Quantitative Imaging: CT and MRI

Sources and Mitigation of CT Quantitative Imaging Errors

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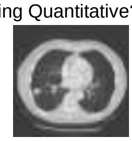
Disclosures

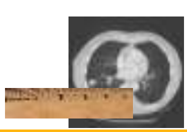
- UCLA Department of Radiological Sciences has a Master Research Agreement with Siemens Healthineers

Quantitative Imaging

- What does it take to make Imaging Quantitative?
- Go from making an Image



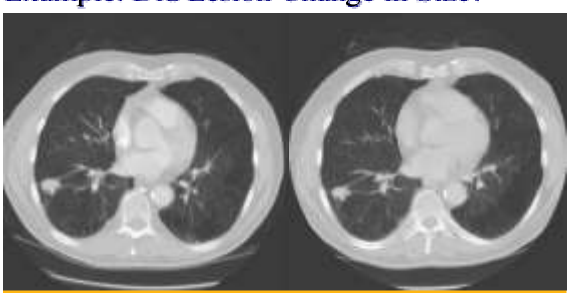
- To
- Making a Measurement



Example: How Big Is This Lesion?

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

Example: Did Lesion Change in Size?



Time 1 Time 2

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

CT to Measure Change

- Change in Size
- Change in Density
- Change in Texture
- 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)

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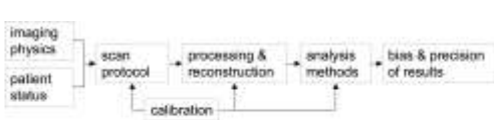
System Description – Sources of Variability



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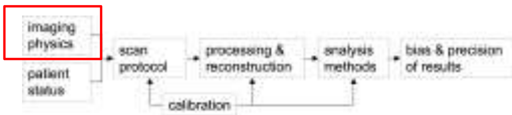
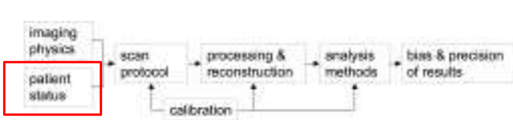
System Description – Sources of Variability



CT Imaging Physics Considerations

- Scanner Design
  - Geometry e.g. Number of Detector Rows
- Scanner Operation
  - kV, mAs, pitch
- Capabilities:
  - Dose reduction technologies
  - Advanced (Iterative) reconstruction
  - Dual Energy
  - Other

System Description – Sources of Variability



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

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Tumor Related Considerations

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

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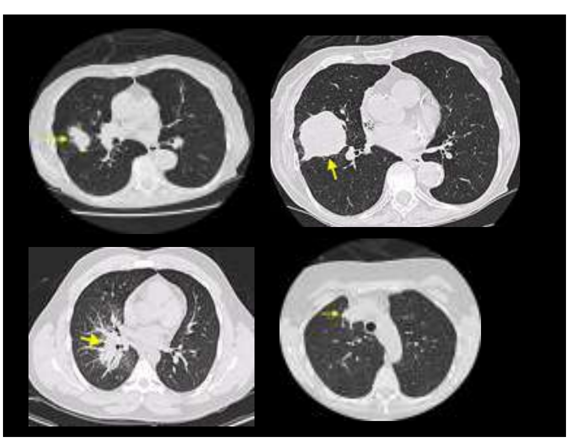
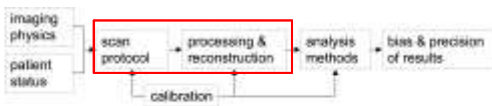


System Description – Sources of Variability



Scan Protocol Considerations

- Reconstructed image thickness
- Reconstructed image interval
- Reconstruction filter

- Resolution and Noise

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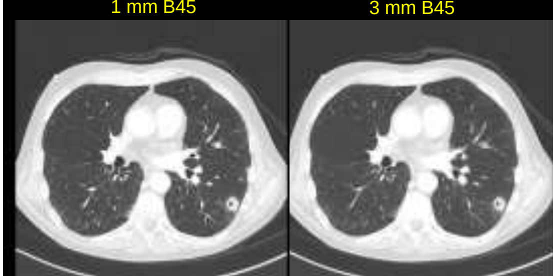
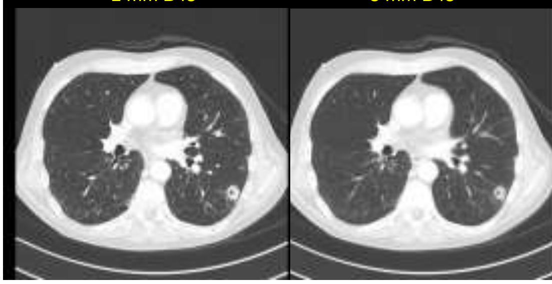
Example Lung Lesion

