Tuesday, July 20, 2010
Imaging Continuing Education Course
CE-Imaging: Multimodality Medical Imaging - I

Multimodality Imaging – Current State of the Art

Michael W. Vannier, M.D.
University of Chicago

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

Hospital-based departments:
Radiology, Pathology, Rad Oncology

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, MR, 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

4

Multimodality Imaging

Breast Imaging

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- Emergency

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- MRI-PET

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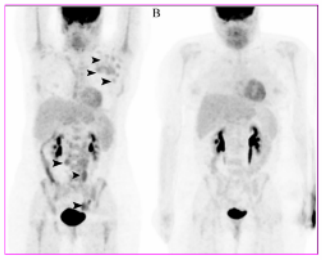
SNM
Advancing Molecular Imaging and Therapy

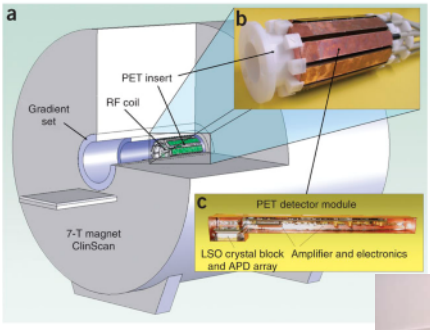
Image of the Year 2009



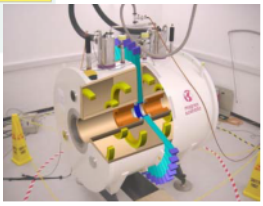
FDG-PET
Before Rx

After Rx

A 36-year-old woman with NHL had a complete response after Y-90 Zevalin® treatment.



Integration of the multislice PET scanner into a 7-T MRI apparatus.

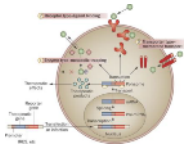


Simultaneous PET-MRI: a new approach for functional and morphological imaging
Martin S Judenhofer, et al.
Nature Medicine 14, 459 - 465 (2008)

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.

Multimodality & Molecular Imaging



PET-CT or PET-MRI

HYBRID IMAGING + **MOLECULAR IMAGING**

S. Fanti, University of Bologna

Fluorinated tracers for imaging cancer with positron emission tomography

Olivier Couturier[1], André Luxen[2], Jean-François Chatal[3], Jean-Philippe Vuillez[3], Pierre Rigo[4], Roland Hustinx[3]

^{18}F-TYR	^{18}F-FMAU	^{18}F-FMOX	^{18}F-MISO	^{18}F-FAMP
^{18}F-FMT	^{18}F-FAU	^{18}F-FESD	^{18}F-FAZA	^{18}F-FHPG
^{18}F-FET	^{18}F-FEC	^{18}F-FENP	^{18}F-FETN	^{18}F-FHBG
^{18}F-DOPA	^{18}F-FBM	^{18}F-FMNP	^{18}F-FETA	^{18}F-FIAU
^{18}F-OCT	^{18}F-FCH	^{18}F-FDHT	^{18}F-EF1	^{18}F-FPCV
^{18}F-TOCA	^{18}F-FPC	^{18}F-FMIB	^{18}F-EF5	^{18}F-RGD
^{18}F-FLT	^{18}F-MEC	^{18}F-MEC	^{18}F-NaF	^{18}F-TP
^{18}F-FBAU	^{18}F-FES	^{18}F-MDH	^{18}F-FU	^{18}F-FMAC
		^{18}F-FAMP	^{18}F-SFB	^{18}F-FBG

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

CHOLINE

↓

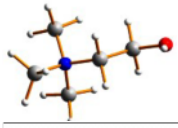
PHOSPHOLIPID

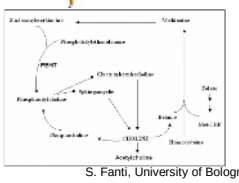
↓

TRACE
CELL
MEMBRANES

^{11}C-CHOLINE

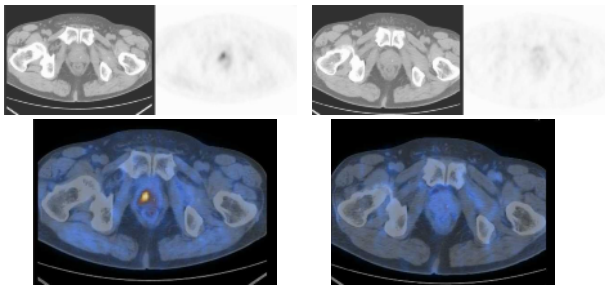
^{18}F-CHOLINE





S. Fanti, University of Bologna

^{11}C-CHOLINE **^{18}F-FDG**



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

S. Fanti, University of Bologna

CHOLINE PET-CT

INDICATIONS

DIAGNOSIS OF PROSTATE CANCER

STAGING OF PROSTATE CANCER

SUSPECTED RELAPSE

RE-STAGING OF PROSTATE CANCER

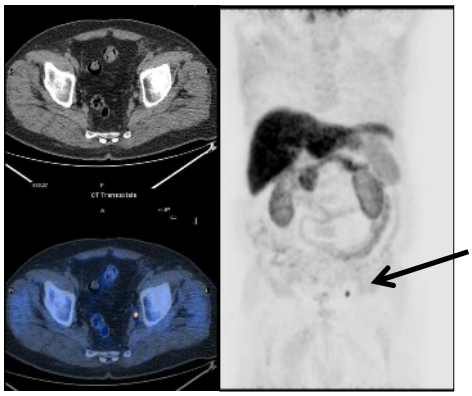
PET Imaging of Prostate Cancer Using Carbon-11-Choline

THE JOURNAL OF NUCLEAR MEDICINE • Vol. 39 • No. 6 • June 1998

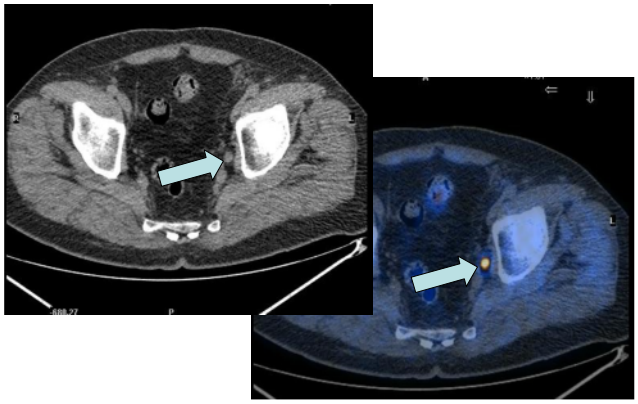
Toshihiko Hara, Noboru Kosaka and Hiroichi Kishi
Departments of Radiology and Urology, International Medical Center of Japan, Tokyo, Japan

