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  (2nd Generation; PI: JHU; Subcontract: GM; 2009-present)
- Research contract from Gamma Medica, Inc.
OUTLINE

- Introduction
  - Rationale
  - Detector technology for MR-compatible SPECT insert
- Brief review of 1st generation SPECT/MR prototype insert
- Development of 2nd generation SPECT/MR prototype insert
  - Instrumentation design and fabrication
  - Corrective image reconstruction methods
  - SPECT system calibration and corrections
- Preliminary phantom and small animal studies
  - Phantom and small animal studies with stand-alone SPECT insert
  - Simultaneous SPECT/MR phantom study
- Conclusions
# Rationale for PET/CT and SPECT/CT

<table>
<thead>
<tr>
<th></th>
<th>PET</th>
<th>SPECT</th>
<th>CT</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Information</strong></td>
<td>Functional</td>
<td>Functional</td>
<td>Anatomical</td>
</tr>
<tr>
<td><strong>Anatomical Detail</strong></td>
<td>Poor</td>
<td>Poor</td>
<td>Good</td>
</tr>
<tr>
<td><strong>Soft tissue differentiation</strong></td>
<td>- - -</td>
<td>- - -</td>
<td>Poor</td>
</tr>
<tr>
<td><strong>Ionizing Radiation</strong></td>
<td>Yes (Internal)</td>
<td>Yes (Internal)</td>
<td>Yes (External)</td>
</tr>
<tr>
<td><strong>Sensitivity</strong></td>
<td>pico molar</td>
<td>nano molar</td>
<td>- - -</td>
</tr>
<tr>
<td><strong>Spatial Resolution (Clinical)</strong></td>
<td>3 – 8 mm</td>
<td>8 – 15 mm</td>
<td>1 mm</td>
</tr>
<tr>
<td><strong>Spatial Resolution (Pre-clinical)</strong></td>
<td>1 - 1.5 mm</td>
<td>0.5 – 1.5 mm</td>
<td>0.05 – 0.2 mm</td>
</tr>
</tbody>
</table>

PET/CT & SPECT/CT have enjoyed tremendous success in recent years!
### RATIONALE FOR PET/MRI AND SPECT/MRI

<table>
<thead>
<tr>
<th></th>
<th>PET</th>
<th>SPECT</th>
<th>CT</th>
<th>MR</th>
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</thead>
<tbody>
<tr>
<td>Information</td>
<td>Functional</td>
<td>Functional</td>
<td>Anatomical</td>
<td>Anatomical/Functional</td>
</tr>
<tr>
<td>Anatomical Detail</td>
<td>Poor</td>
<td>Poor</td>
<td>Good</td>
<td>Excellent</td>
</tr>
<tr>
<td>Soft tissue differentiation</td>
<td>- - -</td>
<td>- - -</td>
<td>Poor</td>
<td>Excellent</td>
</tr>
<tr>
<td>Ionizing Radiation</td>
<td>Yes (Internal)</td>
<td>Yes (Internal)</td>
<td>Yes (External)</td>
<td>No radiation</td>
</tr>
<tr>
<td>Sensitivity</td>
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<td>nano molar</td>
<td>- - -</td>
<td>Poor</td>
</tr>
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<td>Spatial Resolution (Clinical)</td>
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<td>1 mm</td>
<td>1 mm</td>
</tr>
<tr>
<td>Spatial Resolution (Pre-clinical)</td>
<td>1 - 1.5 mm</td>
<td>0.5 – 1.5 mm</td>
<td>0.05 – 0.2 mm</td>
<td>0.02 – 0.2 mm</td>
</tr>
</tbody>
</table>

**PET/MRI and SPECT/MRI can potentially provide**

- improved multi-modality information
- no additional ionizing radiation
- excellent soft tissue differentiation
DETECTORS IN SPECT SYSTEMS

- Conventional scintillation detector
  - Scintillator coupled with PMT
  - Indirect conversion
    - \( \text{Photon} \rightarrow \text{(scintillator)} \rightarrow \text{light} \rightarrow \text{(PMT} \rightarrow \text{amplification}) \rightarrow \text{large \# of fast electrons} \rightarrow \text{electrical signal} \)
  - \( B_0 \) field has large effect on fast electrons in PMT

