AAPM Scientific Meeting
Imaging Symposium

State of the Art in Quantitative Imaging CT, PET and MRI

Michael McNitt-Gray, PhD, FAAPM; UCLA
Paul Kinahan, PhD, U. Washington
Ed Jackson, PhD, FAAPM, UT-MD Anderson

State of the Art in Quantitative Imaging CT, PET and MRI

- Intro and Overview (McNitt-Gray)
- Quantitative Imaging in CT (McNitt-Gray)
- Quantitative Imaging in PET (Kinahan)
- Quantitative Imaging in MR (Jackson)
- Common issues/barriers to Quantitative imaging (Jackson)
- Questions/Discussion

Which Imaging Modality is the "Most Quantitative"

20%	1. CT
20%	2. PET
20%	3. MRI
20%	4. US
20%	5. None of the Above

10
Countdown

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Quantitative Imaging: CT

Michael McNitt-Gray, PhD, DABR, FAAPM; UCLA

Financial disclosure

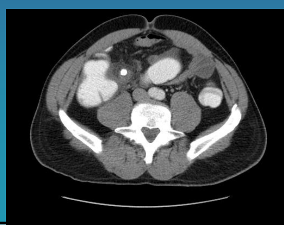
- Michael McNitt-Gray receives research grant support from Siemens Medical Solutions

Diagnostic Imaging with CT

- Used Clinically for many purposes/indications
  - Trauma evaluation (especially head trauma)
  - Cancer diagnosis, staging
  - Response to Treatment

Diagnostic Imaging with CT

- Used Clinically for many indications
- (right flank pain – R/o Appendicitis)



Diagnostic Imaging with CT

- Diagnosis of Lung Diseases

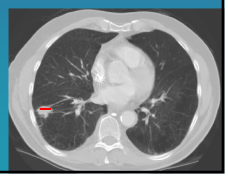
Quantitative Imaging in CT

- CT is inherently Quantitative (isn't it?)
- Each voxel reports a CT number
- And it even has units (HU)
- Which are defined internationally
- CT number = $\left(\frac{\mu_{tissue} - \mu_{water}}{\mu_{water}}\right)*1000$

- Water ($\mu = \mu_{water}$) ---> 0 HU
- Air ($\mu \sim 0$) ---> -1000 HU

Quantitative Imaging in CT

- Current Clinical Applications that use QCT
- Coronary Artery Calcium Scoring
- Bone Mineral Density (BMD)
- RECIST (Semiquantitative)



What is the Most Common Quantitative CT Application in Your Practice

20%	1. Coronary Artery Calcium Scoring
20%	2. Bone Mineral Density (with CT)
20%	3. Emphysema Scoring (Density Mask)
20%	4. RECIST
20%	5. None of the Above

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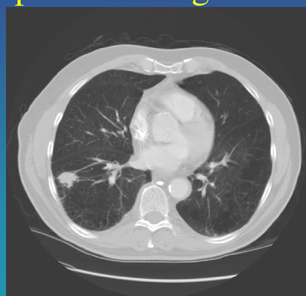
Countdown

Quantitative Imaging

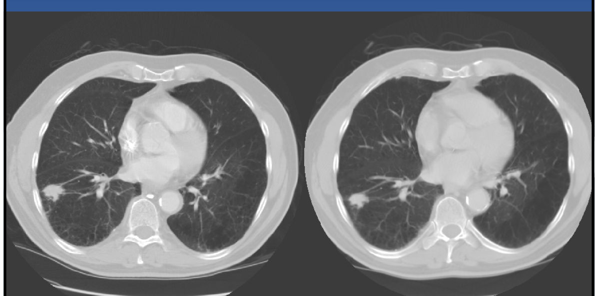
- What does it take to make Imaging Quantitative?
- Go from making an Image
- To
- Making a Measurement

Example: How Big is Lesion?



What size metric should we use? Currently use one or two linear measurements

Example: Did Lesion Change in Size?