Suspicion for Relapse

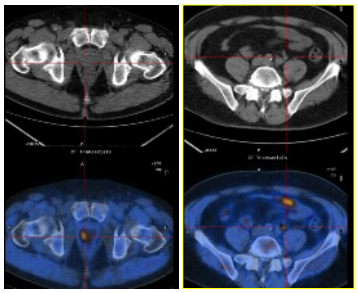
Prostatectomy
PSA 1.3 ng/ml
BS neg



Suspicion for Relapse



STAGING OF PROSTATE CANCER



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

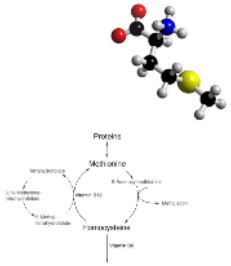
AMINO ACID

↓

TRACE PROTEIN SYNTHESIS & METABOLISM

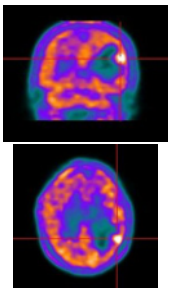
^{11}C-METHIONINE

^{18}F-FET



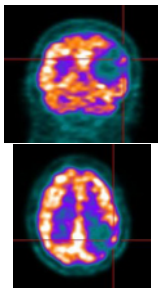
S. Fanti, University of Bologna

^{11}C-METH



P.L. 38 yo, treated with S + RT for glioma
MR suspect of relapse

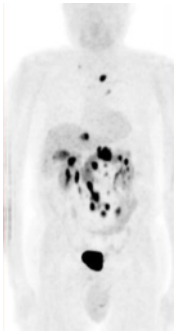
^{18}F-FDG



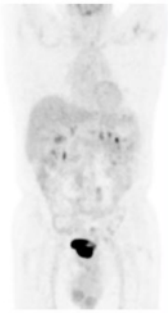
Methyl-[^{11}C]-L-methionine uptake as measured by positron emission tomography correlates to microvessel density in patients with glioma

Eur J Nucl Med Mol Imaging (2003) 30:868–873
DOI 10.1007/s00259-003-1148-7

GI NEUROENDOCRINE TUMOURS



^{18}F-DOPA

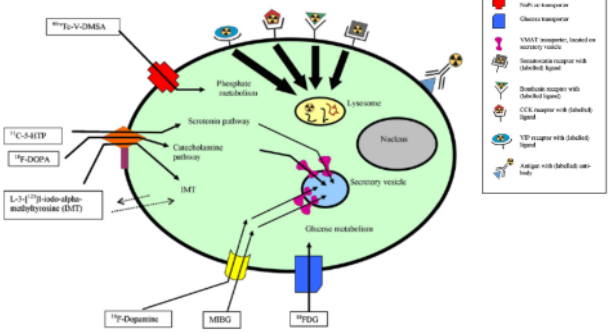


^{18}F-FDG

Molecular imaging in neuroendocrine tumors: Molecular uptake mechanisms and clinical results☆

Klaas P. Koopmans[a], Oliver N. Neels[a], Ido P. Kema[b], Philip H. Elsinga[a], Thera P. Links[c], Elisabeth G.E. de Vries[d,*], Pieter L. Jager[a]

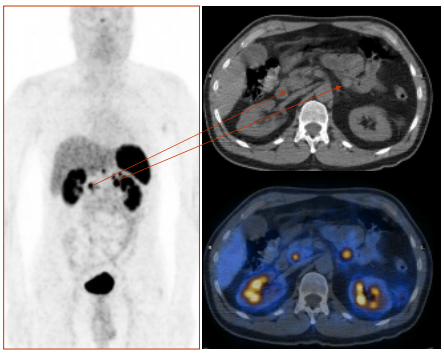
Critical Reviews in Oncology/Hematology 71 (2009) 199–213



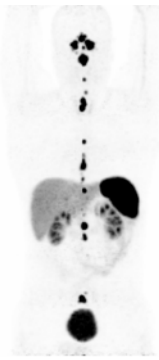
NEUROENDOCRINE TUMOURS

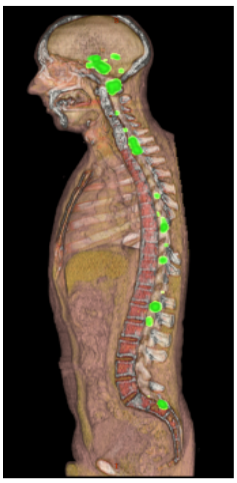
Staging small NET of the pancreas:

GaDOTA NOC shows the primary NET and some secondary peripancreatic lymph nodes



Multiple vertebral paraganglioma





Case History

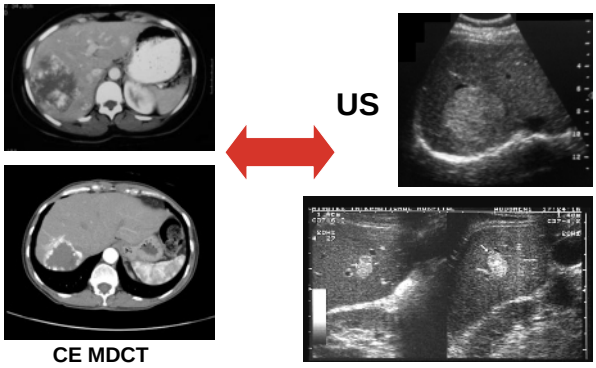
65 year old male with elevated liver function tests.

Status post sigmoidectomy for colon cancer 5 years ago.

CT exam to rule out mass or biliary tract disease.

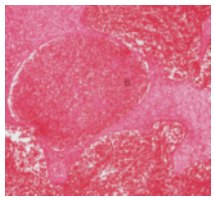
THE UNIVERSITY OF CHICAGO
Department of Radiology

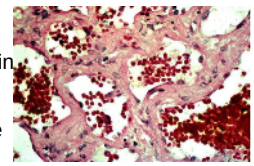
Liver Mass



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

Tools ~ Modalities

- Use the right tool for the job
- No single tool will suffice
- One size doesn't fit all
- May be used separately or in combination
- Some require a skilled operator; others are simple enough for anyone to use

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….

30

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….

31

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.

CT ? With or without IV contrast ?

MRI ?

US ? Oral contrast ?

Doppler ?

PET ?

Delayed images?

32

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

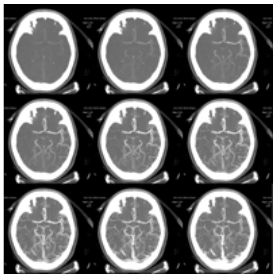
Multitemporal imaging

- 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

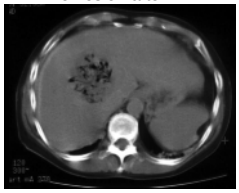
- Common in CT and MRI
- Essential for liver, pancreas, kidneys
- CT angiography typically consists of both a non-contrast and post-contrast enhanced series (same for MRA)
- Multiphase cardiac CTA:
  - Precontrast coronary calcium scan
  - Post-contrast retrospective gating