- MR-compatible solid-state detector
  - CZT (cadmium zinc telluride) coupled w/ ASIC (application specific integrated circuit)
  - Direct conversion
    - \( \text{Photon} \rightarrow \text{electron-hole pairs} \rightarrow \text{electrical signal} \)
  - \( B_0 \) field has tractable effect on fast electrons
  - Minimum metallic components

Conventional detectors with photomultiplier tube (PMT)

- PMT
- PET detector w/ PMT

MR-compatible solid-state detector

- CZT detector module w/ ASIC
- Gamma photon
- electron-hole pair
- \( h^+ \)
- \( e^- \)
- ASIC

-Courtesy of Bernd Pichler, Ph.D., University of Tübingen
MR-COMPATIBLE CZT SOLID-DATE DETECTOR

- No spectral degradation due to magnetic field
  - tested to 9.4 T
- High energy resolution
  - <4 kev pixel, <6% overall
  - allows simultaneous multiple isotope studies

Tri-Isotope SPECT with CT In Vivo Mouse Image

- Tc99m bone
- I-123 thyroid
- TI-201 heart

Courtesy of Gamma Medica, Inc.
First-Generation Prototype MR-Compatible Small Animal SPECT Insert

Gamma Medica, Inc.

- Design goal/constraint
  - MR compatible detectors
    - CZT detector with 16x16 1.6 mm pixels
  - Use in small bore SA MRI system
    - 12 cm outer diameter
  - High detection efficiency
    - Multiple detector rings w/ multi-pinhole collimator

Bruker 9.4T MRI system with 12 cm diameter bore

MR-compatible CZT detector with low-power ASIC

Complete ring w/ 8 CZT each w/ single pinhole collimation

Offset adjacent rings for increased # of projection views

3-ring system with 24 CZT detectors
Design goal/constraint

- Multi-pinhole collimator
  - MR compatible high Z material
  - 24 pinhs match to 24 CZT detectors
  - Inner diameter allows mouse imaging
- RF coil
  - Birdcage design for high SNR
  - Fit over collimator sleeve

Prototype evaluation

- Stand alone
- Inside a Philips Achieva 3T clinical MRI system
MINIMIZING EFFECT OF SPECT ON MR IMAGES

- Minimize use of ferromagnetic materials in CZT detector modules
- Minimize use of ferromagnetic materials in SPECT insert
- Use of high density powder in collimator construction

Ultra-SPECT Phantom w/ Cu$_2$SO$_4$ solution

<table>
<thead>
<tr>
<th>MR images</th>
<th>Normal</th>
</tr>
</thead>
</table>

all detector pixels were disabled

all detector pixels were enabled

No noticeable MR image artifact due to SPECT system
EFFECT OF STATIC MAGNETIC FIELD ON SPECT

Lorentz Force

\[ F = q(E + \nu \times B) \]

Mean Lorentz Drift

- Electrons, 1 kV/cm
- Electrons, 2 kV/cm
- Holes, 1 kV/cm
- Holes, 2 kV/cm

Magnetic Field (T)

Lorentz drift (mm)
CORRECTING EFFECT OF STATIC MAGNETIC FIELD ON SPECT

- Direct conversion CZT detector
- electron charge cloud shift ~1.5mm in 3T $B_0$ field inside 5 mm thick CZT detector
- hole cloud shifts ~60 micron
- Lorentz shift can be corrected for improved image quality
SPARSE-VIEW SPECT IMAGE RECONSTRUCTION with modeling of MPH point response function (PRF)

- No rotation: 24 views
- 1 step rotation: 48 views
- 2 steps rotation: 72 views

Point source phantom

Pinhole aperture size: 0.5mm (labeled), 1.3mm (measured)

Reconstruction method: Iterative ML-EM with PRF modeling (Gaussian)
EVALUATION OF FIRST GENERATION SPECT INSERT FOR STANDALONE AND SIMULTANEOUS SMALL ANIMAL SPECT-MR IMAGING

