-AC and $^{68}$Ge-AC
  - All studies free breathing
“Fast” CT-AC

Potential issues:
- Patient not following breathing instructions
- Patient unable to control breathing
- Coughing / sneezing / yawning
- Failure to monitor respiratory status
- Failure to repeat CT scan when needed

Frequency and severity of artifacts need to be investigated (given the patient population)
Cheyne-Stokes respiration
Cheyne-Stokes respiration

Good CT  Bad CT  Transmission Scan →

Amplitude

Time [seconds]

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“Fast” CT-AC

Questions to be answered:

- How to guarantee proper respiratory status?
  - Patient compliance with breathing instructions
  - Respiratory monitoring / triggering hardware
  - QC check by technologist / repeat CT scans

- Robust enough for routine clinical use?

- Can physicians “read through” artifacts?

- Can registration / warping software fix artifacts?
“Slow” CT-AC

- Alternative to “Fast” CT-AC
- Slow CT acquisition (~40sec over 16cm FOV)
  - Increase rotation speed (1.5 sec)
  - Reduce table feed and pitch
- Beam current at minimal setting to reduce dose
- Shallow free breathing
- Produce blurry CT images
- Similar approach as PET transmission scan
“Slow” CT-AC

Example images:
Cheyne-Stokes respiration

![Graph showing Cheyne-Stokes respiration with time in seconds on the x-axis and amplitude on the y-axis.]
Slow vs. Fast CT-AC

Example: Fast CT (red) fused with Slow CT 
Both under free-breathing

Impact on reconstructed images:
(Fast CT vs. Slow CT)

Apex + 2%
Anterior - 9%
Septal - 1%
Inferior - 3%
Lateral - 12%
Slow vs. Fast CT-AC

- **Slow CT-AC**: more likely to experience deep breathing (longer acquisition), but impact is minimized
- **Fast CT-AC**: less likely to experience deep breathing, but impact may be significant
- Further study needed to assess impact in diagnostic accuracy (large number of patients)
- Consistency of CT-AC is important, especially for Rest / Stress studies
PET Respiratory gating?

CT at “freezes” respiratory motion
→ Freeze motion in PET data too

(+) Matched emission and attenuation data
(+) Improved spatial resolution

(−) Reduced PET image quality (especially for $^{82}\text{Rb}$)

(−) Added complexity
(−) Costly additional hardware
CT Respiratory monitoring?

- Use external device to monitor breathing status
- Trigger a rapid CT acquisition at proper respiratory phase
- Can this achieve sufficient consistency for Fast CT-AC for cardiac PET?…
Metal artifact

Patient with implanted ICD (defibrillator)

- Note the radio-opaque electrodes
Metal artifact

- Intense focus in CT
- Overcorrection of PET images with CT-AC
- ICD leads much more problematic than pacemaker leads
- Potentially corrected through automated segmentation techniques
Metal artifact (ICD lead)
Advantages (CT vs. Trans. source)

Use x-ray topogram for positioning

- Eliminate scout scan
- Reduce study time
Advantages (CT vs. Trans. source)

Use CT for attenuation map

- “Noiseless” attenuation correction
- No emission or scatter contamination

PET Transmission  Segmented PET mu-map  CT mu-map
Advantages (CT vs. Trans. source)

CT much faster than Transmission scan

- Reduce study time
- Less likelihood of patient motion between emission study and attenuation study
- For Rest/Stress studies, more feasible to acquire attenuation data at time of peak stress
Advantages (CT vs. Trans. source)

Patient comfort
- Faster exam
- Wider bore size (70cm vs 56cm)
  - Some patients unable to be scanned in PET cameras, but can be scanned in PET-CT
- “One-stop shop” for CTA & PET exam
Disadvantages (CT vs. Trans. source)

- Potential for breathing misregistration
- Metal artifact
- 3D-only acquisition
- Table motion (between CT and PET FOVs)
- Radiation dose
- Cost, space, etc.
Cardiac Image Fusion

- PET-CT developed originally for wholebody oncology
  - Faster scan times
  - Anatomic localization
- It is generally accepted that fusing both PET and CT images improves diagnostic accuracy for oncology

→ Does “1 + 1 > 2” apply to cardiac PET also?
Coronary CT Angiography

CTA made possible by ultra-fast CT
- Fast rotation speed
- Multi-row detector (16-slice common)
- ECG gating
Normal coronary arteries (MDCT)
Atypical chest pain (coronary angio)
CTA – PET image fusion

CTA provides anatomic information
- Physical anatomy of the coronary arteries
- Coronary artery stenosis

PET provides functional information
- Perfusion and/or Viability

→ Correlate PET and CTA with image fusion
CTA – PET image fusion

CTA often displayed as surface-rendered (2D) image
PET and CT images are 2D slices of 3D volumes

→ New software required for viewing co-registered images
CTA – PET image fusion
CTA – PET image fusion

- Image registration may need to be manually adjusted if CTA is performed at full inspiration.
- Will PET enhance the CTA, or vice-versa, or both?
- How best to present images to referring physician?
- Will there be a measurable benefit to patients?
Other Applications

Cardiac tumor (FDG image)
Other Applications

Arteritis – FDG image
Open Issues in Cardiac PET-CT

- Issues are mainly vendor-independent…
- Optimal method of CT-based attenuation correction (CT-AC) for cardiac PET?
- How much error from CT-AC is tolerable?
- Should respiratory monitoring be routine?
- Different normal database for CT-AC?
Open Issues in Cardiac PET-CT

- Metal artifact correction
- Value of respiratory gating?
- Software for routine visualization of fused CTA / PET
- Does CTA / PET fusion improve diagnostic accuracy?
Open Issues in Cardiac PET-CT

- Advantage of hardware fusion (PET-CT or PET+CT) vs. software fusion (PET&CT)?
- Economics of combined PET-CT system vs. PET-only system?
- “Multi-modality” physicians and technologists?
Thank you!

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