# Progress in Understanding Sources in Variance with Quantitative Imaging

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# Purpose/Outline

- Discuss quantitative CT imaging research progress within OSEL/DIAM & through collaborative efforts

- Outline

  Part 1: Overlapping reconstruction in CT volume estimation

  Part 2: Update on “final” QIBA 1A reader study analysis

# Part 1
# Effect of overlapping CT reconstructions

RSNA 2011

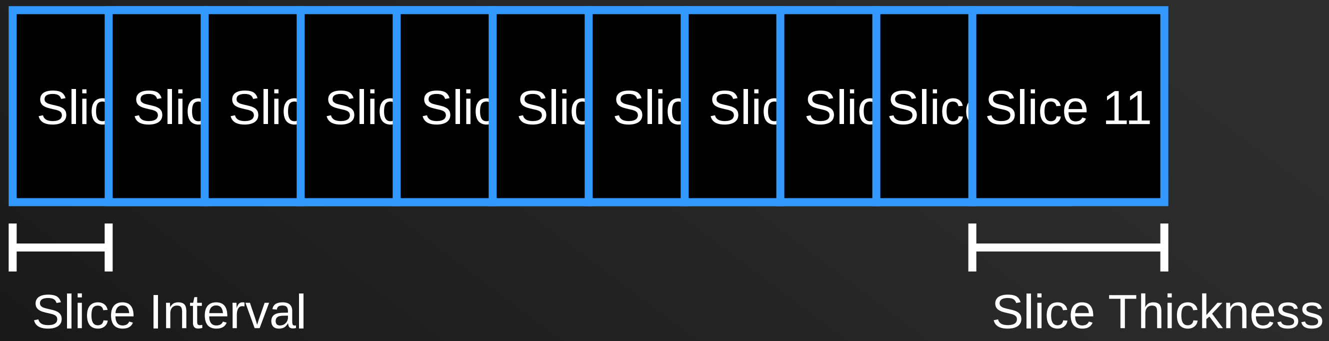
Marios Gavrielides, OSEL/DIAM

# Purpose

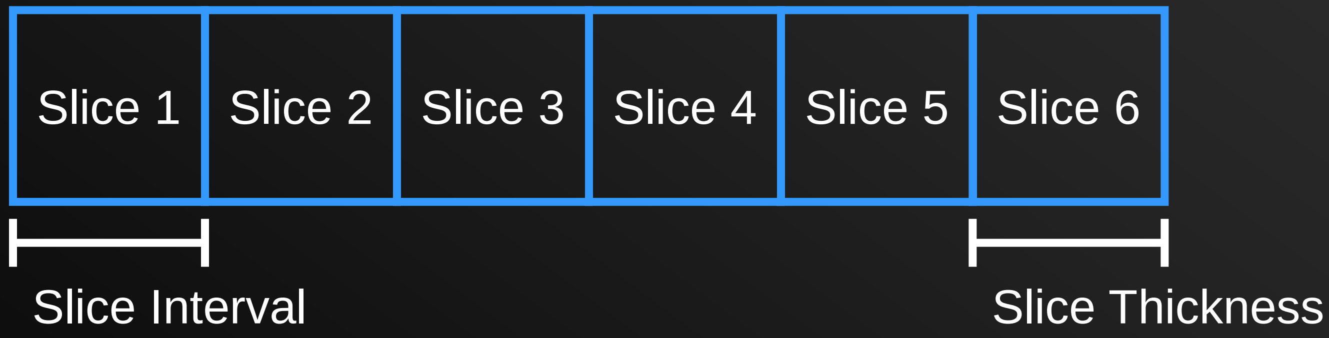
- To compare overlapping reconstruction to contiguous slice reconstruction
  - For the task of estimating nodule volume

# Reconstructed CT slices

- Overlapping slice reconstruction




- Contiguous reconstruction



# Reconstructed CT slices

- Overlapping reconstruction
  - Expressed as % of slice thickness
    - 50% overlap
- Contiguous reconstruction
  - Reconstruction interval = slice thickness
    - 0% overlap
- Same dose with each recon techniques

# Trade-off between overlapping & contiguous recons

- Practical issues
  - Overlap increases no. of slices
    - Reading time, storage size increases
- Improved z-dim resolution
  - Overlap minimizes partial-volume effects
  - Maximize contrast for central lesion slice*

*Kalender, JCAT, 1994., Wang, Med Phys, 1994, Leung J Thor Imag., 1997

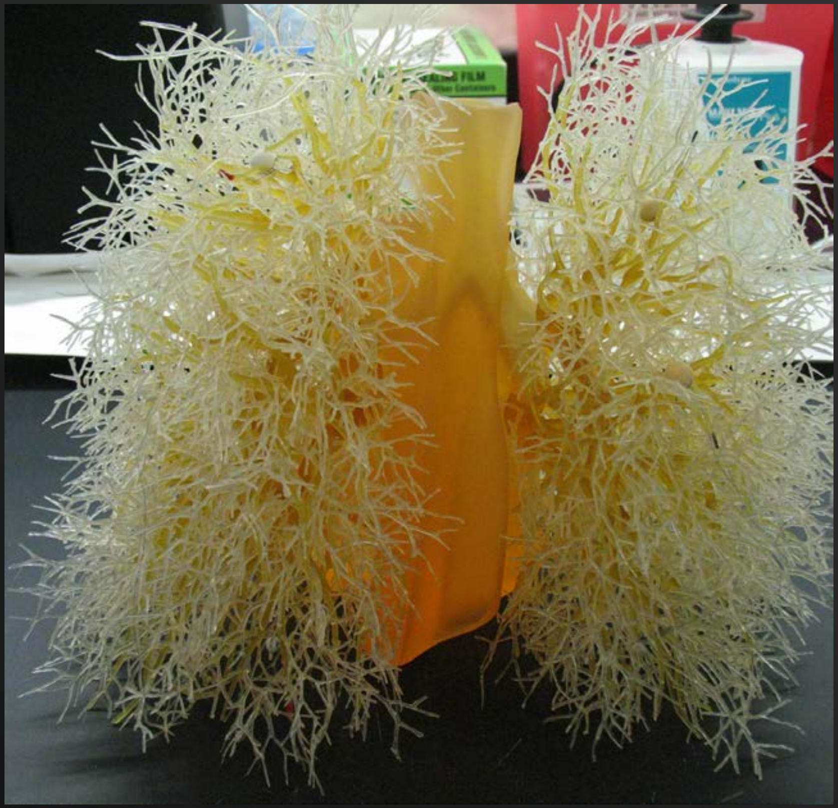
# Reconstructed CT slices

- Studies show improved detection with overlapping slices*
  - Effect on volume estimation not examined
- Compare overlapping to contiguous reconstructed CT slices for volume estimation task
  - CT data from our anthropomorphic phantom containing synthetic nodules

*Urban, AJR, 1993., Diederich, Eur Radiol 1999., Buckley, Radiol, 1995.