Multiphase CT

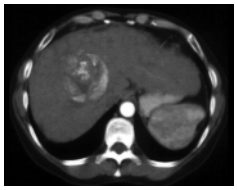

Same slice, multiple time points

Liver lesion after RFA

Pre-



Post-


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; …

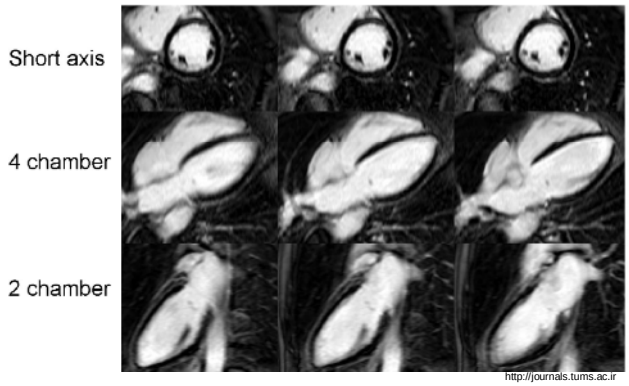
Modalities

SPECT
Cath / PCI
CCTA
CorCa CT
Echo
CMRI

Delayed CT/MRI imaging

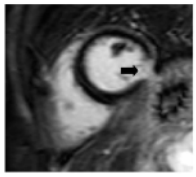
- Redistribution phenomena
  - Gd contrast into fibrosis (Myocardial viability)
  - Cholangiocarcinoma (malignant)
  - Adrenal adenoma (benign)
  - Hemangioma (benign, but may be very large)
- Renal excretion
  - Antegrade opacification of urinary tract
  - Basis of CT urogram (akin to IVP / EXU)

Delayed CE-MRI:
Normal myocardial viability

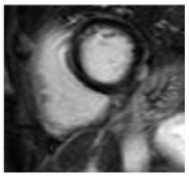


http://journals.tums.ac.ir

Delayed CE-MRI



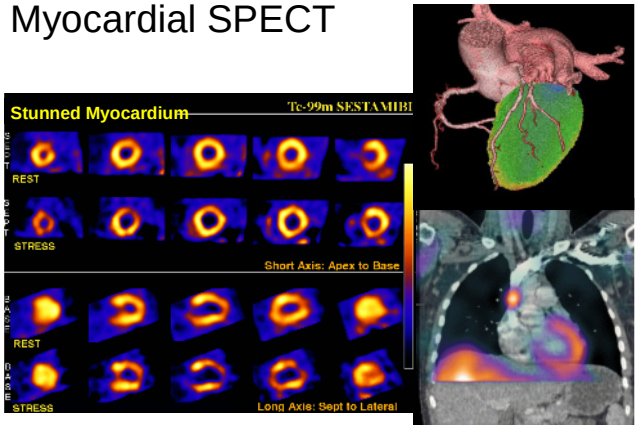
Mid-ventricular slice demonstrating abnormal enhancement (arrow)



