Introduction to SPECT/CT

IAEA PET/CT Workshop: Improving Patient Care
Midrand, November 2010

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Medical imaging provides physicians with **sight** and **insight** on disease.
CT provides information regarding:

- changes in organ size & tissue density
- precise spatial localization
- topographic landmarks

*Structural data do not necessarily correlate with the metabolic status of disease*
Nuclear Medicine provides data regarding:
- functional characteristics of disease processes
- whole body assessment

*Lack of anatomic landmarks for accurate localization*
Definitions

- A SPECT/CT scanner is an integrated device containing both a CT scanner and a SPECT gamma-camera with a single patient table.

- SPECT/CT registration is the process of aligning SPECT and CT images for the purposes of combined imaging.

- SPECT/CT fusion is the combined display of registered SPECT and CT image sets.

- The method of attenuation correction is the use of CT transmission data with SPECT/CT scanners.

Dominique Delbeke et al., Procedure Guideline for SPECT/CT Imaging 1.0*, JNM 2006
SPECT/CT - The Simple Principle
Improved localization of radiotracer foci

SPECT
- Improved contrast & resolution
- Higher lesion detectability & sensitivity

The SPECT/CT cascade (Adding specificity)
- Precise lesion localization & characterization
- Better image interpretation
- Higher diagnostic confidence
- Accurate diagnosis (localization & extent)
- Improved clinical decision making

The Simple Principle - A Big Difference
Hybrid SPECT/CT Imaging
the best of both worlds

Tc-MDP bone scan

SPECT/CT
Myositis Ossificans
Tc-MDP SPECT/CT Improves Bone Scan Specificity

(Horger et al, Arch Orthop Trauma Surg, 2007)

Courtesy Drs. Eschman & Bares, Tubingen
History of SPECT/CT (1999-2010)

- We thought we know it all (general NM)

- We were busy understanding PET/CT (“the new toy in town”) which seemed to provide more prestige [& reimbursement]

- SPECT/CT was considered [by some]: 2\textsuperscript{nd} class hybrid imaging

- No. presentations SNM 2006: ~30
- No. presentations SNM 2010: >150
Hybrid Imaging

The Rambam Experience

- August ’99: VG Hawkeye (1st SPECT/CT)
- June ‘01: Discovery LS (1st PET/CT)
- February ‘03: Infinia Hawkeye (2nd SPECT/CT)
- March ’05: SPECT/Lightspeed16 CT (Prototype)
- June ‘06: Infinia Hawkeye-4 (3rd SPECT/CT)
- Oct ’06: Ventri/VCT (1st cardiac SPECT/CT)
- May ‘09: Discovery NM/CT 570c (1st ultrafast cardiac SPECT/CT)
- January ‘10: New PET/CT & SPECT/16CT
SPECT/CT
“Classic” Clinical Applications (1999-2009)

Tumor Imaging
- Iodine$^{131}$ - Thyroid cancer
- Iodine$^{123}$ MIBG - Neural crest tumors
- Indium$^{111}$ Octreotide - Neuroendocrine tumors
- Gallium$^{67}$ - Lymphoma
- Lymphoscintigraphy – Melanoma, Breast, H&N
- Tc99m MDP – Bone metastases

Non-Oncologic Imaging
- Tc99m MIBI - Parathyroid adenoma
- Gallium & Labeled WBC – Infections
- Tc99m MDP – Benign bone & extraosseous lesions

Cardiac
- Myocardial perfusion – Attenuation Correction
SPECT/CT & NM
Discovering new patterns & pitfalls
(Lessons learned from PET/CT)

Potential false positive reports
- Brown fat uptake of SPECT tracers (MIBG, Ga67, MIBI)
- Thymic uptake
- Uptake in processes unrelated to cause of referral
IN111-Octreotide SPECT/CT
Physiologic Biodistribution

M, 48, Islet cell tumor
Monitoring response to treatment

Physiologic tracer uptake in gallbladder
M, 20, Thyroid Ca & cervical LN mets s/p Radioiodine treatment