# Imaged anthropomorphic phantom

- Limitations
  - No airway, no lung parenchyma

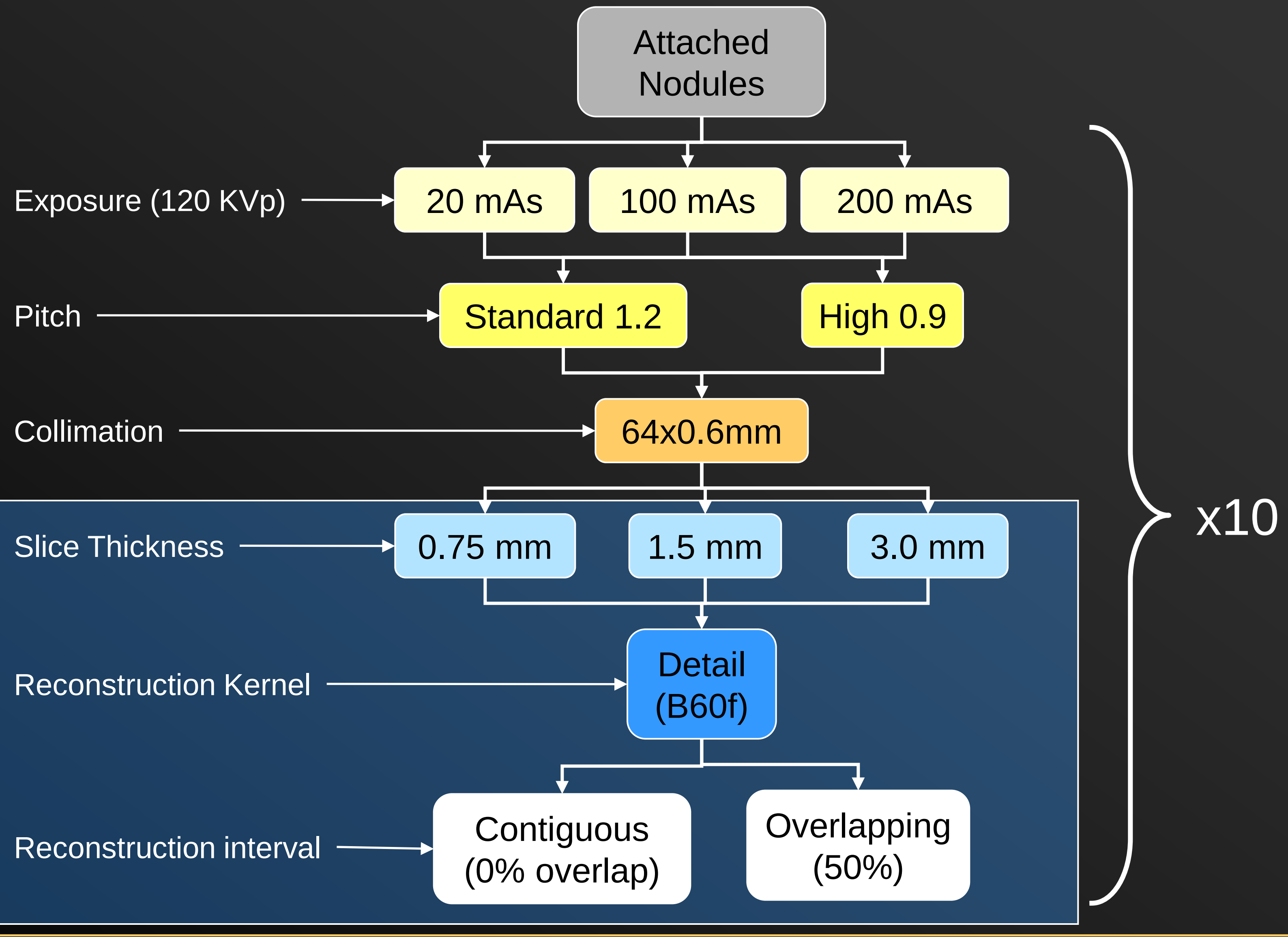


# Inserted synthetic nodules

- Spherical nodules
  - Size: 5, 10, 20 mm
  - Density: -630HU, +100HU
  - Attached to lung vasculature

- CT Scanner
  - Siemens 64-slice, Somatom 64
    - Images collected at the Mallinckrodt Institute of Radiology (MIR), Washington University School of Medicine

# Collection protocol



# Nodule Volume Estimator

- Matched filter-based approach*
  - Incorporates properties of imaging system

*Gavrielides et al., IEEE TMI, vol. 29, n. 10, pp. 1795-1807, 2010.