Basal slice demonstrating no abnormal LV enhancement

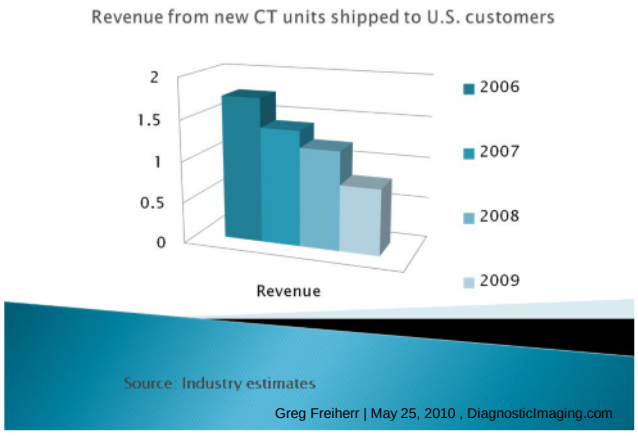
http://journals.tums.ac.ir

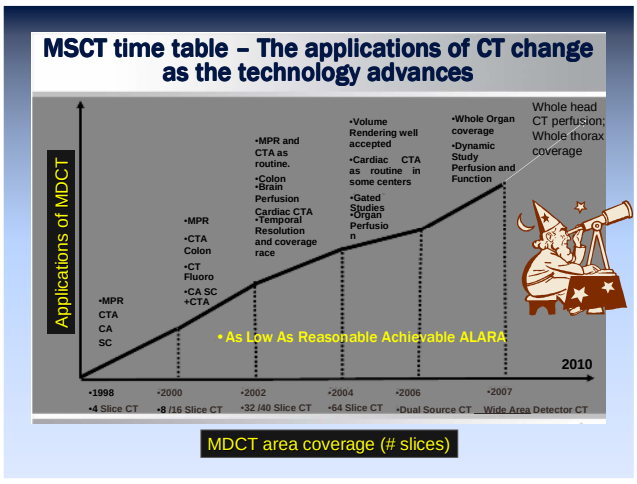
Myocardial SPECT



brighamrad.harvard.edu/education/online/Cardiac/

www.gehealthcare.com/euen/advantage-workstation/

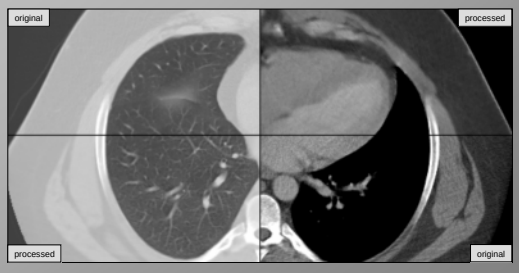




http://www.pedrad.org/associations/5364/ig/

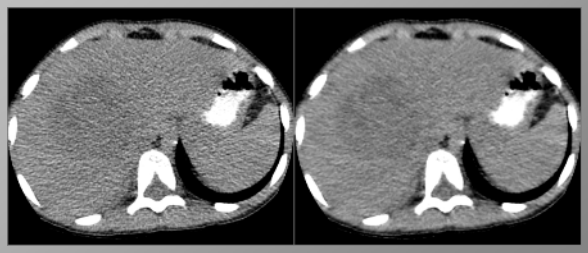
Clarity™ Tissue Adaptation

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



Pediatric - Liver

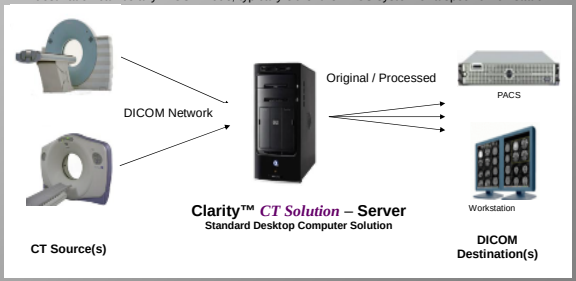
original processed



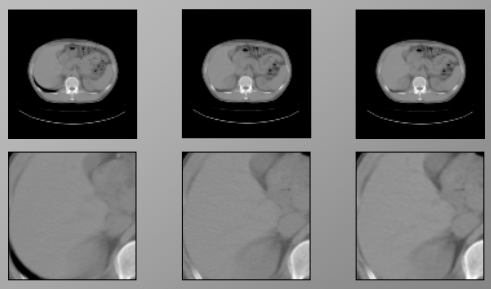
Thin slice 0.6 mm

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

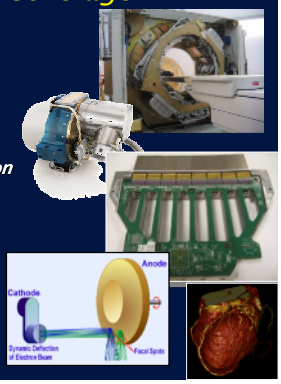


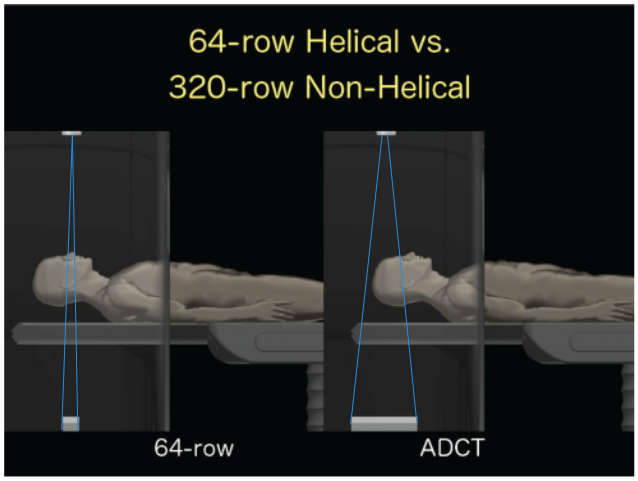
100 % (standard dose) | 50 % (low dose) | 50 % dose (processed)

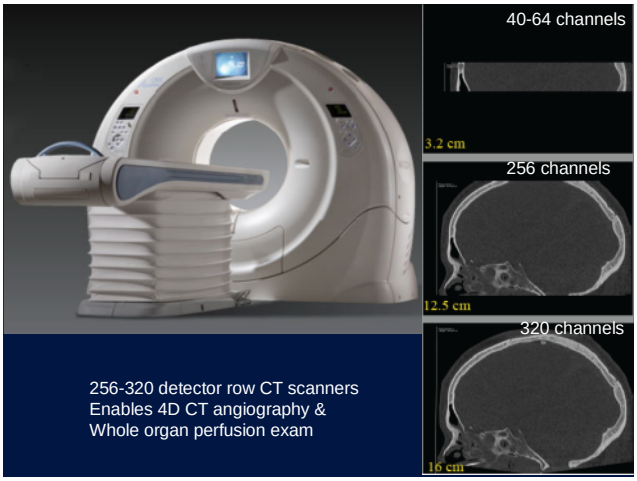
Multirow Detector CT (MDCT) Scanner

128 detector rows; 256 slices (iCT)
Increased Speed, Power, Coverage

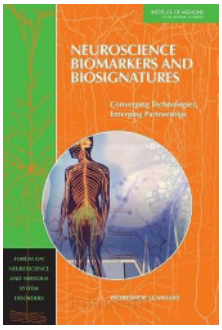
- *Higher temporal resolution*
  - *0.27 sec rotation*
- *Increased Tube Power*
  - *120 kW / 1,000 mA*
  - *X-Y and Z focal spot modulation*
- *Greater coverage per rotation*
  - *8 cm*
  - *256 slices*







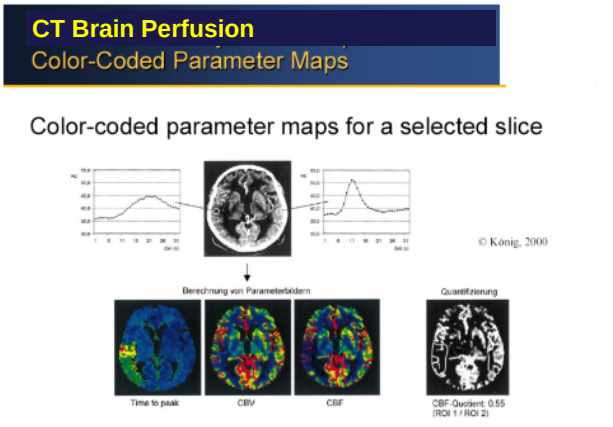
Neuroscience Biomarkers



[IOM 2008]

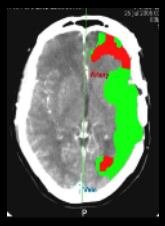
Biological markers, or biomarkers, are quantitative measurements that provide information about biological processes, a disease state, or about response to treatment, providing insight into preclinical and clinical data.

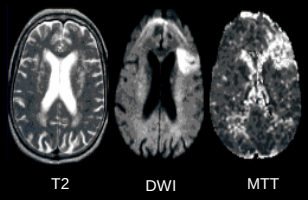
Biomarkers hold the potential of a better understanding of the etiology and pathogenesis of a given disorder, providing insight into diagnosis, treatment, and prognosis for many debilitating disorders and diseases.



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

Perfusion



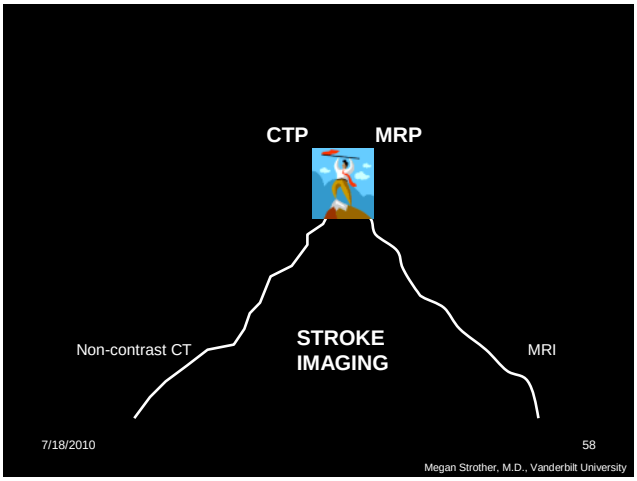


CT vs. MRI

vs. xenon CT vs. PET vs. SPECT

7/18/2010 57

Megan Strother, M.D., Vanderbilt University



7/18/2010 58

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Imaging Ischemia--Vascular

Angiogram
1950-60's (pre-CT era)