Complete ring w/ 8 CZT each w/ single pinhole collimation

SPECT system w/ 3 offset ring ≈ & 24 CZT detectors

24-pinhole collimator with birdcage RF coil

Fitting in a 9.4 T MRI system w/ 12 cm diameter bore

Evaluation in Philips Achieva 3T clinical MRI system

Simultaneous SPECT-MR imaging of a mouse*

MIP images from Bone SPECT study of a mouse using Tc$^{99m}$-MDP*

1.3 mm diameter pinhole collimator ML-EM, 30th iteration & postprocessing

2 mm diameter pinhole collimator & ML-EM, 30th iteration & postprocessing

Time activity curves from dynamic study of kidney

Preliminary data

MR + SPECT = Fused SPECT/MR

Average image pixel value in ROI

*injected w/ Tc$^{99m}$ MIBI
SUMMARY

First-Generation MR-Compatible SPECT Insert

- Proofs-of-concept
  - MR compatible CZT detector modules
  - Feasibility of simultaneous SPECT-MR imaging
  - High efficiency multiple detector ring system
  - Possibility of sparse-view image reconstruction
  - Possibility of fast dynamic study w/o system rotation

- Limitations
  - Poor system spatial resolution
  - Relatively poor detector intrinsic resolution
  - Suboptimal RF coil configuration and characteristics

- Areas for further improvement
  - New SPECT insert design for higher system spatial resolution
  - MR-compatible material
  - Specialized system calibration and correction methods
  - Sparse-view image reconstruction methods
### DESIGN CONSIDERATIONS OF 2nd-GENERATION MR-COMPATIBLE SPECT INSERT

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Solutions</th>
</tr>
</thead>
<tbody>
<tr>
<td>MR compatible detectors</td>
<td>same CZT detector modules w/ 1.6 mm pixels</td>
</tr>
<tr>
<td>MR compatible collimator</td>
<td>improve non-magnetic collimator material (tungsten alloy powder)</td>
</tr>
<tr>
<td>Higher detection efficiency</td>
<td>multiple complete ring detector system</td>
</tr>
<tr>
<td>Higher system resolution</td>
<td>larger detector ring</td>
</tr>
<tr>
<td>More accurate sparse-view 3D MPH image reconstruction</td>
<td>theory and algorithm development</td>
</tr>
<tr>
<td>Improved SPECT images</td>
<td>specialized calibration &amp; correction methods</td>
</tr>
<tr>
<td>Compatible with high-field small animal MRI systems</td>
<td>SA MRI system with OD &gt;=20 cm</td>
</tr>
<tr>
<td>RF coil with higher Q and SNR</td>
<td>quadrature birdcage transmit/receive</td>
</tr>
<tr>
<td>Improved MRI images</td>
<td>specialized small animal pulse sequences</td>
</tr>
</tbody>
</table>
SECOND GENERATION MR-COMPATIBLE SPECT INSERT

Ring SPECT insert with multi-pinhole collimator design geometry

Each detector ring consists of 19 CZT detectors with an outer diameter of 20 cm.

SPECT insert with 5 complete rings of 2.54x2.54 cm² CZT detectors with an outer diameter of 19.8 cm.

SPECT insert additional MPH collimator sleeves & pinhole projections.

Unfolded ring SPECT insert showing detector array and pinhole projections.

Total detector area for acquisition of MPH projections.

Total detector area with sample pattern of MPH projections.
MULTI-PINHOLE (MPH) COLLIMATOR DESIGNS FOR MOUSE IMAGING

- **Design goal:** Given a target system resolution, design a MPH collimator for mouse imaging with the highest possible geometric detection efficiency.