# Analysis plan

- Comparison of biases
  - Normalized size
    - $$Size_{Norm} = \frac{Size_{Est} - Size_{True}}{Size_{True}} \bullet 100\%$$
  - Relative bias
    - $$Bias_{Rel} = E\left\{Size_{Norm}\right\}$$

# Results
# Function of size

| Nodule Size mm | Overlapping $Bias_{Rel}$ (Std) | Contiguous $Bias_{Rel}$ (Std) |
|---|---|---|
| **All sizes ($N^*$=1080)** | 3.2 (15.0) | 8.8 (29.2) |
| **5 (N=360)** | 4.4 (24.1) | 29.7 (33.2) |
| **10 (N=360)** | 1.2 (7.7) | 5.2 (9.9) |
| **20 (N=360)** | 4.0 (5.6) | -8.4 (24.9) |

- N= 1080
  - 3 sizes x 2 pitches x 3 exposures, 2 densities x 3 slice thicknesses x 10 repeats

# Results
# Fixed nodule to slice thickness ratio

| Nodule Size/ Slice Thick Ratio | Overlapping $Bias_{Rel}$ (Std) | Contiguous $Bias_{Rel}$ (Std) |
|---|---|---|
| 3.3 (N=240) | -1.2 (13.9) | 7.3 (7.3) |
| 6.6 (N=360) | 0.5 (10.8) | -11.5 (23.3) |
| 13.3 (N=240) | 2.0 (7.5) | 4.2 (8.5) |

- 3.3: 5 mm @ 1.5 mm ST, 10mm @ 3 mm ST
- 6.7: 5 mm @ 0.75  mm ST, 10 mm @ 1.5 mm ST,  20mm @ 3 mm ST
- 13.3: 10 mm @ 0.75 mm ST, 20mm @ 1.5 mm ST

# Part 1 summary

- Reduced $Bias_{Rel}$ for overlapping slices compared to contiguous
  - Finding consistent across nodule sizes, nodule densities & imaging protocols
- Studies needed to determine whether increase in accuracy/precision outweigh workload issues
  - Contiguous for interpretations?
  - Overlap for nodule evaluation only?

# Part 2
# Update on QIBA 1A reader study analysis

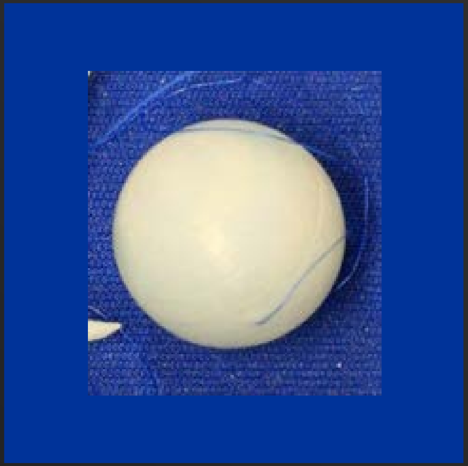
QIBA volumetric CT Working Group

# Purpose

- General purpose
  - To provide supporting data and a methodological pathway for validating the technical performance of lesion sizing techniques
- Specific purpose
  - To estimate the bias and variance of radiologists measuring the size of simple and complex synthetic nodules through a controlled reader study

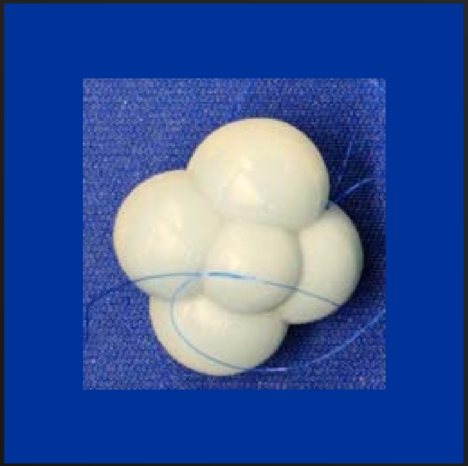
# Study design

- Data from QIBA 1A reader study
  - Readers size synthetic nodules from CT scan data
  - 10 synthetic nodules
    - Types
      - 10 mm Sphere
      - 20 mm Sphere
      - 20 mm Ellipsoid
      - 10 mm Lobulated
      - 10 mm Spiculated
    - Density
      - -10 HU
      - +100HU
- Readers sized nodules from 40 CT datasets
  - 10 nodules X 2 slice thickness X 2 repeat scans



