Multimodality Imaging – Current State of the Art

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Outline

• Multimodality Imaging
• Challenges in medical imaging technology (2010)
  – Multimodality – What, why, how?
  – Applications

• Identify trends
  – Changing requirements; soft market
  – New scanners and applications
  – CT scanners:
    • Point of Care CT; DentoMaxilloFacial/ENT;
      Portable CT, dose management, CTP

Multimodality Imaging

Clinical Specialties
• Gastroenterology
• Urology
• Cardiovascular
• Oncology
• Pulmonary
• Neurology
• Pediatrics
• Musculoskeletal
• ENT
• Emergency

Imaging Modalities
• CT
• MRI
• Ultrasound
• Radiography
• X-ray Fluoroscopy
• SPECT & PET

“Multimodality” systems
• PET-CT or SPECT-CT
• MRI-PET

Multimodality imaging is frequently used, but most systems are NOT integrated...

• Clinical management of many conditions requires multimodality imaging
  – Screening, e.g., virtual colonography, pulmonary nodule CT, US
  – Diagnosis, e.g., image-guided biopsy, CE-CT or MRI
  – Staging, e.g., CT or MRI
  – Treatment, e.g., stereotactic surgery
  – Follow-up, e.g., CXR, CT of cyst or mass

• Integrated systems for PET-CT are widely available
• For other types of imaging, e.g., CT, MRI, US, fluoro, radiography, the review of multiple modalities is done at the PACS workstation
• Some modalities are so costly that they must be shared: one does all
e.g., CT and MRI
• Each specialty has different requirements, so optimal imaging may be very complex
  – Cardiovascular: Same patient may have cardiac echo, SPECT, coronary CTA, and cardiac cath at different times
Multimodality Imaging

Clinical Specialties
- Gastroenterology
- Urology
- Cardiacvascular
- Oncology
- Pulmonary
- Neurology
- Pediatrics
- Musculoskeletal
- ENT
- Emergency

Hospital-based departments: Radiology, Pathology, Rad Oncology

Imaging Modalities
- CT
- MRI
- Ultrasound
- Radiography
- X-ray Fluoroscopy
- SPECT & PET

“Multimodality”
- PET-CT or SPECT-CT
- MRI-PET

Breast Imaging

PET-CT

Image of the Year 2009

FDG-PET
Before Rx
After Rx

A 35-year-old woman with NHL had a complete response after Y-90 Zevalin® treatment.
Multimodality, multitemporal imaging

- Payors will reimburse for a single exam from a single modality (pre-cert) at a single time – for diagnosis/staging
- Follow-up scans to evaluate disease status (e.g., restaging; response evaluation)
- Common scenario:
  - Detect lesion on CT, and characterize it with MRI. Biopsy with US.

There are dozens of F-18 PET tracers available for research. Several of these are available for clinical use.
**INDICATIONS**

- **CHOLINE PET-CT**
  - Diagnosis of Prostate Cancer
  - Staging of Prostate Cancer
  - Suspected Relapse
  - Re-staging of Prostate Cancer

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**PET Imaging of Prostate Cancer Using Carbon-11-Choline**

The Journal of Nuclear Medicine • Vol. 39 • No. 6 • June 1998

Department of Radiology and Imaging, International Medical Center of Japan, Tokyo, Japan

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**11C-CHOLINE**

**18F-CHOLINE**

**18F-FDG**

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P.V. 66 yo, treated with RT for prostate adenocarcinoma; recent increase of PSA (10 ng/ml).

S. Fant, University of Bologna

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Prostatectomy
PSA 1.3 ng/ml
BS neg

Suspicion for Relapse

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S. Fant, University of Bologna
Suspicion for Relapse

69 yo PSA: 21 ng/mL
Stage T2a Gleason 7 pN 2/18
PET+ =1 (8mm) Iliac
PET+ =1 (7mm) Iliac

P.L. 36 yo, treated with S + RT for glioma
MR suspect of relapse

Methyl[14C]carnitine uptake as measured by positron emission tomography correlates to transaxial density in patients with glioma

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S. Fanti, University of Bologna
GI NEUROENDOCRINE TUMOURS

18F-DOPA

18F-FDG

Staging small NET of the pancreas:
GaDOTA NOC shows the primary NET and some secondary peripancreatic lymph nodes

NEUROENDOCRINE TUMOURS

Molecular imaging in neuroendocrine tumors: Molecular uptake mechanisms and clinical results
E rins P. Kooyman,
Olgierd N. Much,
Loic P. Paris,
Philip H. Ehlinger,
Thierry E. Lebots,
Elisabeth C. J. de Vries P.*
(Dept. of Surgery, Leuven, Belgium)

Critical Reviews in Oncology/Hematology 71 (2009) 199-213

Multiple vertebral paragangioma
**Case History**

65 year old male with elevated liver function tests.