1 mm B45 | 3 mm B45



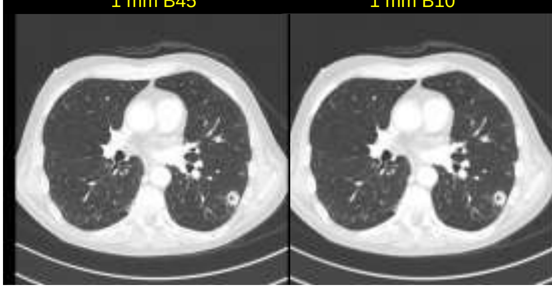
Example Lung Lesion

1 mm B45 | 5 mm B45



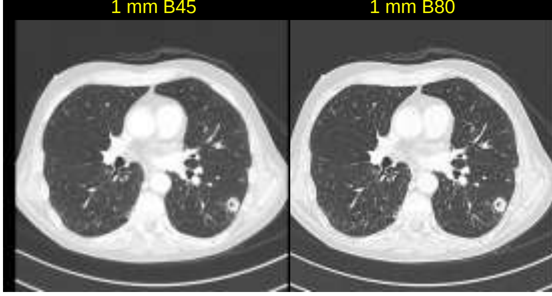
Example Lung Lesion

1 mm B45 | 1 mm B10



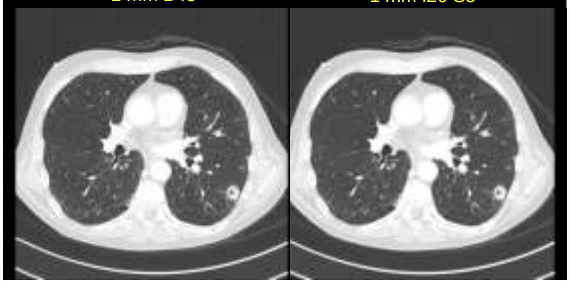
Example Lung Lesion

1 mm B45 | 1 mm B80

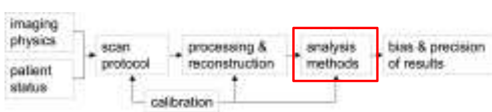


Example Lung Lesion

1 mm B45 | 1 mm I26 S5



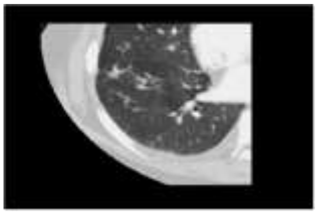
System Description – Sources of Variability



Analysis Method

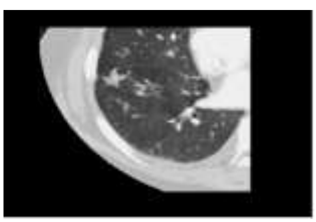
- Fully Automated
- Some human intervention
  - Radiologist measuring diameter
  - Contouring boundary
- Measurement itself
  - Diameter
  - Volume
  - Mass/density
- Registration method if change is measured

Original Image

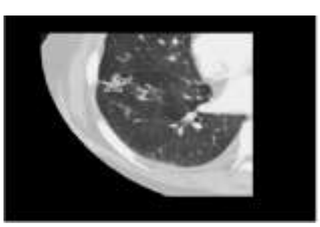


From Meyer at al, Acad Radiol. 2006

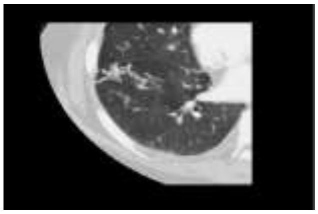
Contour 1



Contour 2



Contour 3



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Possible Mitigation Strategies

- Limiting the acceptable conditions under which measurements are made
  - Only allow measurements under specified conditions for each of the elements in the measurement chain;
    - Imaging Physics conditions
    - Patient conditions (disease, health status, nodule size/shape)
    - Acquisition/Reconstruction Conditions
    - Analysis (Segmentation, Feature Calculation) Conditions

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Some Attempts at Standardization

- National Lung Screening Trial (NLST)
  - No quantitative measure as an endpoint
  - Positive Screen meant there was a nodule present or not on CT or CXR
- ACRIN 6678
- COPD/Gene

- These have informed the RSNA QIBA Protocols

https://www.rsna.org/QIBA-Profiles-and-Protocols/

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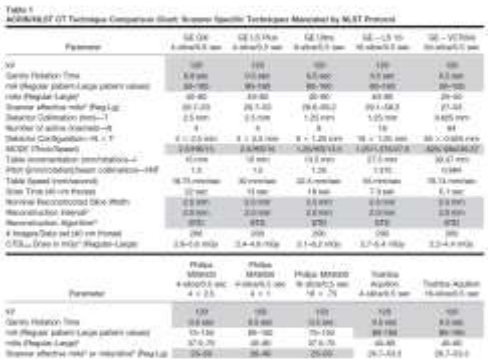
From Cagnon et al Academic Radiology, 2006



Possible Mitigation Strategies

- Post-Acquistion/Reconstruction steps
  - Image DeNoising
  - Image Normalization
    - Regardless of the original Acquisition/Reconstruction Parameters, transform the images to a standard set of conditions (thickness, spatial resolution, contrast resolution, noise, etc.)
  - Deep Learning (!!??!!)

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Possible Mitigation Strategies

- These strategies may vary based on task
- Mitigation used to measure change in volume MAY NOT BE same used measure change in texture.

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Summary

- Converting an Imaging Modality to a Measurement System is not easy
- LOTS of sources of variability (including patient)
- Mitigation methods being explored
- Sources of Variability AND Mitigation methods may be task dependent.

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Summary

- As we listen to presentations today, let's consider:
- What is the task? (Or is a specific task identified?)
- What are sources of variability?
- What is the mitigation approach?
- How do these affect QI metric?
  - Repeatability?
  - Reproducibility?
- (NOTE: Each presentation does NOT have to solve ALL of these problems at once! ☺)

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Thank You

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Terminology

From a previous QIBA Annual Meeting

"Ten Things to Remember from the QIBA Metrology Workshop" by Nancy Obuchowski, PhD

"1. Do not use *repeatability* and *reproducibility* interchangeably"

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Repeatability

- This is the *within-subject* variability
- It is the agreement between measurements made within a short period of time (test-retest) holding variables constant
  - Example: Coffee Break Experiments
- Includes variability due to scanner adjustment, image noise, subject positioning

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Reproducibility

- The observations are performed on the same subject (usually) over a short period of time, ***but the location, operator and/or measuring system differs***

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