Spherical

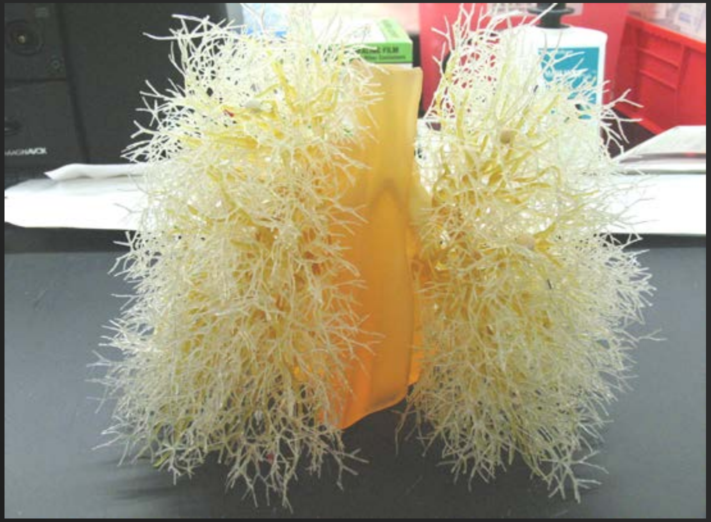
Ellipsoid



Lobulated

Spiculated

# Study design



- Anthropomorphic thorax phantom
  - Kyotokagaku Incorporated, Tokyo, Japan

# Reading protocol

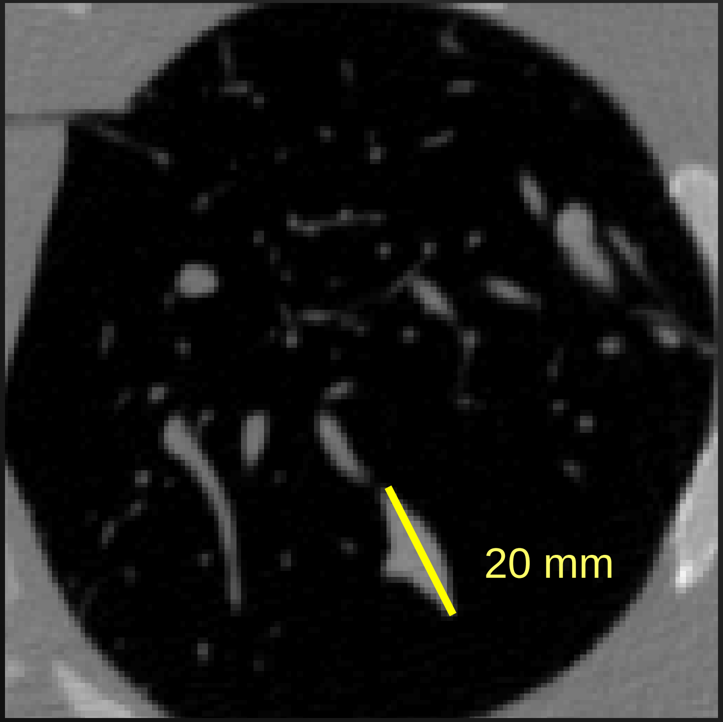
- Readers
  - 6 radiologists familiar with evaluating lesion response in drug trials

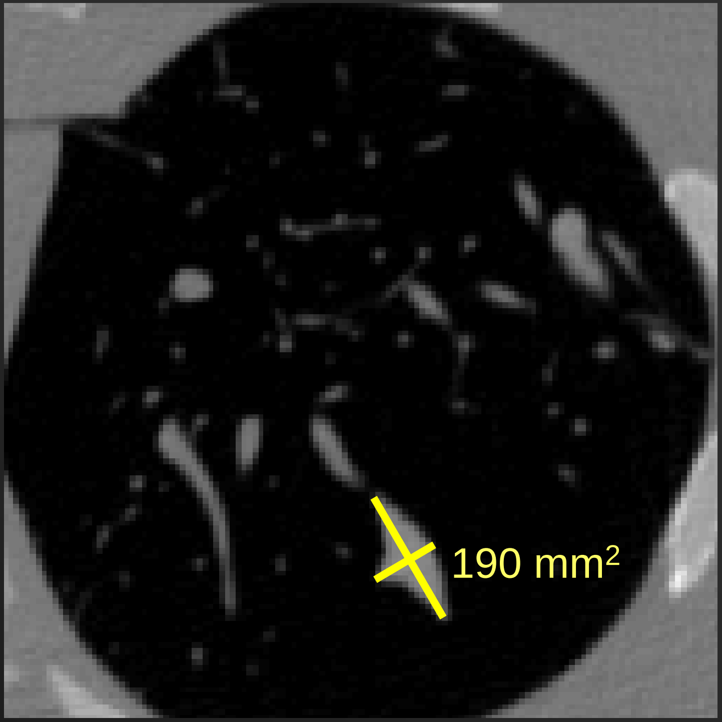
- Sizing Methods
  - 1D technique (linear distance)
    - Largest in-slice diameter for the lesion
    - Based on RECIST criteria
  - 2D technique (area)
    - Largest in-slice diameter for the lesion
    - Largest perpendicular diameter within same slice
    - Based on WHO criteria
  - 3D technique (volume)
    - Semi-automated volumetric measurement tool

# Analysis plan

- Comparison of biases and variances
  - Normalized size
    - $$Size_{Norm} = \frac{Size_{Est} - Size_{True}}{Size_{True}} \bullet 100\%$$
  - Relative bias
    - $$Bias_{Rel} = E\left\{Size_{Norm}\right\}$$
  - Relative standard deviation
    - $$Std_{Rel} = \mathrm{Std}\left\{Size_{Norm}\right\}$$