Vascular occlusion

Thrombolysis

Recanalization ≠
Clinical improvement

7/18/2010 59

Megan Strother, M.D., Vanderbilt University

Imaging Ischemia- Parenchyma

Head CT

No ICH

<1/3 MCA territory

<3 hours

IV Thrombolysis

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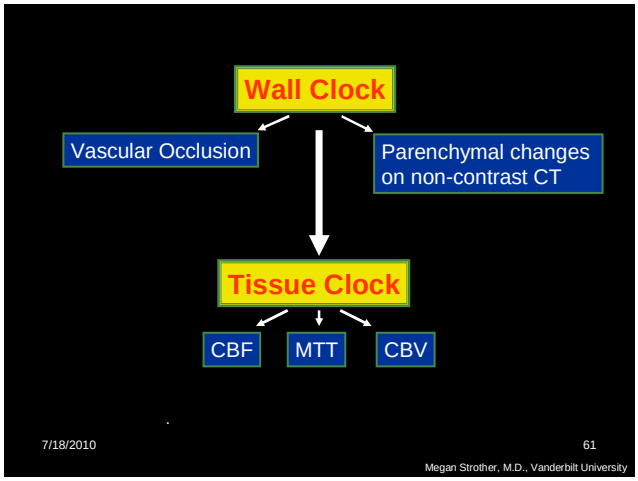
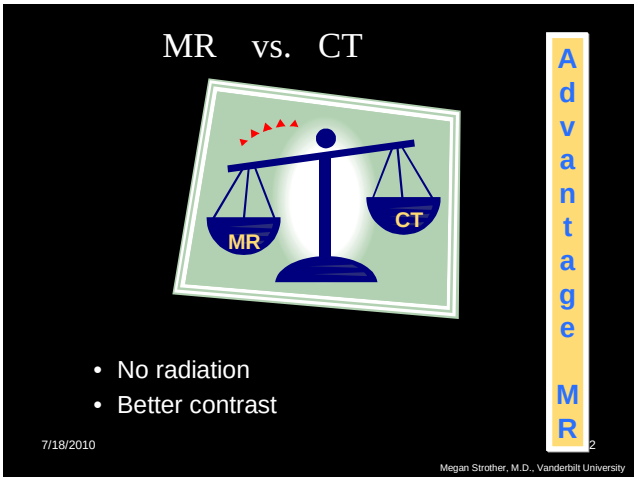
Megan Strother, M.D., Vanderbilt University


Wall Clock
Vascular Occlusion
Parenchymal changes on non-contrast CT
Tissue Clock
CBF
MTT
CBV
7/18/2010
61
Megan Strother, M.D., Vanderbilt University


MR vs. CT
MR
CT
Advantage MR
• No radiation
• Better contrast
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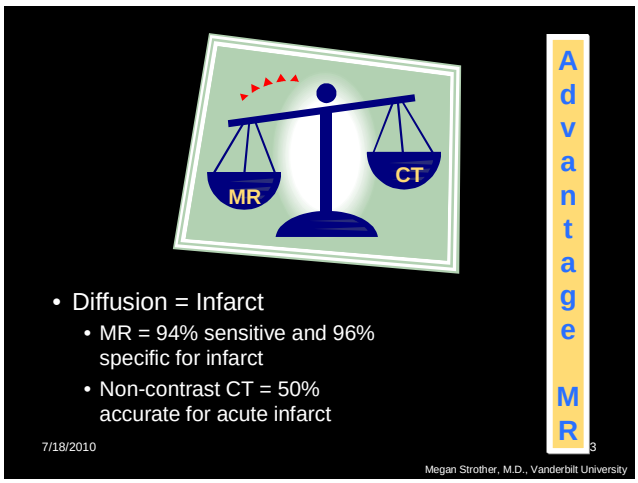
MR
CT
Advantage MR
• Diffusion = Infarct
• MR = 94% sensitive and 96% specific for infarct
• Non-contrast CT = 50% accurate for acute infarct
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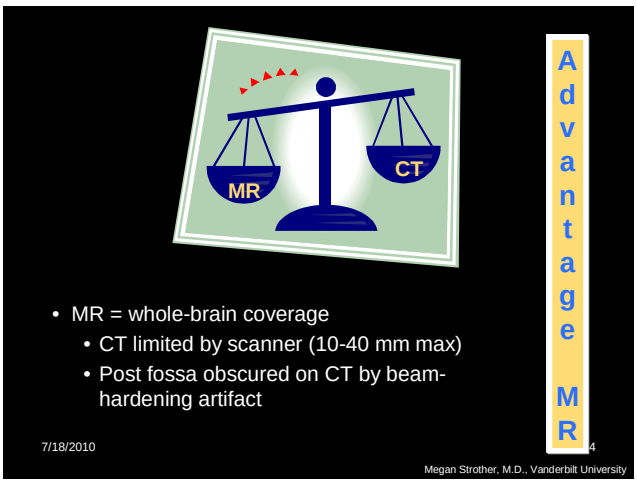
MR
CT
Advantage MR
• MR = whole-brain coverage
• CT limited by scanner (10-40 mm max)
• Post fossa obscured on CT by beam-hardening artifact
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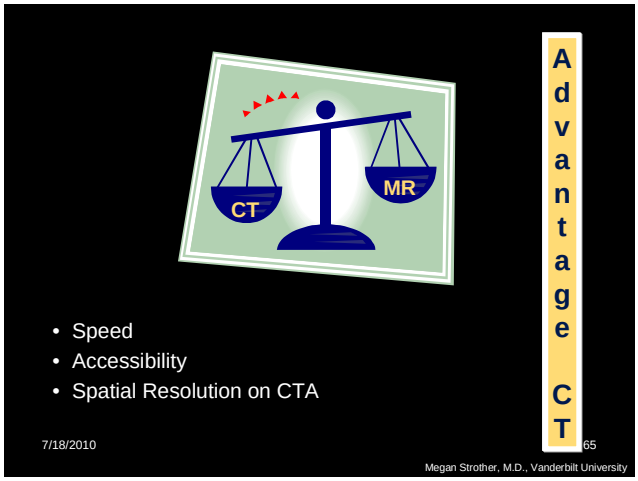
CT
MR
Advantage CT
• Speed
• Accessibility
• Spatial Resolution on CTA
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65
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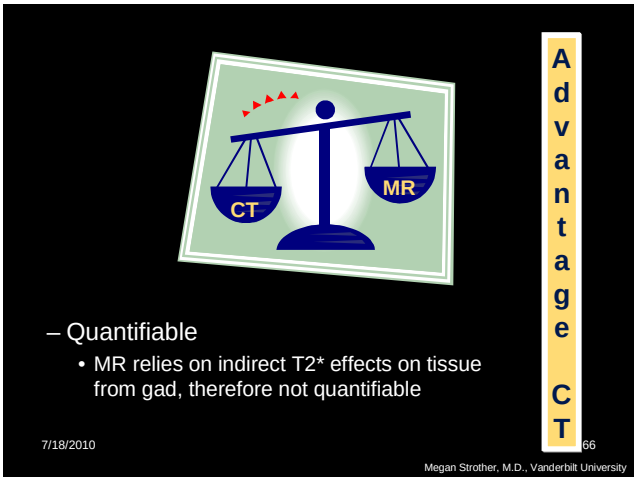
CT
MR
Advantage CT
– Quantifiable
• MR relies on indirect T2* effects on tissue from gad, therefore not quantifiable
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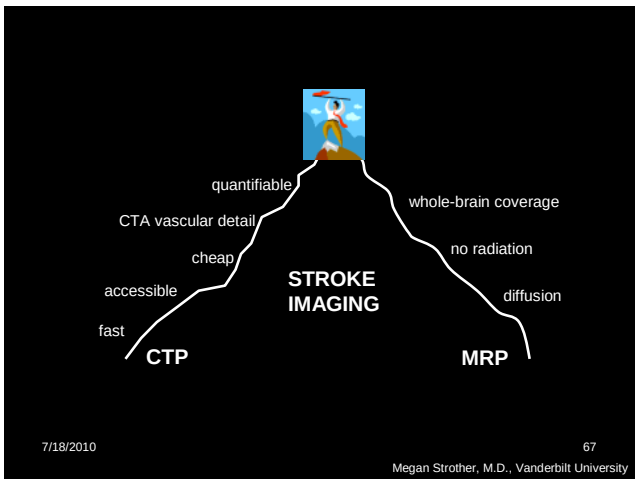
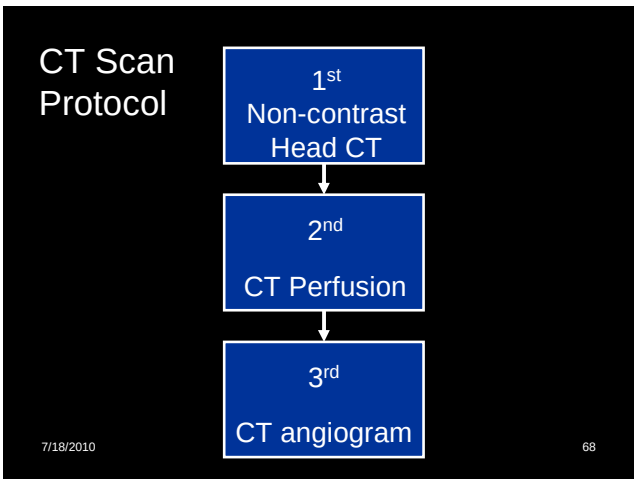
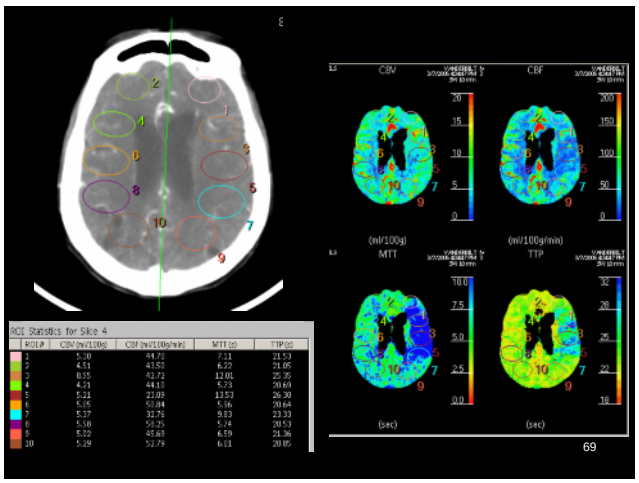
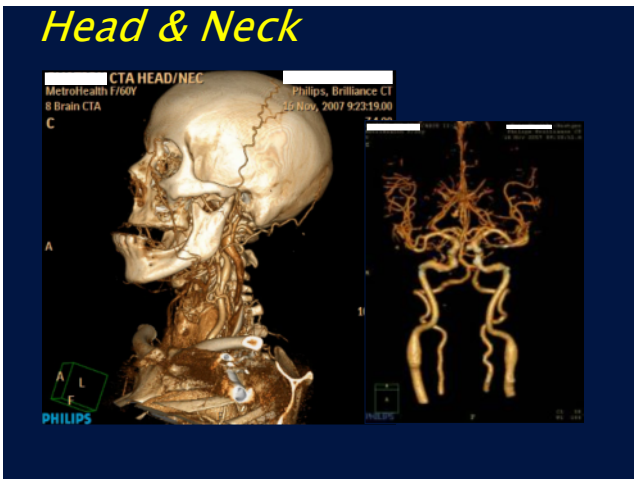
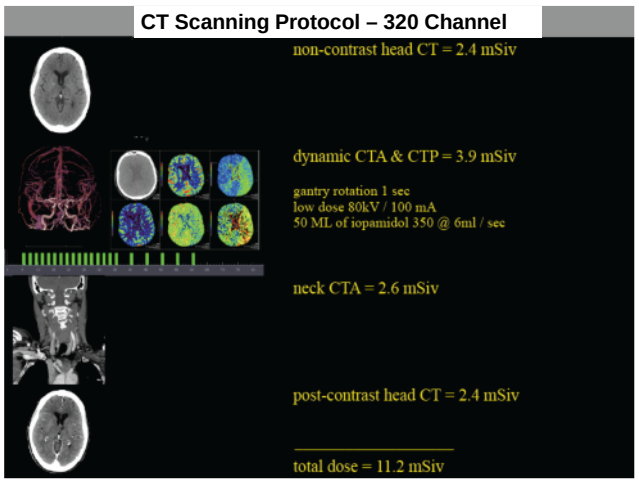
66
Megan Strother, M.D., Vanderbilt University