Tracer uptake in thymus hyperplasia
M, 60, Rt. PTA
Enlarged rt. & Hypoplastic lt submandibular gland
Rt. posterior, Paratracheal PTA
Sources of Error

SPECT/CT image fusion errors

- Movement in the interval between SPECT and CT data collection
  - Whole-body or extremity motion
  - Diaphragmatic motion with breathing
  - Bowel motility
  - Contrast motion or change in contrast concentration
  - Rapid filling of urinary bladder
- Attenuation artifacts
  - Particularly dense materials such as dental work
  - Metallic implants
  - Lack of data for CT technique
- Software misalignment of SPECT and CT data

Delbeke et al. Procedure Guideline for SPECT/CT Imaging 1.0* JNM 2006
Sources of Error

Display errors

- Inadequate windowing of SPECT or CT data on fused images
- Inadequate windowing of SPECT or CT data when viewed separately
- Cursor misalignment on SPECT and CT images
- Inappropriate color table selection for SPECT data
Misregistration in Cardiac SPECT/CT
SPECT/CT
Referral criteria

Clinical Data

- High suspicion for active disease, or known structural pathology that SPECT/CT may detect and localize
- Multiple sites, and define extent of disease
- Treatment planning
- Monitoring treatment response
SPECT/CT
Referral criteria

Data from previous Anatomic Imaging tests:

- Abnormal structural findings of equivocal functional significance:
  - at diagnosis
  - post treatment
- Absence of overt structural pathology in the presence of high clinical suspicion
SPECT/CT
Referral criteria

[Planar] Nuclear Medicine Data

- Foci of increased radiotracer uptake of unclear localization and clinical significance
- Tracer-related factors
  - Poor physical characteristics
  - High target-specificity
  - Physiologic biodistribution
- Patient/disease-related factors
  - Complex regional anatomy
  - Anatomic distortion after Rx
SPECT/low-doseCT - GE Hawkeye 4

X-ray Tube and HV Generator

Low Dose X-ray tube
1, 1.5, 2.0 & 2.5 mA

140 KeV High Energy Beam

23 s rotation
CT duration < 5 min

CdWO4 CT Detector Array

Slip Ring design

Front View

Side View

4x384 detectors of 1.844 x 31.4 mm

Robust Gantry

GE Healthcare
SPECT/multi-slice spiral CT: Siemens Symbia T series

MPI:
- IQ SPECT Technology
- Partially Converging Collimation
- 4 min cardiac SPECT, 1 min CT

Siemens SPECT/CT: Symbia T series
SPECT/multi-slice spiral CT: Phillips Precedence
SPECT/CT: Dedicated Cardiac Solid-state Ultrafast CZT Camera

- Solid-state design
- No rotation of NM gantry
- High sensitivity
- High resolution
- Cardiocentric imaging
- Fast acquisitions
- Dynamic studies
- 64-slice CT
<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Model</th>
<th>CT</th>
<th>Special Features</th>
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<tr>
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<td>GE</td>
<td>Hawkeye 4</td>
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<td>Discovery 570c 64</td>
<td>diagnostic</td>
<td>dedicated cardiac 64 slice &amp; solid state CZT</td>
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<td>Discovery 670c 16</td>
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<td>3D Bone</td>
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<td>Anyscan SC 16</td>
<td>diagnostic</td>
<td>modular</td>
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<tr>
<td>Digirad</td>
<td>Cardius X-ACT*</td>
<td>CTAC</td>
<td>dedicated cardiac, upright solid state CsI[Tl]</td>
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Nuclear Medicine Procedures

Pros:
- Highly sensitive
- Whole body imaging
- Detection & characterization of **functional** alterations
  Disease may be visualized in their early phases when anatomic lesions are not yet detectable.