Time 1 Time 2

Measurements

- Should have “minimal” bias
  - Should provide a good estimate of true value
  - No consistent offset (no overestimate, no underestimate)
- Should have “minimal” variance
  - Random effects
  - Non-random effects
- Should be reproducible
  - Same measurement under same conditions -> same result

Examples of Desired Quantitative Imaging Applications

- Screening followup – once a nodule has been detected, the growth of that nodule over time has been suggested as metric to identify cancers.
- Assessing individual responses to therapy
  - Detect small changes and make early decisions about whether therapy is working or not
- Developing / testing new therapies
  - Again, detect small changes and make early decisions about whether therapy is working or not

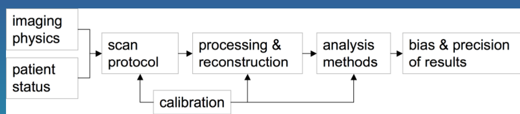
CT to Measure Change

- Change in Size
- Change in Density
- Change in Function (Perfusion, etc.)
- Can we measure these Changes Reliably?
  - Good enough to aid Dx?
  - Or Assess Treatment Efficacy?

CT to Measure Change

- Can we do this in a robust fashion
  - Across scanners
  - Across centers
  - Across patients (with similar condition/disease)

Workflow to Measure Change



Where Do You Think the Largest Source of Variation/Error Is?”

20% 1. Imaging Physics/Scan Protocol?
20% 2. Patient Status?
20% 3. Calibration?
20% 4. Processing and Reconstruction?
20% 5. Analysis Methods?

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Countdown

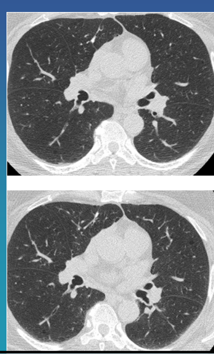
CT Imaging Physics Considerations

- Scanner Design
  - Geometry e.g. Number of Detector Rows
- Scanner Operation
  - kV, mAs, pitch
- Image reconstruction
  - Reconstructed Image Thickness
  - Reconstruction Filter

Patient Considerations

- Health Status of Individual patient
  - Ability to breathhold if required
  - Ability to use oral or IV contrast
  - Ability to perform study without motion
- Abnormalities and Concomitant Disease
  - Inflammation which may mask progression
  - Patient Health Status during trial

Patient Breathhold Variability

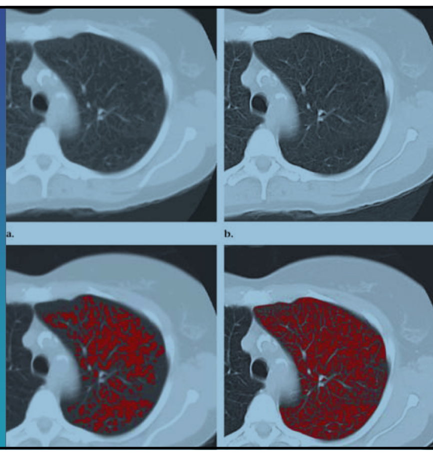


Tumor Related Considerations

- Complexity of Tumor
  - Shape (Spherical or Complex) can make determining boundaries "difficult" (i.e. not reproducible)
  - Location
  - Physiology (contrast uptake, washout)

Processing and Reconstruction

- Reconstructed image thickness
- Reconstructed image interval
- Reconstruction filter
- Resolution and Noise



Analysis Method

- Fully Automated
- Some human intervention
  - Radiologist measuring diameter
  - Contouring boundary
- Measurement itself
  - Diameter
  - Volume
  - Mass/density
- Registration method if change is measured

Tumor Related Considerations

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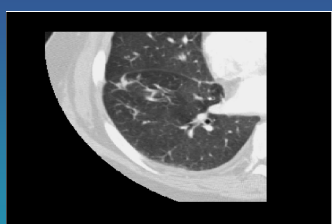
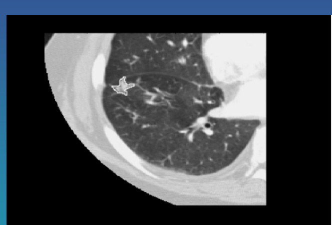
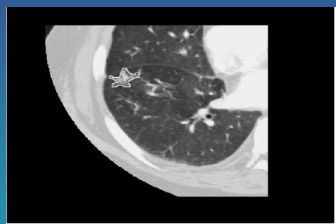
Original Image