- **Design constraints**
  - Field-of-view (FOV): 25 mm for whole-body mouse imaging
  - Total detector area
  - Magnification: limit by FOV & outer SPECT insert diameter
  - Collimator material: MR compatible and high Z

- **Design considerations**
  - MPH pattern: *pinhole placements*
  - Data acquisition methods:
    - static (w/ or w/o collimator rotation)
    - dynamic (no collimator rotation)
MPH COLLIMATOR DESIGN METHOD

- Given a target system resolution & detector area, calculate geometric efficiency, $E_G$, as a function of number of pinholes (or diameter of pinhole projections)
- Determine the optimum number of pinholes that maximizes $E_G$
- Determine optimal MPH collimator design that provides the highest possible $E_G$ under the design constraints

<table>
<thead>
<tr>
<th></th>
<th>Design # 1</th>
<th>Design #2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Field-of-view</td>
<td>30 mm</td>
<td>30 mm</td>
</tr>
<tr>
<td>Target system resolution</td>
<td>1.0 mm</td>
<td>1.5 mm</td>
</tr>
<tr>
<td>Number of rows of pinholes</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Total number of pinholes</td>
<td>18</td>
<td>36</td>
</tr>
<tr>
<td>Pinhole aperture size</td>
<td>0.3 mm</td>
<td>0.5 mm</td>
</tr>
<tr>
<td>Diameter of MPH collimator sleeve</td>
<td>49 mm</td>
<td>63 mm</td>
</tr>
<tr>
<td>Magnification of pinhole geometry</td>
<td>2.1</td>
<td>1.4</td>
</tr>
<tr>
<td>Geometric efficiency (%)*</td>
<td>0.026</td>
<td>0.069</td>
</tr>
<tr>
<td>Collimator rotation requirement</td>
<td>Yes</td>
<td>No (?)</td>
</tr>
</tbody>
</table>

*Based on Anger’s formulation with tungsten inserts, 122 keV photons and 100% absorption by detector
SPARSE-VIEW IMAGE RECONSTRUCTION METHODS

Iterative 3D MPH ML-EM algorithm w/ and w/o geometric response modeling

Effect of collimator rotation
18-PH collimator w/ 1mm Target resolution

Effect of number of iterations
36-PH collimator w/ 1.5mm target resolution

- Hot rod phantom
  - 0.7 mm
  - 1.0 mm
  - 1.35 mm
  - 1.7 mm

- 2.0 mm
- 2.4 mm

- 20th iteration
- 40th iteration
- 80th iteration

- no rotation
- 1 rotational step
- 2 rotational steps

- without GRF modeling
- with GRF modeling

w/ GRF modeling
MULTI-PINHOLE COLLIMATOR FABRICATION

18-Pinhole Collimator

Stereolithography rapid prototyping model of multi-pinhole collimator sleeve with cavity to hold high Z material with low conductivity

Sample pinhole inserts made with solid tungsten

Pinhole aperture size: 0.3 mm

Multi-pinhole collimator sleeve with 2 sample pinhole inserts in place

Completed MPH collimator

36-Pinhole Collimator

Pinhole aperture size: 0.5 mm

Sample pinhole inserts made with solid tungsten
Design of a transmit/receive quadrature birdcage RF coil for mouse MR imaging that fit inside the MPH collimator sleeve and directly over small animal for high SNR.

Components of the 128 MHz transmit/receive quadrature birdcage RF coil for mouse imaging.

Sample MR image of a mouse kidney using a similar RF coil.
SECOND GENERATION SPECT-MR SYSTEM

- Shielded quadrature transmit/receive birdcage RF coil
- Multi-pinhole collimator (stationary or rotating)
- Digital Electronic
- Collimator exchange position

Schematic diagrams of SPECT-MR system

SPECT-MR system (w/ cover off) showing 5 rings of 19 CZT modules at bottom & electronic on top

Initial testing of CZT detectors and data acquisition electronics

18-pinchole collimator assembly with rotating

With additional 4 air cooling hoses

Experimental set-up with SPECT-MR system and scanning bed
SPECT SYSTEM CALIBRATION, AND GEOMETRIC MISALIGNMENT AND NON-UNIFORMITY CORRECTION

- **Energy calibration**
  - Calibrate positions of measured photo peaks of each CZT detector pixel with known photon energies