Status post sigmoidectomy for colon cancer 5 years ago.

CT exam to rule out mass or biliary tract disease.

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**Liver Mass**

Liver hemangioma

- Hepatic hemangiomas are present in about 7% of healthy people.
- Hemangiomas are four to six times more common in women than in men.
- Hemangiomas, although referred to as tumors, are not malignant and do not become cancerous.
- Hemangiomas are not unique to the liver and can occur almost anywhere in the body.
- Giant hemangiomas do occur and are susceptible to occult bleeding

**Why so many modalities?**

- Each has strengths and weaknesses; Synergy
- One size / type does not fit all
- Reimbursement; instrument/operator availability
- CT is most available and widely used
  - Essential technology for emergency dept.
  - CT is fast; 24/7 access
- MR is expensive, time consuming
  - Some patients are ineligible or unable to tolerate
- US is operator dependent
  - Skilled examiner is required, otherwise many errors
  - Real time; versatile; safe; widely available
When is multimodality imaging used?

- **Breast** imaging: mammography, ultrasound, MRI
- **Cardiac** imaging: echo, SPECT, cardiac cath, CCTA, CMRI
- **Prostate** imaging: US, MRI, CT (for staging)
- **Brain** tumors: MRI, MRS, CT
- **Stroke**: CT (CTA and perfusion), MRI
- **Solid tumors**: CT, MRI, PET
- **Transplant**: US, MRI, CT
- **Interventional**: fluoroscopy, US, CT, MRI
- **Orthopedic**: radiography, MRI, fluoroscopy, CT

- And many others….  

When is multimodality imaging NOT used?

- **Emergency**: CT
- **ICU**: radiography (sometimes head CT or portable US)
- **O.R.**: fluoroscopy (sometimes US or radiography)
- **Thyroid**: US (and sometimes SPECT)
- **Follow-up** solid tumor/surveillance: CT

- And many others….  

Choice of modality and scanning protocol is difficult and complex.

- Limited knowledge of the clinical status and history
- Similar history may require very different exams:
  - Abdominal pain
    - Depends on renal function and allergy to iodinated contrast
    - Acute vs. chronic; where does it hurt?
    - WBC; fever
    - Jaundice
    - Gender and gynecologic history
  - Altered mental status
    - Prior surgery
    - Known malignancy
    - Intoxicated?
  - Search for primary tumor – occult malignancy
    - Serum biomarkers
    - Known metastases
- Payor may deny reimbursement for repeat or additional exams.
Exceptions
• Diversity of patients; generalizations are difficult
  – Massive obesity
  – Children (including neonates and infants)
  – ICU patients – on respirator
  – Immunosuppressed; contagious (e.g., Tb)
  – Mental impairment; claustrophobia
  – Pregnancy
  – Renal failure – acute and chronic

Multitemporal imaging
• Contrast-enhanced: (within exam session)
  – Multiphase: arterial, venous, equilibrium
  – Perfusion: DCE
  – 10+ minute: excretion; redistribution

• Sequential (e.g., monthly, quarterly encounters)
  – Restaging in oncology; Baseline + followup
  – Revascularization; vessel patency
  – Measure of response to therapy
    • e.g, Imaging biomarker

Multiphase contrast-enhanced imaging
• Common in CT and MRI
• Essential for liver, pancreas, kidneys
• CT angiography typically consists of both a non-contrast and post-contrast enhanced series (same for MRA)
• Multiphase cardiac CTA:
  – Precontrast coronary calcium scan
  – Post-contrast retrospective gating

Multiphase CT

Liver lesion after RFA
Pre-

Post-

Same slice, multiple time points

Liver malignancy prior to RFA
Cardiac imaging – an example

- EKG and stress testing – cardiac SPECT
- Abnormal SPECT – cardiac cath & PCI
  or may choose coronary CTA
- Coronary calcium measurement with CT
  – Risk assessment by age and gender norms
- Valvular disease: echocardiography
- Cardiac MRI
  – Congenital anomalies, congenital heart disease
  – Myocardial viability, cardiac function

Future? – PET-CT; MRI-PET; ...