# Reading process

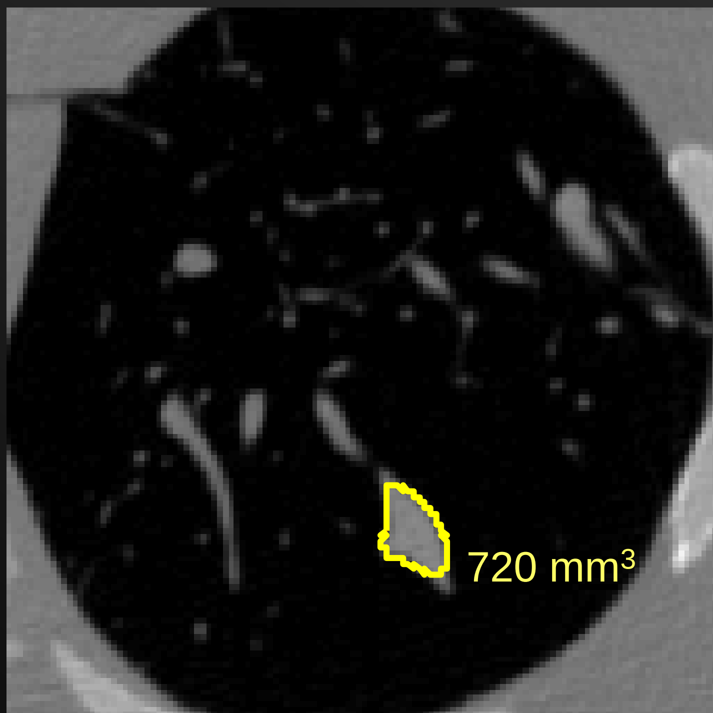


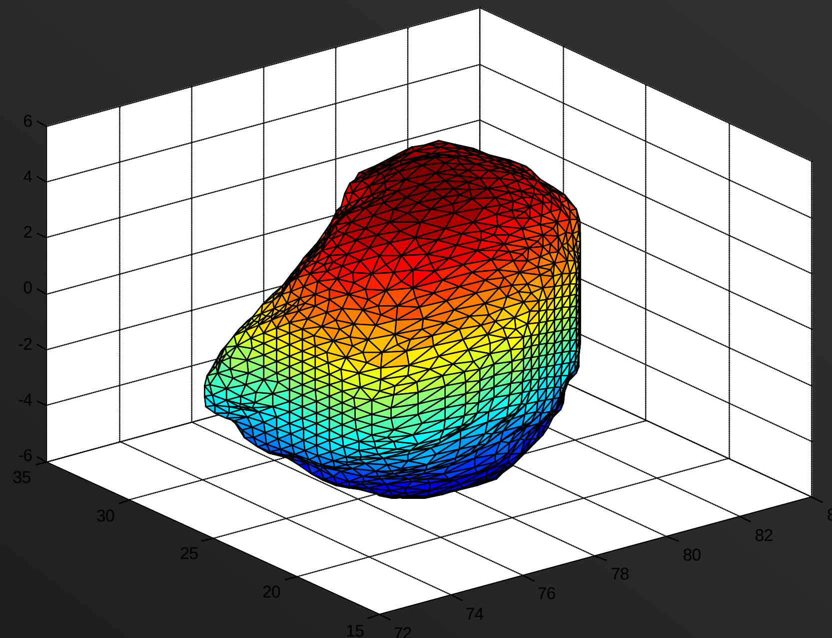




1D $Size_{Norm}$= -9.1%

2D $Size_{Norm}$= -44.6%

# Reading process




3D In-slice

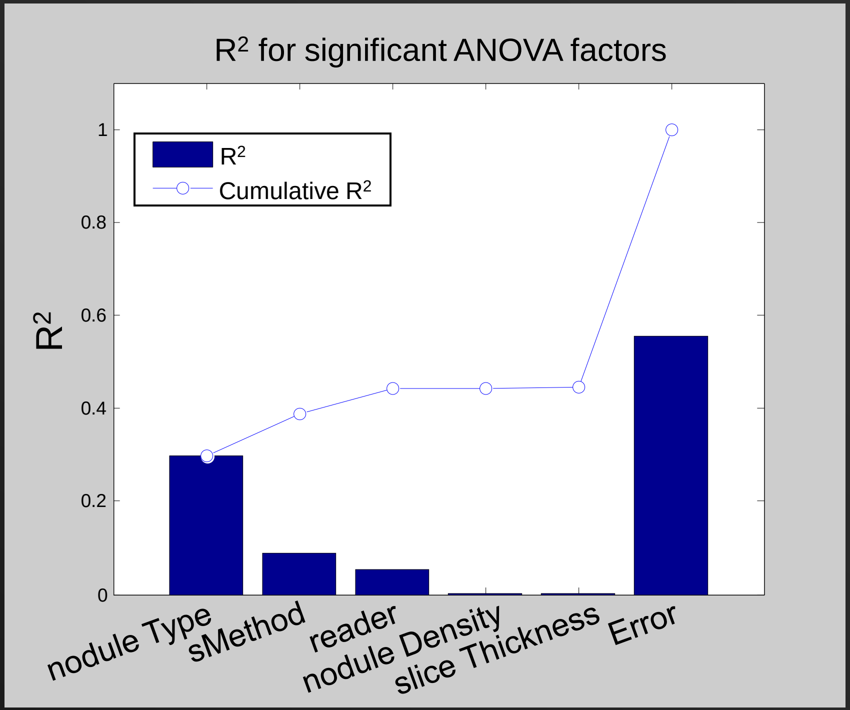
3D $Size_{Norm}$= +36.1%

# Analysis plan

- ANOVA & goodness-of-fit statistics ($R^2$) to identify important contributing factors
- Multiple comparisons of difference in $Bias_{Rel}$ among sizing methods
  - $Bias_{Rel}$ & bias comparisons based on t-test within each subgroup
- Multiple comparisons of difference in relative variability among sizing methods
  - $Std_{Rel}$ & Std comparisons based on bootstrapping within each subgroup

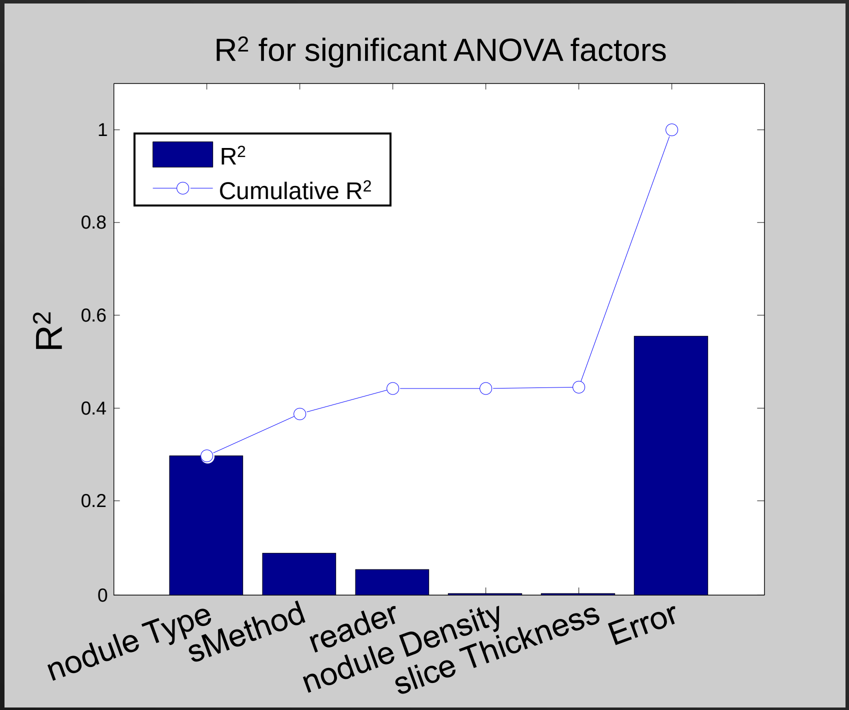
# Results
# ANOVA single factor

| Source | Prob>F | Significant ($p \leq 0.05$) |
|---|---|---|
| Nodule Type | 0 | ✓ |
| Sizing Method | 0 | ✓ |
| Readers | 0 | ✓ |
| Nodule Density | 0.0074 | ✓ |
| Slice Thickness | 0.0084 | ✓ |
| Nodule Set | 0.35 | ✗ |
| Reading Session | 0.7032 | ✗ |