- **System geometric misalignment correction**
  - Determine system geometric parameters for use in artifact-free image reconstruction
  - using $^{57}$Co point source placed at 7 positions

- **Non-uniformity correction**
  - Acquire flood image of CZT detector modules using a specially designed annual ring shell phantom
  - Identify and treat non-responsive and badly behave detector pixels
  - Apply flood image to acquired data uniformity correction
SYSTEM CALIBRATION AND CORRECTION OF GEOMETRIC MISALIGNMENT

- Acquire projections of $^{57}$Co point source placed at 7 positions
- Determined relative rotational orientation between each pinhole collimator and detector using
- Incorporate geometric misalignment in multi-pinhole image reconstruction algorithm

Reconstruction image of a line source

projection data        reconstructed images

without correction

with correction
DETECTOR PIXEL UNIFORMITY CORRECTION

- **Goal**
  - To determine CZT detector pixel variations
  - To develop method for non-uniformity correction

- **Method**
  - Develop a cylindrical shell phantom for non-uniformity measurement
    - Phantom fit snugly inside SPECT detector ring without collimator
  - Acquired flood images of all CZT detector models
  - Identify and treat non-responsive and hyper- and hypo-active detector pixels
  - Apply flood image to acquired data uniformity correction
DETECTOR PIXEL UNIFORMITY CORRECTION

Projection data

Reconstructed image

uncorrected

After application of uniformity flood map

Additional processing to correct for non-responsive, hyper- & hypo-active pixels

Phantom SPECT images

uncorrected

After application of uniformity flood map

Additional processing to correct for non-responsive, hyper- & hypo-active pixels
LORENTZ FORCE SHIFT CORRECTION

- When the SPECT system is placed inside an MRI system, the Lorentz force effect results in shifting of the detected count distribution of the CZT detector

- The Lorentz force shift effect is corrected by shifting the count distribution back to its original position

- The average amount of corrective shift can be estimated from:
  - theoretical calculation: \( \sim 1.6 \text{ mm} \)
  - Experimental method (minimum reconstructed resolution): \( \sim 2 \text{ mm} \)

\[ F = q(E + v \times B) \]
EXPERIMENTAL EVALUATION STUDIES

- CZT detector energy resolution measurement
- SPECT system sensitivity measurement
  - $^{57}$Co point source
- SPECT system resolution measurement using
  - $^{99}$mTc line source
- Phantom studies using stand-alone SPECT system
  - Data Spectrum Ultra-Micro Hot Spot Phantom
- Small animal studies using stand-alone SPECT system
  - normal mice injected with $^{99}$mTc Medronate
- Preliminary phantom study using simultaneous SPECT-MR system
Energy resolution is determined by fitting the energy peak with a Gaussian and calculate its FWHM.

Average energy resolution at 140keV over ~98% of pixels: ~3.9%

Energy spectrum of CZT detector modules

*Obtained with the cylindrical shell phantom filled with $^{99m}$Tc*
### Measured Imaging Performance Characteristics

System sensitivity measurements using a reference $^{57}$Co point source

<table>
<thead>
<tr>
<th>Multi-Pinhole Collimator</th>
<th>Predicted Geometric Efficiency$^1$</th>
<th>Predicted System Sensitivity$^2$</th>
<th>Measured System Sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(%)</td>
<td>(cps/MBq)</td>
<td>(%)</td>
</tr>
<tr>
<td>18-pinhole</td>
<td>$2.63E-04$</td>
<td>0.0197</td>
<td>197</td>
</tr>
<tr>
<td>36-pinhole</td>
<td>$6.87E-04$</td>
<td>0.0515</td>
<td>515</td>
</tr>
</tbody>
</table>

$^1$Based on Anger’s formulation with tungsten inserts, 122 keV photons and 100% absorption by detector

$^2$Taken into account the 75% absorption of 122 keV photons by 5 mm thick CZT detector