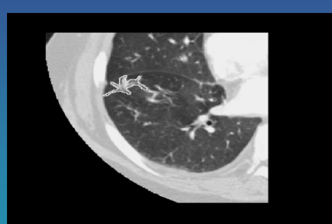
Contour 1



Contour 2

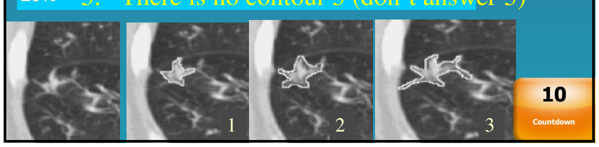


Contour 3



Which of these is “Most Correct” contour of lesion?

- 20% 1. Contour 1
- 20% 2. Contour 2
- 20% 3. Contour 3
- 20% 4. There is no contour 4 (don’t answer 4)
- 20% 5. There is no contour 5 (don’t answer 5)



Where Do You Think the Largest Source of Variation/Error Is?”

20%	1. Imaging Physics/Scan Protocol?
20%	2. Patient Status?
20%	3. Calibration?
20%	4. Processing and Reconstruction?
20%	5. Analysis Methods (incl. Humans)?

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Countdown

Underlying Issues

- Measurements need some standardization
- Who is responsible for each of these parts
  - Manufacturers
  - Physicians
  - Technologists
  - Physicist
- Each has a role along this measurement path

Some Attempts at Standardization

- National Lung Screening Trial (NLST)
- Protocol Chart
- ACRIN 6678
- COPD/Gene

From Cagnon et al Academic Radiology, 2006

Table 1
ACRIN/NLST CT Technique Comparison Chart: Scanner Specific Techniques Mandated by NLST Protocol

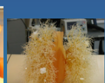
Parameter	GE QXi 4-slice/0.8 sec	GE LS Plus 4-slice/0.5 sec	GE Ultra 8-slice/0.5 sec	GE – LS 16 16-slice/0.5 sec	GE – VCT(64) 64-slice/0.5 sec
kV	120	120	120	120	120
Gantry Rotation Time	0.8 sec	0.5 sec	0.5 sec	0.5 sec	0.5 sec
mA (Regular patient-Large patient values)	50–100	80–160	80–160	80–160	50–100
mAs (Regular-Large)[1]	40–80	40–80	40–80	40–80	25–50
Scanner effective mAs[2] (Reg-Lg)	26.7–53	26.7–53	29.6–59.2	29.1–58.2	27–53
Detector Collimation (mm)—T	2.5 mm	2.5 mm	1.25 mm	1.25 mm	0.625 mm
Number of active channels—N	4	4	8	16	64
Detector Configuration—N × T	4 × 2.5 mm	4 × 2.5 mm	8 × 1.25 mm	16 × 1.25 mm	64 × 0.625 mm
MODE (Thick/Speed)	2.5/HS/15	2.5/HS/15	1.25/HS/13.5	1.25/1.375/27.5	.625/.984/39.37
Table incrementation (mm/rotation)—I	15 mm	15 mm	13.5 mm	27.5 mm	39.37 mm
Pitch ([mm/rotation]/beam collimation)—I/NT	1.5	1.5	1.35	1.375	0.984
Table Speed (mm/second)	18.75 mm/sec	30 mm/sec	22.5 mm/sec	55 mm/sec	78.74 mm/sec
Scan Time (40 cm thorax)	22 sec	13 sec	18 sec	7.3 sec	5.1 sec
Nominal Reconstructed Slice Width	2.5 mm	2.5 mm	2.5 mm	2.5 mm	2.5 mm
Reconstruction Interval[3]	2.0 mm	2.0 mm	2.0 mm	2.0 mm	2.0 mm
Reconstruction Algorithm[3]	STD	STD	STD	STD	STD
# Images/Data set (40 cm thorax)	200	200	200	200	200
$CTDI_{vol}$ Dose in mGy[4] (Regular–Large)	2.8–5.6 mGy	2.4–4.9 mGy	3.1–6.2 mGy	2.7–5.4 mGy	2.2–4.4 mGy