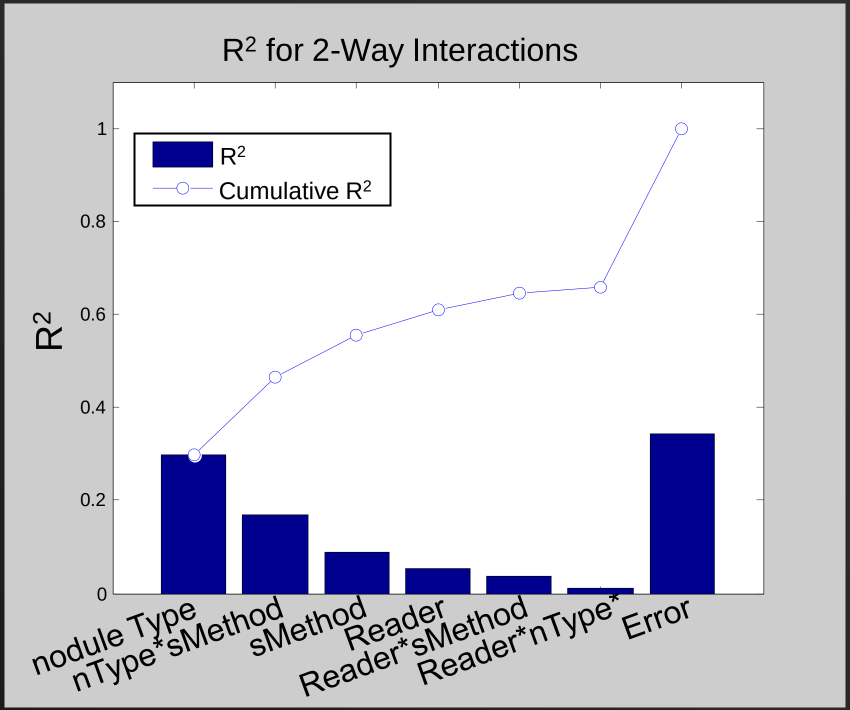
# Results
# ANOVA single factor

| Source | Prob>F | Significant (p≤0.05) |
|---|---|---|
| Nodule Type | 0 | ✓ |
| Sizing Method | 0 | ✓ |
| Readers | 0 | ✓ |
| Nodule Density | 0.0074 | ✗ |
| Slice Thickness | 0.0084 | ✗ |
| Nodule Set | 0.35 | ✗ |
| Reading Session | 0.7032 | ✗ |



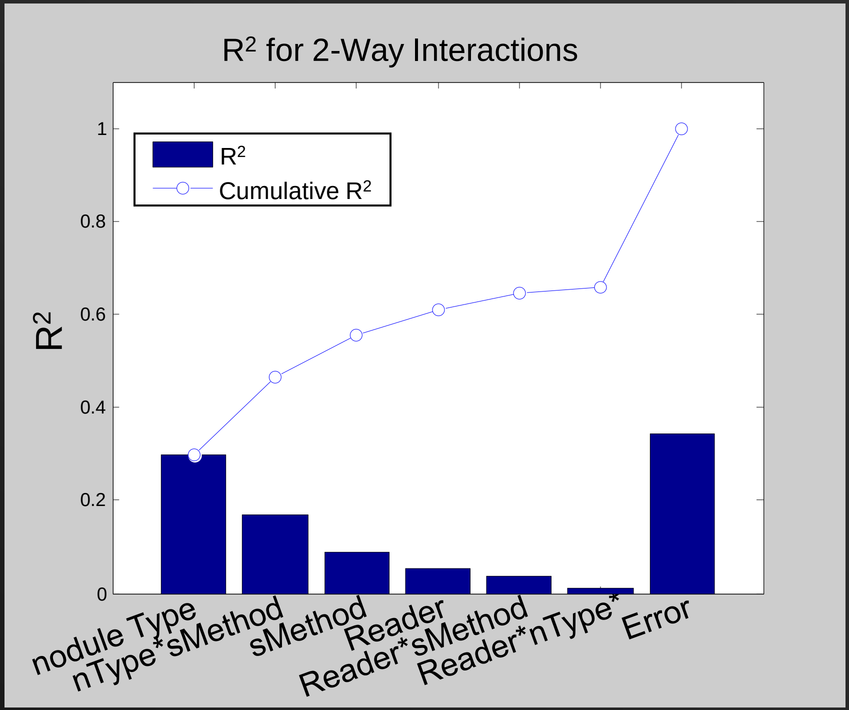
# Results
# ANOVA 2-way interactions

| Source | Prob>F | Significant (p≤0.05) |
|---|---|---|
| Nodule Type | 0 | ✓ |
| NType X SMethod | 0 | ✓ |
| Sizing Method | 0 | ✓ |
| Readers | 0 | ✓ |
| Readers X SMethod | 0 | ✓ |
| Readers X NType | 0.0002 | ✓ |