Cons:
- Poor physical characteristics leading to image quality degradation
- Lack of anatomical landmarks
- Non-specificity of tracers
NM (SPECT) & CT
Complementary Role in Suspected Infection

SPECT – detection of a suspicious focus
CT – precise localization to tissue/organ

CT – detection of an anatomic lesion
SPECT - confirmed as active infectious process

Correlation of anatomical & functional data obtained from tests performed on different devices, on different days, is difficult
M, 63, NHL, FUO, susp. recurrence

Ga-SPECT/CT: uptake in gallbladder
Dg: Cholecystitis
F, 24, s/a Mediastinal Hodgkin, FUO

$^{67}$Ga SPECT/16 slice CT

SPECT/CT guided diagnosis:
Mediastinal Abscess
Lymphoscintigraphy - Planar at the level of the thorax - patient with breast cancer (4 point intra-dermal injection around the tumor)

Anterior view
10 minutes

Anterior view
30 minutes

Right anterior oblique

Right lateral
Lymphoscintigraphy - SPECT

SPECT - can improve SLN identification:

- contrast enhancement
- improved resolution

SPECT stand-alone lacks anatomical landmarks
Lymphoscintigraphy - Breast Cancer

Anterior Planar view
2 foci of uptake

Internal mammary SLN

Contamination

SPECT/CT: Localization of internal mammary SLN
Exclusion of additional SLN

Courtesy Dr. Lerman, Tel-Aviv
Sentinel Node Mapping – Summary
Value of SPECT/CT

Addition of SPECT/CT to the acquisition protocol of scintigraphic SLN mapping provides clinically relevant data for further patient management

- Detects nodes missed on planar scintigraphy
- Provides accurate localization of SLNs to common & uncommon drainage basins
- Excludes non-nodal false positive foci of radiotracer uptake
Bone Scintigraphy in Cancer Patients

Whole body bone scintigraphy (± SPECT)
The standard of care

Main indications:
- Staging - detection of metastases, local invasion
- Predicting prognosis
- Assessment of pathologic fractures
- Suspected & restaging of recurrence
  (clinical / biochemical)
- Monitoring treatment response
Skeletal Involvement in Cancer

Skeletal metastases: in 30-70% of cancer pts

- Breast carcinoma - 73%
- Lung carcinoma - 32%
- Prostate cancer - 70%
- Renal cancer - 24%

Bone scintigraphy:
- high sensitivity (focal areas of increased bone turnover in response to tumor growth)
- low specificity (tracer uptake in benign lesions)
Prevalence of degenerative disease of the spine according to age group

Up to 71%
Hybrid imaging using SPECT/CT increases sensitivity and specificity of bone scintigraphy (mainly by defining bone lesions as benign)

SPECT/CT should be applied whenever there are equivocal findings on planar bone scintigraphy

SPECT/CT is a valuable tool to optimize bone imaging, which might become even more important if new radiopharmaceuticals become available to image specific cell functions

Horger M, Semin Nucl Med 2006
Prostate cancer, staging

Tc$^{99m}$ MDP Bone Scintigraphy

Uptake in previously unknown fractured rib

Uptake in calcified accessory spleen
Bone SPECT/CT
Breast Cancer, Staging

Planar
Equivocal vertebral uptake

SPECT/CT
Facet Joint Disease
Bone SPECT/CT
Lung Cancer, Staging

Planar (& SPECT)
Equivocal vertebral uptake

SPECT/CT
Tc$^{99m}$ MDP uptake in lytic lesion

Bone Metastasis

Courtesy of Dr. T. Kuwert
Cancer-Related Non-Osseous Foci on Bone SPECT/CT

Uptake in primary tumor
- Lung Cancer
- Neuroblastoma
- Breast Cancer
- Ovarian Cancer
- Sarcoma
- Thyroid cancer

Uptake in mets
- Colon cancer
- Ovarian cancer
- Pancreatic cancer
Bone SPECT/CT
Colon Ca, Pelvic pain

Tc-MDP uptake in calcified metastasis in lt. psoas muscle

Extraskeletal Tc-MDP foci
Bone SPECT/CT in Cancer Patients

- Increase in specificity through accurate anatomic localization in skeleton and/or soft tissues
- Precise diagnosis: 85-92% of equivocal skeletal lesions (mainly spine, ribs & pelvis)
- Guiding biopsy of equivocal skeletal lesions