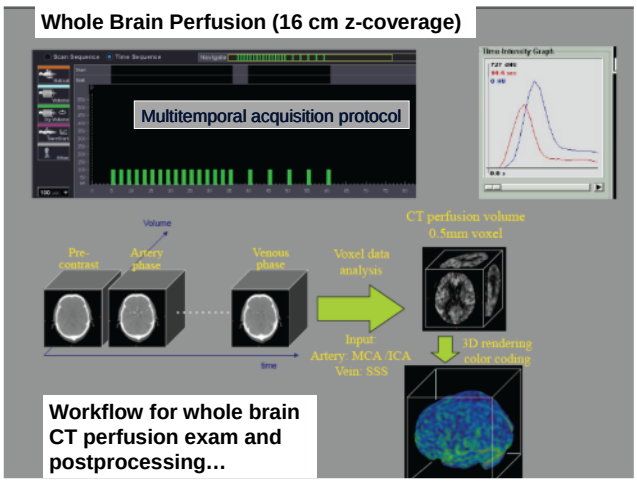

quantifiable
CTA vascular detail
cheap
accessible
fast
CTP
STROKE IMAGING
whole-brain coverage
no radiation
diffusion
MRP
7/18/2010
67
Megan Strother, M.D., Vanderbilt University

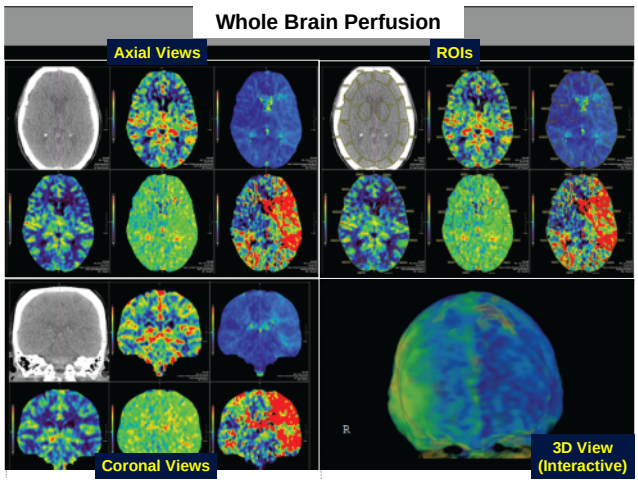

CT Scan Protocol
1st Non-contrast Head CT
2nd CT Perfusion
3rd CT angiogram
7/18/2010
68


69


Head & Neck
CTA HEAD/NEC
MetroHealth F/60Y
8 Brain CTA
C
Philips, Brilliance CT
16 Nov, 2007 9:23:19.00
PHILIPS


CT Scanning Protocol – 320 Channel
non-contrast head CT = 2.4 mSiv
dynamic CTA & CTP = 3.9 mSiv
gantry rotation 1 sec
low dose 80kV / 100 mA
50 ML of iopamidol 350 @ 6ml / sec
neck CTA = 2.6 mSiv
post-contrast head CT = 2.4 mSiv
total dose = 11.2 mSiv


Whole Brain Perfusion (16 cm z-coverage)
Multitemporal acquisition protocol
CT perfusion volume
0.5mm voxel
Pre-contrast
Artery phase
Venous phase
Voxel data analysis
Input:
Artery: MCA /ICA
Vein: SSS
3D rendering
color coding
Workflow for whole brain CT perfusion exam and postprocessing...