# Results
# ANOVA 2-way interactions

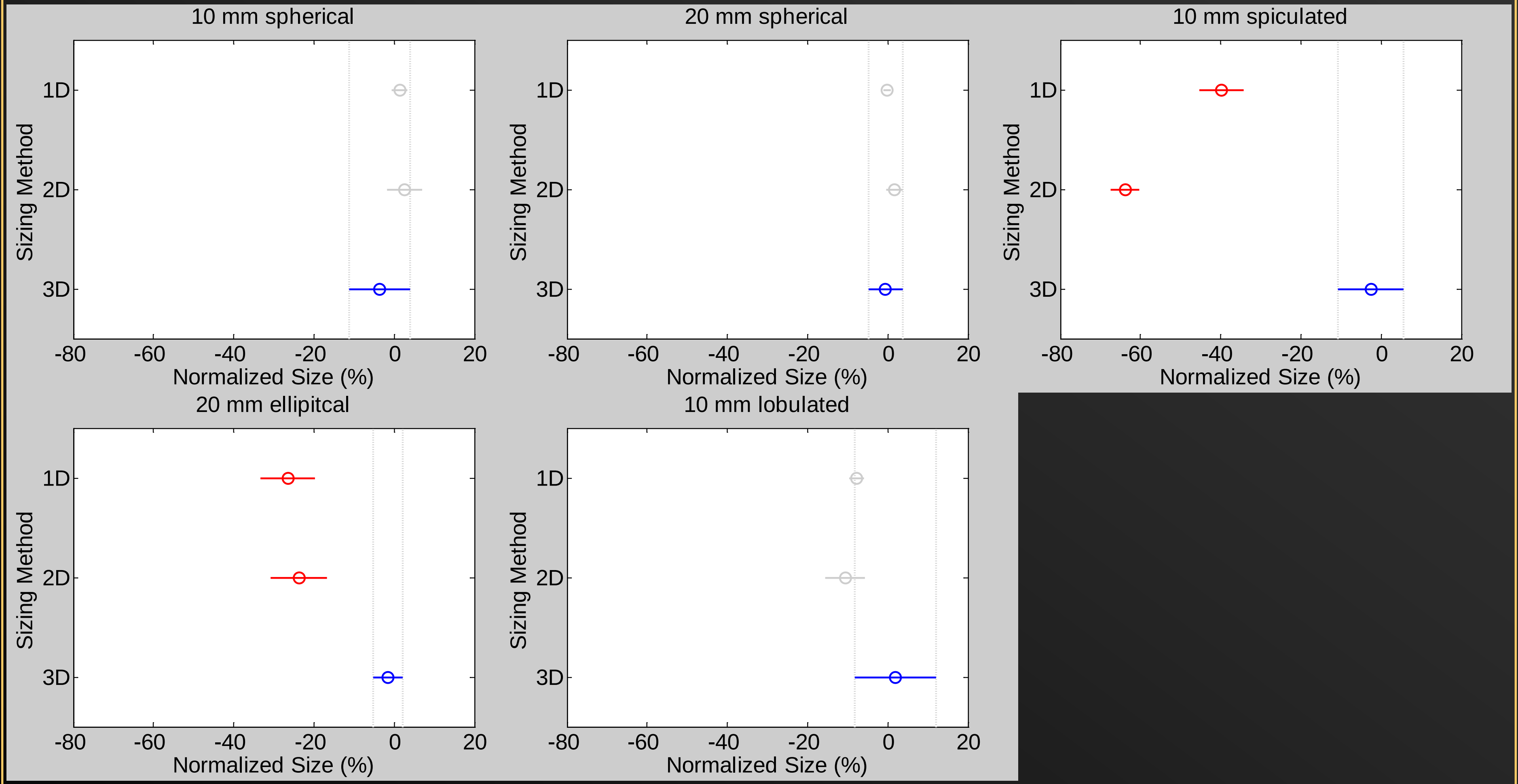
| Source | Prob>F | Significant (p≤0.05) |
|---|---|---|
| Nodule Type | 0 | ✓ |
| NType X SMethod | 0 | ✓ |
| Sizing Method | 0 | ✓ |
| Readers | 0 | ✗ |
| Readers X SMethod | 0 | ✗ |
| Readers X NType | 0.0002 | ✗ |