Results of spatial resolution measurements using a $^{99m}$Tc line source$^3$

<table>
<thead>
<tr>
<th>Multi-Pinhole Collimator</th>
<th>Predicted Spatial Resolution FWHM (mm)</th>
<th>Measured Spatial Resolution FWHM (mm)$^4$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Direct Measurement</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Corrected for Source thickness</td>
</tr>
<tr>
<td>18-pinhole</td>
<td>$1.0 \text{ mm}$</td>
<td>$1.23 \text{ mm}$</td>
</tr>
<tr>
<td>36-pinhole</td>
<td>$1.5 \text{ mm}$</td>
<td>$1.58 \text{ mm}$</td>
</tr>
</tbody>
</table>

$^3$Capillary tube with ~0.5 mm in diameter
PRELIMINARY EXPERIMENTAL PHANTOM STUDY

**Dimensions of hot rods**
- 0.7 mm
- 1.7 mm

**Data Spectrum**
Ultra-Micro Hot Spot Phantom

**Ultra-Micro Hot Spot Phantom**
- Cylinder outside dia.: 3.5 cm
- Cylinder inside dia.: 2.8 cm
- Cylinder inside height: ~2.8 cm
- Diameter of insert: 2.7 cm
- Radioactivity: ~10 mCi (370 MBq) $^{99m}$Tc

**Projection data**

18-pinhole collimator
- 0°, 20° and 40° rotational positions
- 20 min acquisition/positions

36-pinhole collimator
- 0° and 15° rotational positions
- 20 min acquisition/positions

**Sample Reconstructed Images**

* 3D multi-pinhole ML-EM image reconstruction at 40 iteration with CDRF correction & post-filtering w/ median filter

**Dimensions of hot rods**
- 2.0 mm
- 1.7 mm
- 1.35 mm
- 2.4 mm
- 1.0 mm
- 0.7 mm
IMPROVED SPARSE-VIEW IMAGE RECONSTRUCTION

3D MPH ML-EM algorithm
‘without’ pinhole response function modeling & 100 iteration

Projection data are from the hot rod phantom acquired using the 36-pinhole collimator

Image slice is 4 mm and all images have been post-processed with a median filter

3D MPH penalized ML-EM algorithm
‘with pinhole response function modeling & 100 iteration

No collimator rotation

1 additional collimator rotation

No collimator rotation

1 additional collimator rotation
**PRELIMINARY SKELETAL SPECT IMAGING OF A MOUSE**

*with i.v. injection of $^{99m}$Tc Medronate*

18-pinhole collimator

$\sim 5$ mCi (185 MBQ) $^{99m}$Tc-Medronate

- $0^\circ$, $20^\circ$ and $40^\circ$ rotational positions
- 18 min acquisition/positions

36-pinhole collimator

$\sim 8$ mCi (296 MBQ) $^{99m}$Tc-Medronate

- $0^\circ$ and $15^\circ$ rotational positions
- 13 min acquisition/positions

Projection data of the head region
PRELIMINARY SKELETAL SPECT IMAGING OF A MOUSE
with i.v. injection of $^{99m}$Tc Medronate

18-pinhole collimator
- $\sim 5$ mCi (185 MBQ) $^{99m}$Tc-Medronate
- 3 rotational positions w/ 13 min acq. each

36-pinhole collimator
- $\sim 8$ mCi (296 MBQ) $^{99m}$Tc-Medronate
- 2 rotational positions w/ 18 min acq. each

Sample Reconstructed Images of the mouse’s head*

* 3D multi-pinhole ML-EM image reconstruction at 40 iteration with CDRF correction & post-filtering w/ median filter

Mouse #1

Mouse #2

Every 5th 0.25 mm thick image slices
SPECT/MR DUAL MODALITIES NANOPARTICLES

- **Collaboration**
  - Olivier Tillement, François Lus, et al., Laboratoire de Physico-Chimie des Matériaux Luminescents, Université De Lyon, France

- **Dual modality nanoparticle**
  - Ultrasmall (5 nm in size) rigid platforms as multimodal probes
  - Gadolinium core and polysiloxane shell
  - multifunctional silica-based particles that are sufficiently small to escape hepatic clearance
  - enable animal imaging by four complementary techniques