Delayed CT/MRI imaging

- Redistribution phenomena
  – Gd contrast into fibrosis (Myocardial viability)
  – Cholangiocarcinoma (malignant)
  – Adrenal adenoma (benign)
  – Hemangioma (benign, but may be very large)
- Renal excretion
  – Antegrade opacification of urinary tract
  – Basis of CT urogram (akin to IVP / EXU)

Delayed CE-MRI:
Normal myocardial viability

Short axis
4 chamber
2 chamber

Delayed CE-MRI

Mid-ventricular slice demonstrating abnormal enhancement (arrow)
Basal slice demonstrating no abnormal LV enhancement
Myocardial SPECT

CT Market 2010

Revenue from new CT units shipped to U.S. customers

2006
2007
2008
2009

Source: Industry estimates

Greg Freiherr | May 25, 2010 | DiagnosticImaging.com

MSCT time table – The applications of CT change as the technology advances

AAPM 2010 Michael W. Vannier - University of Chicago
Clarity™ Tissue Adaptation

- Automatically adapts to the tissue.
- Decrease noise in the soft tissue and increase the contrast in the lung.

Pediatric - Liver

original

processed

Thin slice 0.6 mm

http://www.pedrad.org/associations/5364/ig/
Clarity™ CT Solution Server

- Clarity™ CT Solution Server acts as a DICOM node that receives DICOM3.0 compliant data, then processes the data, and then forwards the optimized study to the selected destination. This destination can be any DICOM node, typically either the PACS system or a specific workstation.

Clarity™ Ultra Low Dose CT Liver

- 100% (standard dose)
- 50% (low dose)
- 50% dose (processed)

Multirow Detector CT (MDCT) Scanner

- 128 detector rows; 256 slices (iCT)
- Increased Speed, Power, Coverage
  - Higher temporal resolution
    - 0.27 sec rotation
  - Increased Tube Power
    - 120 kW / 1,000 mA
    - X-Y and Z focal spot modulation
  - Greater coverage per rotation
    - 8 cm
    - 256 slices
Neuroscience Biomarkers

Biological markers, or biomarkers, are quantitative measurements that provide information about biological processes, a disease state, or about response to treatment, providing insight into preclinical and clinical data.

Biomarkers hold the potential of a better understanding of the etiology and pathogenesis of a given disorder, providing insight into diagnosis, treatment, and prognosis for many debilitating disorders and diseases.

CT Brain Perfusion

Color-Coded Parameter Maps

Color-coded parameter maps for a selected slice

Bernhard Preim, Visualization Research Group, University of Magdeburg, Germany
Perfusion

CT vs. MRI

CT vs. xenon CT vs. PET vs. SPECT

CTP vs. MRT

Non-contrast CT vs. xenon CT vs. PET vs. SPECT

Megan Strother, M.D., Vanderbilt University

7/18/2010

Imaging Ischemia - Vascular

Angiogram

1950-60's (pre-CT era)

Vascular occlusion

Revascularization

Clinical improvement

24 hours

Head CT

No ICH

<1/3 MCA territory

<3 hours

IV Thrombolysis

Megan Strother, M.D., Vanderbilt University

7/18/2010
**Wall Clock**

- Vascular Occlusion
- Parenchymal changes on non-contrast CT

**Tissue Clock**

![Tissue Clock Diagram](image1)

**MR vs. CT**

- No radiation
- Better contrast

![MR vs. CT Diagram](image2)

**Advantages**

- Diffusion = Infarct
  - MR = 94% sensitive and 96% specific for infarct
  - Non-contrast CT = 50% accurate for acute infarct

- MR = whole-brain coverage
  - CT limited by scanner (10-40 mm max)
  - Post fossa obscured on CT by beam-hardening artifact

![Advantages Diagram](image3)
Multi-modality Imaging:
Current State of the Art - M. Vannier*

- Speed
- Accessibility
- Spatial Resolution on CTA

CTA vascular detail
CTP
MRP
Cheap
Fast
Whole brain coverage
No radiation
Diffusion
Quantifiable

- Quantifiable
- MR relies on indirect T2* effects on tissue from gad, therefore not quantifiable

STROKE IMAGING
CT Scan Protocol

1st
Non-contrast Head CT

2nd
CT Perfusion

3rd
CT angiogram

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CT Scanning Protocol – 320 Channel

- non-contrast head CT = 2.4 mSv
- dynamic CTA & CTP = 3.9 mSv
- neck CTA = 2.6 mSv
- post-contrast head CT = 2.4 mSv
- total dose = 11.2 mSv