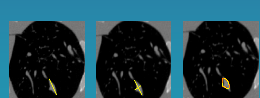
Parameter	Philips MX8000 4-slice/0.5 sec 4 × 2.5	Philips MX8000 4-slice/0.5 sec 4 × 1	Philips MX8000 16 slice/0.5 sec 16 × .75	Toshiba Aquilion 4-slice/0.5 sec	Toshiba Aquilion 16-slice/0.5 sec
kV	120	120	120	120	120
Gantry Rotation Time	0.5 sec	0.5 sec	0.5 sec	0.5 sec	0.5 sec
mA (Regular patient-Large patient values)	75–150	80–160	75–150	80–160	80–160
mAs (Regular-Large)[1]	37.5–75	40–80	37.5–75	40–80	40–80
Scanner effective mAs[2] or mAs/slice[2] (Reg-Lg)	25–50	20–40	25–50	26.7–53.3	26.7–53.3

RSNA's Quantitative Imaging Biomarker Alliance (QIBA)

- CT committee
  - Tumor Volumetrics (Change in tumor size)
  - COPD/Asthma (Change in airway size, lung density)
- Some experiments to
  - help identify sources of variance (and bias)
  - Mitigation measures
- Develop a "Profile" to describe best practices in making tumor volumetric measurements

Phantom Measurements of size

Size Method	Spherical Nodules 0.8 mm	Spherical Nodules 5.0 mm	Non-spherical Nodules 0.8 mm	Non-spherical Nodules 5.0 mm
1D	2% (±5)	0% (±4)	-23% (± 20)	-27% (±21)
2D	4% (±10)	0% (±11)	-33% (±26)	-33% (±29)
3D	1% (±12)	5% (±23)	0% (±14)	-2% (±30)

Lessons

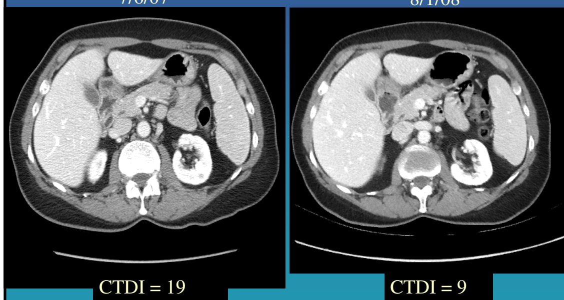
- For Spherical Lesions
  - Diameters and thick slice images are good enough
- For non-Spherical Lesions
  - Thin section images and volumetrics are better than diameters, even at thin sections

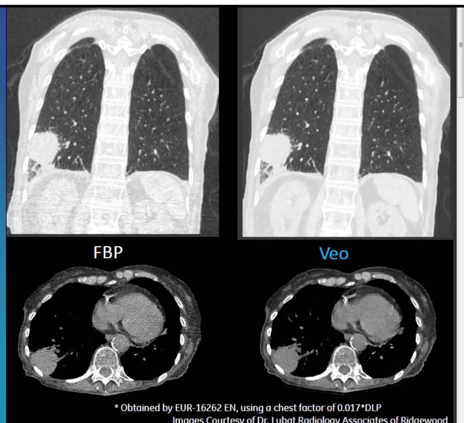
Immediate/Future Challenges

- Technological Advances
  - Iterative Reconstruction (Dose reduction)

Iterative Recon with 50% Less Dose

LightSpeed VCT, routine dose 7/6/07 | CT750 HD, 50% reduced dose, ASIR 8/1/08





Images from Dr. Dianna Cody of MD Anderson via GEHealthcare

Dual Energy

- Dual Energy and Spectral CT
  - Aims to separate out "materials" such as iodine from bone, etc.
  - Could improve our estimates of density
  - Could contribute to reducing variance

Conclusions for Quantitative Imaging for CT

- Making an image to making a measurement
- LOTS of variables (scanner, patient)
- To make a measurement, need standardization
  - Not complete and rigid standardization
  - But that reduces variance in measurement
- Some significant efforts to address this
  - RSNA QIBA

Conclusions for Quantitative Imaging for CT

- Immediate Goal
  - Reduce Variance
  - Reducing Bias too, but harder to assess
- Rewards:
  - More precise assessments
  - Tighter tolerances
  - Earlier detection of change
  - Smaller sample sizes