*Courtesy of Olivier Tillement and François Lus*
MOUSE SPECT STUDY USING NAOPARTICLES

Methods
- Labeled nanoparticles with ~2.33 mCi of Tc-99m in 0.112 ml
- A ~26 gm normal mouse was i.v. injected through tail vein
- After ~5 min, the mouse was i.m. injected with ~0.5 ml of Xylazine
- The mouse was position using inside the prototype stationary SPECT insert using the 36-pinhole collimator with the FOV covering the Liver/kidney region
- Acquired listmode data for ~5 minutes

Projection data
MOUSE SPECT STUDY USING NAOPARTICLES

- 3D ML-EM with 40 iterations
- Voxel size: 0.25 mm
- Reconstruction matrix: $121^3$

3D MPH pinhole SPECT images

Sample enlarged images of the kidneys

Transaxial slices

Coronal slices

MIP images
EVAULATION OF SIMULTANEOUS SPECT-MR

System configuration using a clinical 3T MRI system

MR compatible SPECT system inside a clinical 3T MRI system for evaluation

Power supply for SPECT system placed at low $B_0$ region of MRI room

Data cable from SPECT system came through waveguide to laptop PC in control room
Preliminary Results

Projection data of hot rod phantom obtained with the SPECT insert

Outside MRI room
(58,068 total counts)

Inside 3T clinical MRI
with gradient field off
(57,626 total counts)

Inside 3T clinical MRI
simultaneous SPECT-MR data acquisition
(56,846K total counts)
Preliminary Results

Images of the hot rod phantom obtained with the SPECT system

- As stand-alone outside MRI room
- Inside a 3T MRI system with gradient field off simultaneously SPECT/MR

- Using the 36-pinhole collimator without collimator rotation
- All SPECT images had about the same total detected counts (~12 mCi in phantom and ~20 min. acquisition)
- Image reconstruction using a penalized ML-EM reconstruction method with CDRF correction at 20 iterations & post-filtering with a median filter
- Slight image degradation in the simultaneously acquired SPECT images
Preliminary Results

MR Images of the hot rod phantom obtained with the SPECT system inside a 3T clinical MRI system and

- Using the 36-pinhole collimator without collimator rotation
- The hot rod section of the phantom is placed directly under the central row of pinholes
- Simultaneously acquired MR images in the center of SPECT FOV show
  - minimum image artifact
  - ~7x decrease in SNR
  - Image artifacts at edge and outside SPECT FOV

(Showing higher background noise)
CONCLUSIONS

- Simultaneous SPECT/MR offers a new multi-modality imaging capability that provides unique anatomical and functional information from small animals and patients.

- The development and application of a 1st generation MR-compatible SA SPECT insert demonstrated feasibility of simultaneous SPECT-MR imaging.

- A 2nd generation SPECT insert with larger detector ring diameter (<20 cm) was designed and constructed.

- A 18- and a 36-pinhole collimators with optimized parameters & system resolution of 1 and 1.5 mm were designed and fabricated with special materials and methods.
CONCLUSIONS

- Sparse-view reconstruction method was developed to allow dynamic SPECT data acquisition without system rotation.
- The predicted SPECT system performance of the multi-pinhole collimators compared well with results from experimental phantom and small animal studies.
- Preliminary results of simultaneous SPECT-MR image of phantom demonstrate minimum image degradation to the SPECT and MR images at the center of the SPECT FOV.
- However, a ~7x decrease in SNR is found in the simultaneously acquired MR phantom images and image artifacts at the edge and outside the SPECT FOV.
FUTURE WORK

- Investigate and develop methods for further improvement in simultaneously acquired SPECT and MR images by
  - Increase understanding of the effects of SPECT system components and data acquisition system on MR images
  - More accurate determination of the Lorentz force effect

- Develop quantitative image reconstruction methods for improved high-resolution SPECT image quality

- Develop improved sparse view image reconstruction method for dynamic SPECT without system rotation

- Develop new RF coil and multi-pinhole collimators for simultaneous SPECT-MR imaging of rats
Thank you for your attention