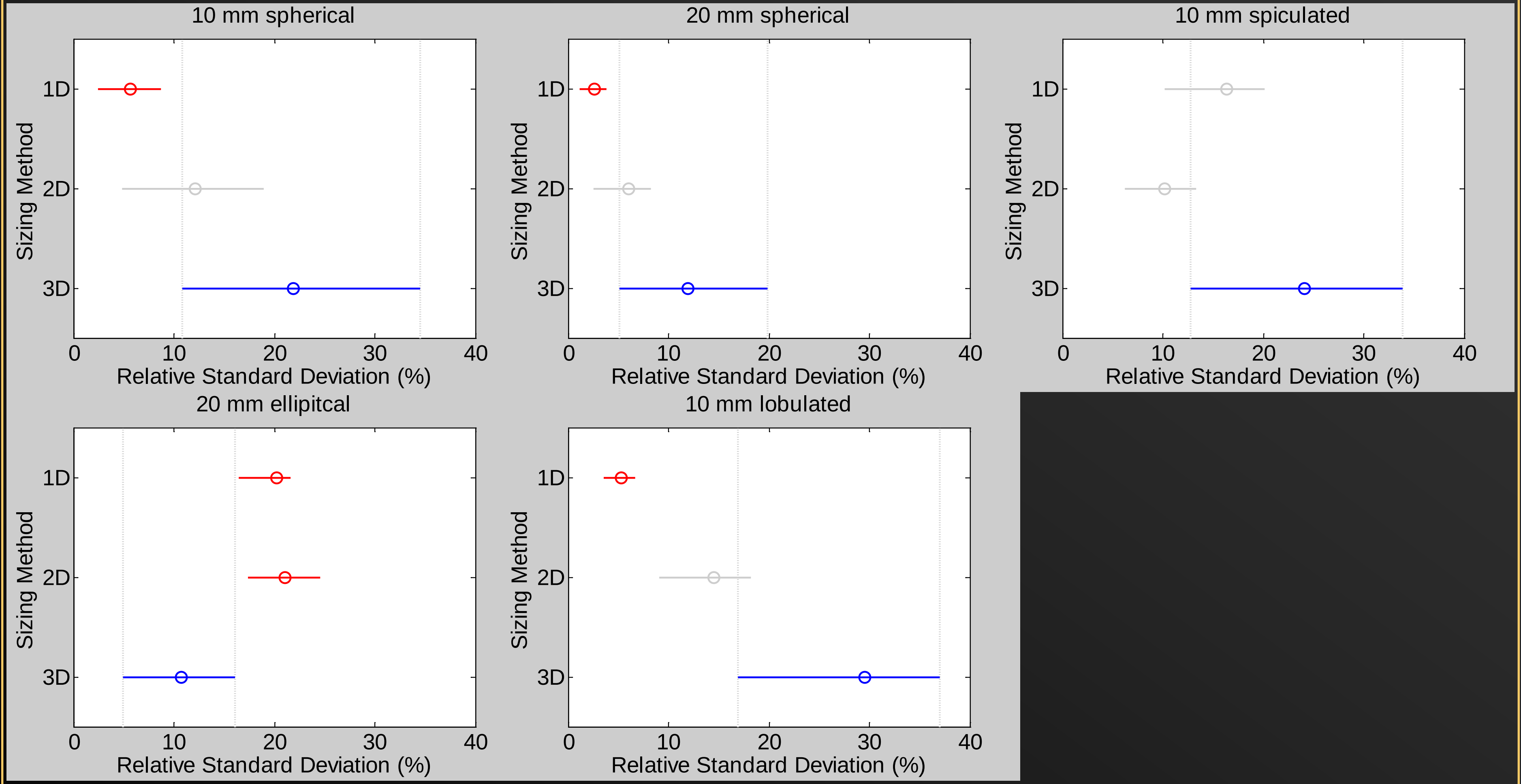
# Results
# ANOVA

- Important subgroups for analysis
  - Sizing method by nodule type
    - Compare sizing methods for
      - 10 mm Sphere
      - 20 mm Sphere
      - 20 mm Ellipsoid
      - 10 mm Lobulated
      - 10 mm Spiculated

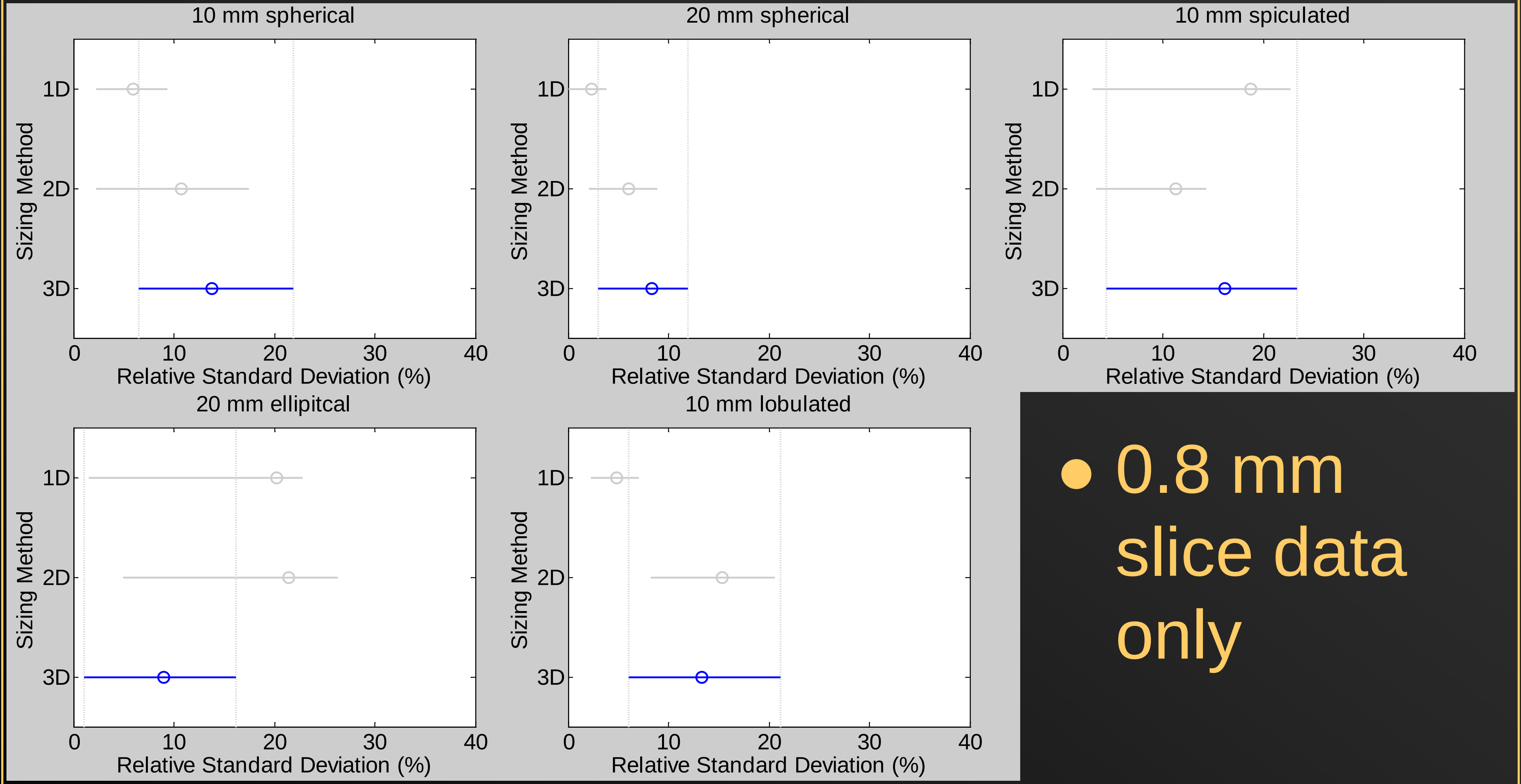
# Results
# Bias comparisons



# Results
# Variance comparisons



# Secondary analysis
# Variance comparisons




- 0.8 mm slice data only

# Part 2 Summary

- Bias analysis
  - Radiologist 3D volume estimates were close to unbiased across all nodule types
  - Radiologist 1D & 2D sizes systematically underestimated true size for complex nodules
    - Different biases for elliptical, lobulated and spiculated nodules
    - Not shown
      - Nodule orientation critical factor for 1D & 2D but not 3D
- Variance analysis
  - Variability lower for 1D/2D sizing compared with 3D volume
  - Not shown
    - Scaling 1D & 2D sizes to 3D resulted in more comparable variability across methods
- Each sizing method had its own unique bias/variance tradeoff

# Acknowledgments


- We acknowledge Corelab's strong support to this QIBA vCT Part 1A groundwork effort.  CoreLab Partners LLC conducted the reader study component of this investigation and CoreLab radiologists participated as readers

- We acknowledge the substantial contributions of Lisa M. Kinnard (Medical Research Program, Department of Defense, Fort Detrick, MD) in the design and conduct of the QIBA 1A reader study
-
- We acknowledge the members of the QIBA Volumetric CT Technical Committee and especially the members of the QIBA vCT Part 1A subcommittee for making substantial contributions to Part 3.

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