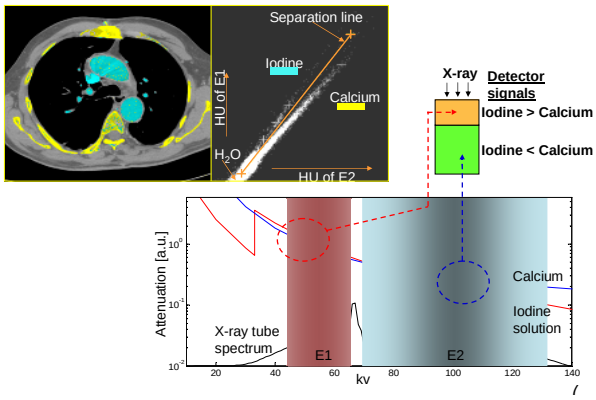
Spectral and Dual Energy CT

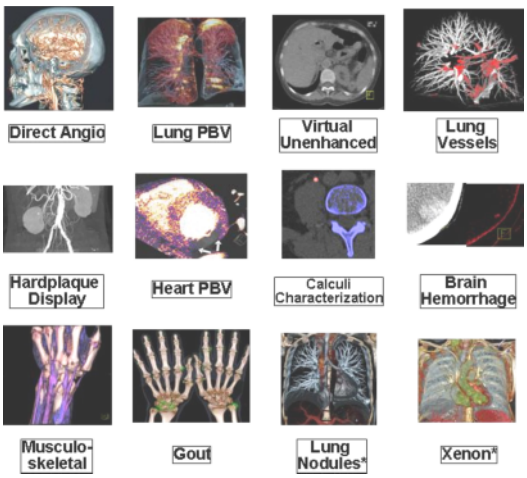
Simple Analogy

Traditional CT	Spectral CT	Limited Spectral CT	Dual Energy CT
Yesterday & Today	Future	Future	Today

75

Dual-energy Material Separation

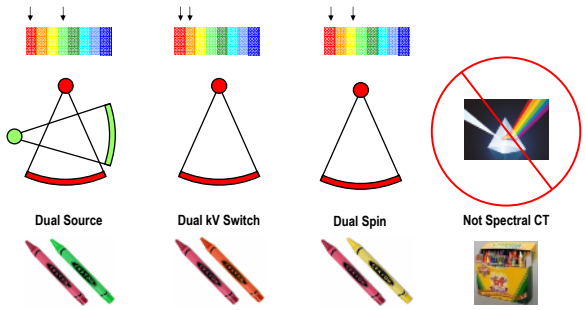




Siemens

Spectral vs. Dual Energy CT

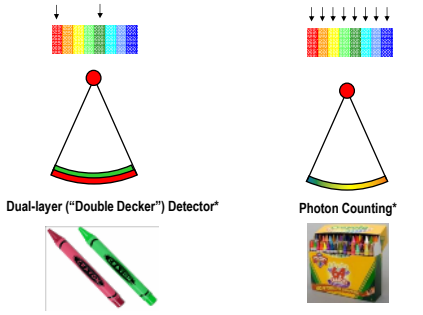
Techniques That are Possible on Commercial Systems



78

Spectral vs. Dual Energy CT

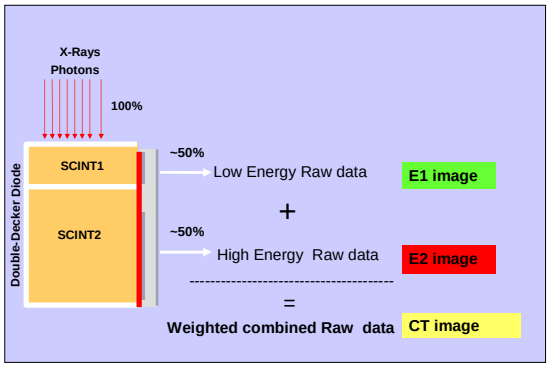
Techniques That are Available on Research Systems



*Works-in-Progress: Pending commercial availability and regulatory clearance

79

Dual-Layer CT (Orion-N)



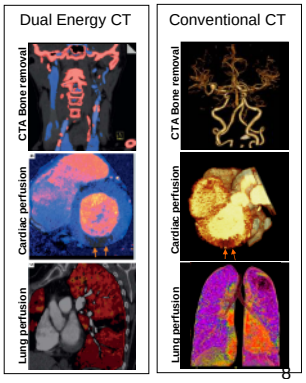
8

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" Imaging Sg2 Question of the Month

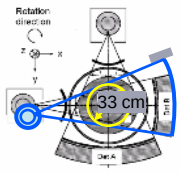
- No medical guidelines include spectral CT
- No reimbursement for spectral CT
- No large studies have been published for spectral CT
- Alternative approaches exist for proposed spectral CT clinical applications
- Rapidly changing technology