Horger M, Semin Nucl Med 2006
Utsunomiya D, Radiology 2006
Hybrid SPECT/CT devices
Historical development goal:
CT-based attenuation correction

CT-AC for nuclear cardiology
Widely used; recommended by society guidelines

- Improved diagnostic accuracy through improved specificity
- Improves the detection of severe and extensive CAD

*Nuclear cardiology at Rambam*
~30 patients/day, all with AC!
Skeletal scintigraphy with $^{99m}$Tc- HMDP shows superior localization of bone metastasis in os sacrum (green circle) after CT attenuation correction (CTAC). Without CTAC, background activity may be overestimated, especially in peripheral structures (red circles) and may appear with similar intensity as pathologic findings.

SPECT/CT Attenuation Corrected Diaphragm Artefact
Single Isotope (Tc99m-MIIBI) Same Day Stress/Rest

M, 81, DM, shortness of breath & atypical chest pain
MPI- SPECT:
  non-AC: fixed defect inferior wall
  AC: normal study
M, 80, obese, new onset of chest pain

MPI-SPECT:
AC: reversible perfusion defect in lateral wall
non-AC: not clearly defined
Integrated SPECT/CTCA diagnosis of hemodynamically significant coronary artery lesions

CTCA

MPI SPECT

SPECT/CTCA

Normal study
Cardiac SPECT/64-CT
Abnormal perfusion

F 75, Ant MI, PCI
Pharmacologic stress
Ischemic response

SPECT
Apical defect, partial reversible
F 75, Ant MI, PCI, Cardiac SPECT/64-CT
Multiple CT Abnormalities

LAD – multiple plaques, borderline stenosis
RDA – significant stenosis (65%) mid-segment
F 75, Ant MI, PCI
Cardiac SPECT/64-CT

Apical ischemia supplied by LAD
Integrated Single-Photon Emission Computed Tomography for the Assessment of Hemodynamically Significant Coronary Artery Lesions

Shmuel Rispler, MD, PhD,* † Zohar Keidar, MD, PhD, † Eduard Ghashin, MD, † Ariel Roguin, MD, PhD, § Adrian Soil, ‖ Robert Dragu, MD,* † Diana Litmanovich, MD, † Alex Frenkel, DSc, † Doron Aronson, MD,* Ahuva Engel, MD, † Rafael Beyar, MD, DSc, FACC, § Ora Israel, MD †
Haifa and Tirat Hacarmel, Israel

<table>
<thead>
<tr>
<th></th>
<th>CTCA</th>
<th>SPECT/CTCA</th>
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<tr>
<td>Sensitivity</td>
<td>96%</td>
<td>96%</td>
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<tr>
<td>Specificity</td>
<td>63%</td>
<td>95%, p&lt;0.01</td>
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<tr>
<td>PPV</td>
<td>31%</td>
<td>77%, p&lt;0.01</td>
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<tr>
<td>NPV</td>
<td>99%</td>
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56 pts, CA within 4 weeks

Anatomic-Functional Imaging by Single-Photon Emission Computed Tomography/Computed Tomography as the Cornerstone of Diagnosis and Treatment for Coronary Patients

A Glimpse Into the (Near) Future?*

William Wijns, MD, PhD, FESC
Aalst, Belgium

The fascinating study by Rispler et al. (1) in this issue of the Journal represents another validation milestone in the search for a noninvasive imaging strategy that will eventually provide integrated evaluation of anatomy and physiology in patients with coronary artery disease.
Cardiac SPECT/CTCA

Potential Clinical Applications

- Replace cath for diagnosis - improve throughput for Rx
- Identify culprit lesion in patients with multiple plaques
- Increase accuracy for diagnosis and prognosis of CAD (e.g. high risk asymptomatic pts)
- Increase confidence of interpretation
- Diagnosis in clinically challenging scenarios with incongruent anatomic & functional findings (e.g. small vessel disease, syndrome x)
- Potential good tool for molecular imaging with new targets (e.g. angiogenesis, inflammation, hypoxia, apoptosis & necrosis)
Improving the SPECT/CT Technology

- Which quality of SPECT & CT is needed?
- SPECT/CT - a true tomographic technique
OSEM-3D: Iterative Reconstruction with Isotropic Resolution Recovery

F, 4y, repeat urinary tract infections, Tc-DMSA SPECT

Loss of renal functional parenchyma in left lower pole. The results are clearer in the OSEM-3D.

