Quantitative Imaging: CT and MRI

Sources and Mitigation of CT Quantitative Imaging Errors

Michael McNitt-Gray, PhD. DABR, FAAPM, FACR
Professor, Department of Radiological Sciences
Director, UCLA Physics and Biology in Medicine Graduate Program
David Geffen School of Medicine at UCLA

AAPM 2018 Annual Meeting
Nashville, TN
July 31, 2018

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?

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 = \( \frac{\mu_{\text{tissue}} - \mu_{\text{water}}}{\mu_{\text{water}}} \times 1000 \)

• Water (\( \mu = \mu_{\text{water}} \)) \( \rightarrow \) 0 HU
• Air (\( \mu = 0 \)) \( \rightarrow \) -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)

System Description – Sources of Variability
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

Tumor Related Considerations
• Complexity of Tumor
  • Shape (Spherical or Complex) can make determining boundaries “difficult” (i.e. not reproducible)
  • Location
  • Physiology (contrast uptake, washout)
System Description – Sources of Variability

Scan Protocol Considerations
• Reconstructed image thickness
• Reconstructed image interval
• Reconstruction filter

• Resolution and Noise

Example Lung Lesion

1 mm B45  3 mm B45
System Description – Sources of Variability

Example Lung Lesion

1 mm B45  1 mm I26 S5

Analysis Method

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

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/
Possible Mitigation Strategies

- Post-Acquisition/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 (!?!!?)

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.
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.

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! ☺)

Thank You
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”

---

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

---

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*