Whole Brain Perfusion (16 cm z-coverage)

Workflow for whole brain CT perfusion exam and postprocessing...
Multi-modal Imaging: Current State of the Art - M. Vannier*

Whole Brain Perfusion

Axial Views

ROIs

Coronal Views

3D View (Interactive)

Dual Energy CT

Spectral and Dual Energy CT

Simple Analogy

Traditional CT

Spectral CT

Limited Spectral CT

Dual Energy CT

Yesterday & Today

Future

Future

Today

Dual-energy Material Separation

X-ray tube spectrum

E1

E2

Calcium

Iodine solution

Iodine > Calcium

Iodine < Calcium

X-ray Detector signals

Calcium

Iodine
Spectral vs. Dual Energy CT
Techniques That are Possible on Commercial Systems

Dual Source
Dual kV Switch
Dual Spin
Not Spectral CT

Spectral vs. Dual Energy CT
Techniques That are Available on Research Systems

Dual-layer ("Double Decker") Detector*
Photon Counting*

*Works in Progress: Pending commercial availability and regulatory clearance

Dual-Layer CT (Orion-N)
Spectral CT

How does spectral CT fit into today’s standard of care?

- New clinical features, such as spectral imaging, may still be works in progress through 2010 and longer
- No medical guidelines include spectral CT
- No reimbursement for spectral CT
- No large studies have been published for spectral CT
- Alternative approaches exist for proposed spectral CT clinical applications
- Rapidly changing technology

Dual Energy CT - Limitations

- High image noise in obese patients (80kVp problem)
- Slightly increased radiation dose of DE
- Limited scanning field of view
- Spectral overlap
Low X-Ray Radiation Dose

Sinus CT with a full-body scanner
- Adult: 1.0-2.0 mSv
- Child: 1.0-2.0 mSv

Sinus CT with the MiniCAT™ low-dose scanner
- Adult: 0.13 mSv (7-15 x lower radiation dose)
- Child: 0.07 mSv (14-28 x lower radiation dose)

Which do you prefer?

This is the same pt scanned within 24 hours using the Ceretom portable scanner and then a GE stationary scanner...
Use of multimodality and multitemporal data

- Post-processing software tools
  - Visualization: MPR and 3D
  - Fusion: usually limited to image pairs
  - Perfusion: based on assumed compartmental model, not standardized
  - Most interpretations are subjective
- Enterprise integration with PACS
  - Access to images and advanced analysis tools remotely
  - Subspecialized experts apply unique tools for planning, implant specification, response measurement

Medical Imaging Workstations

- Thick Client – expensive, with substantial local processing capability
- Thin Client – small, portable, Accessible throughout enterprise

Enterprise Visualization

Should we offer advanced visualization services across the enterprise using a client-server system?
Large amount of local processing capability, linked to PACS. Runs complex proprietary software.

No local processing, linked to remote server. Rudimentary functions are easy to use.

STANDALONE
Speed
Ease of Use
Image Quality
Tools & Features

ENTERPRISE
CAD
Tools
Access
Integration

Evidence-Based Guidelines
Reference Databases
Workstations

STANDALONE

Essential Services

CT or MRI (linked to modality upgrade or new install)

24/7 (linked to EMR upgrade or new install)

Meaningful Use (MU)

CT or MRI

Angiography

CT Urography

CT Enterography

CT Perfusion

Cardiac MRI

Thin Client Solutions

CT viewing plus

- Comprehensive Cardiac Analysis
- Brain perfusion-summary maps
- CT Angiography Applications
  - AVA Stenosis and Stent Planning
  - Lung Nodule Assessment
  - Virtual Colonography

All Key Clinical Applications

Why

- Time is a physician’s most precious asset
- “Every 15-seconds matters”

What

- Images
- 3D Viewing
- All Key Applications

Where

- Scanner
- Workstation
- PACS
- Virtual Private Network
- Department
- Hospital
- Imaging Center
- Home

Thin Client Solutions

Zero Click Footprint
Automated Coronary CTA Analysis

Enterprise Medical Imaging
- Thin Client
- Portal
- Zero Footprint
- Applications Hosting

Conclusion
- Multimodality (and multitemporal) imaging is widely used
- Tailoring systems to solve specific diagnostic imaging problems is complex
- Workflow includes post-processing on imaging workstations, distributed across the clinical enterprise
- New scanners and technologies are emerging – wide area CT, dual energy, cone beam OMF scanners, portable CT, PET/MRI
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