*Pediatric Study:* Sheehy et al, Radiology 2009;251:511-516
“Evolution for Bone”
F, 54, BMI 24, Metastatic Breast Ca, Tc-MDP 25mCi

WB SPECT (3 FOV)
total acquisition time: 28 min
“Half-time” Evolution Bone SPECT/CT

Bone SPECT/CT
Procedure time = 7 min
(GE Infinia Hawkeye 4)

Half-time SPECT with collimator-detector response compensation reconstruction ("Evolution"®, GE Healthcare)

A novel algorithm shortening SPECT acquisition time without a negative effect on image quality - tested, validated & confirmed for clinical use in bone SPECT

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Multi-FOV Bone SPECT/CT Acquisition

Multi-trauma
Multi-FOV Evolution SPECT/CT

Courtesy Dr. Even-Sapir, Tel-Aviv
The Promising Role of SPECT/CT

- Adding high specificity to high sensitivity
  - Better localization
  - Improved image interpretation
  - Higher diagnostic confidence
- Accurate diagnosis, localization & extent
- Optimized clinical decision making
Suggested SPECT/CT Protocols

modified after Buck AK et al, JNM 2008

Low-dose CT
- Recent diagnostic CT
- Localization of tracer-avid foci in majority of cases
- Bridging with dg. CT
- CT-related radiation dose: 2-4 mSv

Diagnostic CT
- No recent diagnostic CT
- When detailed anatomic info is mandatory, such as:
  - cervical region
  - abdomino-pelvic foci adjacent to highly avid organs
- CT-related radiation dose: 6-14 mSv
In-111 SPECT/CT
NET: liver mets, assessment of resectability

Co-registration to ce-CT (previously performed)
Tumor embolus in IVC
SPECT/CT Future Goals

1. Improved referral criteria - specific & related to: disease, patient, clinical problem at hand, tracer

2. Improved technology
   - Decisions on quality of CT & SPECT - based on true needs and less on fashion
   - Need for a true tomographic technique

3. Standardization of scientific evaluation:
   - Interpretation & analysis criteria
   - Clinical value assessment
New (Expensive) Technologies

Can save healthcare cost if they have a higher diagnostic accuracy as compared to other modalities

Most expensive aspect of disease management is the treatment rather than diagnosis

More accurate diagnosis results in more appropriate and less expensive treatment
Extrathoracic Splenosis
Tc-DRBC SPECT/CT
The commercial availability of SPECT/CT devices has emerged over recent years at a rapid pace, benefiting significantly from pioneering technological research.

Shadowed by the spectacular success of PET/CT, SPECT/CT has caught up proving its significant value for a wide range of clinical applications.
SPECT/CT Rebuilds the North American Nuclear Medicine Equipment Market


The single positron emission computed tomography/computed tomography (SPECT/CT) segment (…) leads this charge and opens up numerous lucrative opportunities in niche market....

With the new attenuation correction and image acquisition/reconstruction tools having enhanced SPECT/CT end users' confidence in its diagnostic and prognostic capabilities, SPECT/CT is fast becoming a must-have technology.
“Elements of Danger – The Case of Medical Imaging”
Lauer MS, NEJM August 27, 2009

“We must approach imaging with ... humility”

- Only with a strong evidence base (large body of data coming from well-powered randomized trials clearly showing net benefit) we should feel comfortable recommending [tests] in spite of the fact that they come with their own elements of danger.

- “We have to think and talk explicitly about the elements of danger in exposing our patients to radiation.”
Thank you!