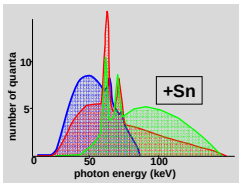


8

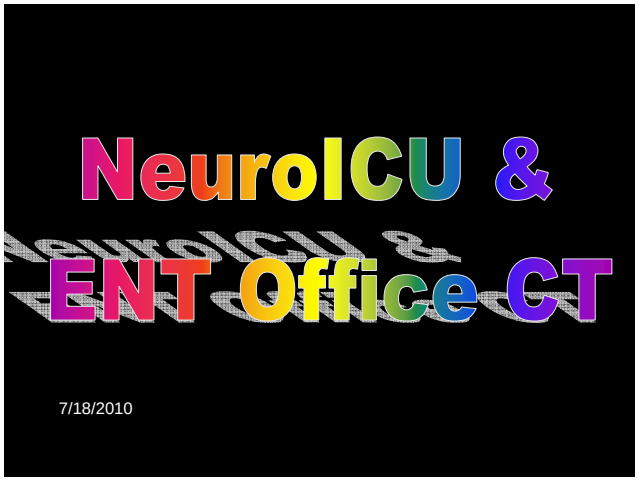
Dual Energy CT - Limitations

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

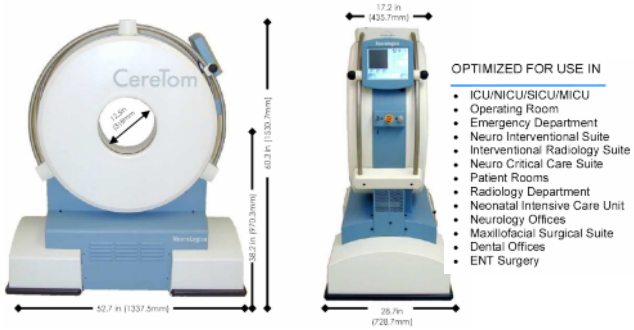




82



8-Slice Portable CT Scanner



85

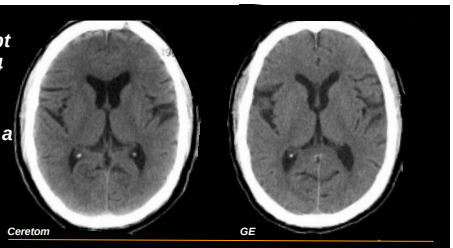
Low X-Ray Radiation Dose

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

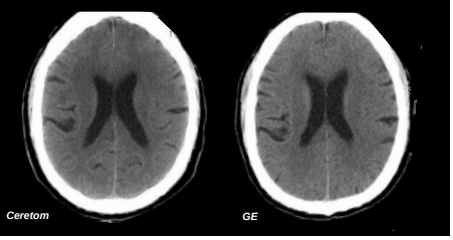
Sinus CT with the MiniCAT™ low-dose scanner
- Adult: 0.13 mSv (7-15 x lower radiation dose)
- Child: 0.07 mSv (14-28 x lower radiation dose)

7/18/2010 86

This is the same pt scanned within 24 hours using the Ceretom portable scanner and then a GE stationary scanner…



Which do you prefer?

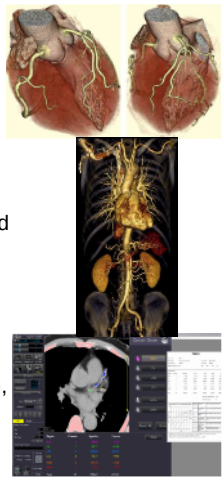


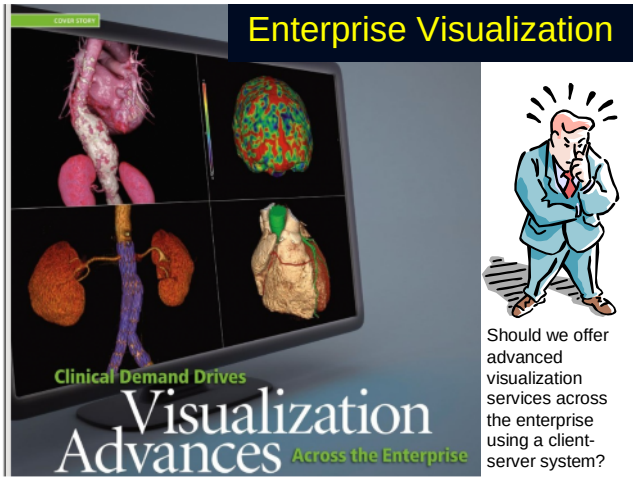
Enterprise Visualization & Analysis

7/18/2010

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



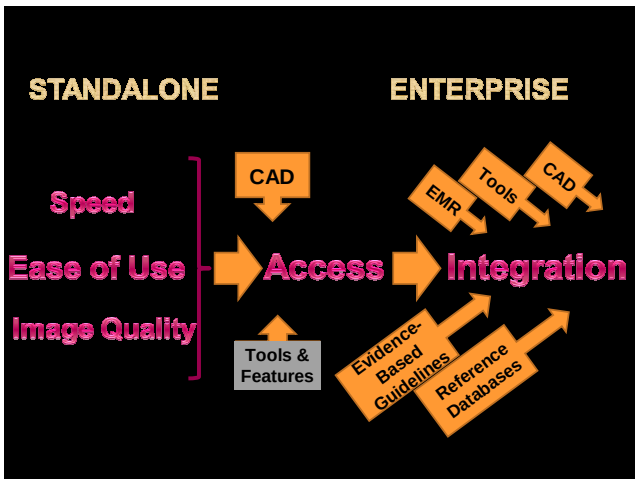


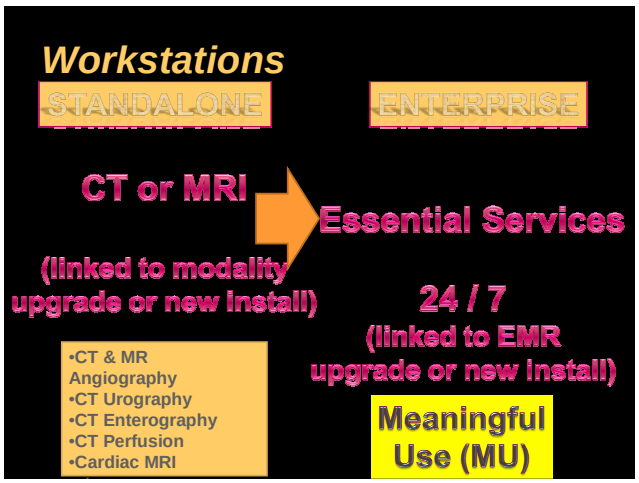
Should we offer advanced visualization services across the enterprise using a client-server system?

Analogy – Medical Workstation and Gaming Platform
≈
Large amount of local processing capability, linked to PACS.
Runs complex proprietary software

Thin Client MWS

Analogy – Portal and Website
MEDICAL IMAGING
Data Access: Images at Your Fingertips
≈
Google
No local processing,
linked to remote server.
Rudimentary functions are easy to use.


STANDALONE
ENTERPRISE
Speed
Ease of Use
Image Quality
CAD
Access
Tools & Features
EMR
Tools
CAD
Integration
Evidence-Based Guidelines
Reference Databases

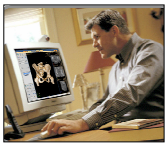


Thin Client Solutions

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

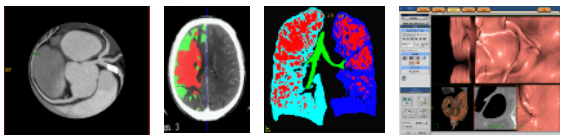


98

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

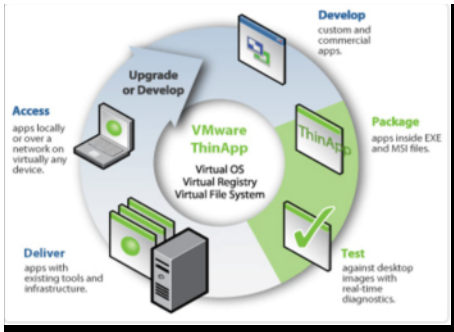
All Key Clinical Applications



99

100

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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