# Hybrid Calibration and Display of CT Images in the Gram Scale
# Can We Ever Give up the HU Unit?

Ben Arnold, MPH, ScD
Image Analysis, Inc

**Conflict-of-Interest Disclosure:** Ben Arnold is the principal stockholder and president of Image Analysis which develops and markets quantitative CT products including the software here reported.

Outline:

* Limitations of water phantom calibrations of HU in MDCT
* Some causes and challenges to making desired corrections
* N-vivo tissue calibrations; specific for patient/scanner/exams
* Hybrid phantom/tissue calibrations; calcium/iodine targets
- Results with Hybrid calibrations and voxels in density units
* A proposed density scale, " the Gram scale"

"Could we, should we, ever give up the Hounsfield scale??"

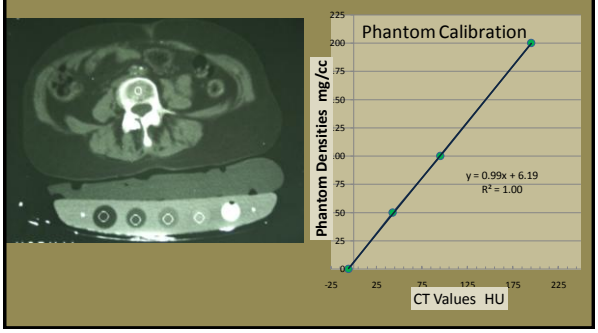
# Unreliability of CT Numbers

**The Unreliability of CT Numbers as Absolute Values**

Clifford Levi, Joel E. Gray, Edwin C. McCullough, Robert R. Hattery

**1982**, *AJR;* 139:443-47

BMD Phantom calibration for single slice CT scanner

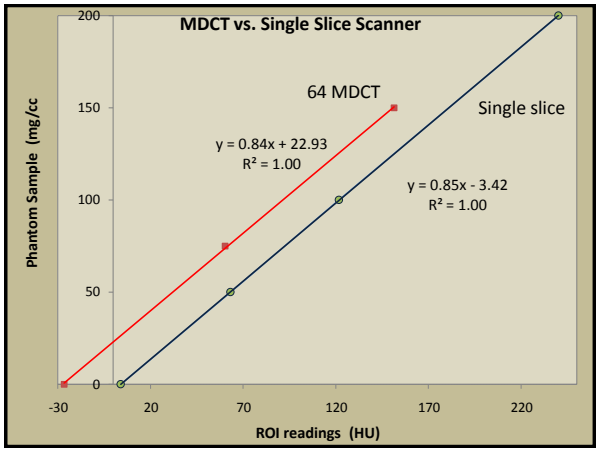


# Very Unreliable MDCT Numbers

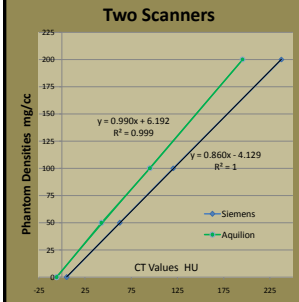
"Water ranged from 1 to 15 HU; air from -962 to -990"
Groell R et al. Comp Med Image Graphics 24 (2); 53-8

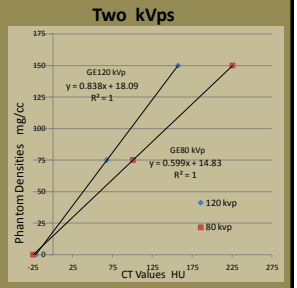
"CT number of adipose tissue decreased with distance from center"

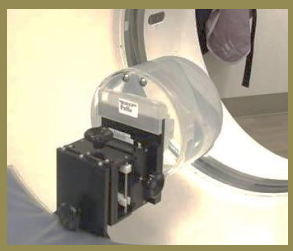
All MDCT scanners ,,,,,,, variability in tissue attenuation ( liver tissue 63.4 HU, cyst –15.7 to 23.9 HU)
Bernard A et al 2007 Radiology, 242; 109-19




# Energy Dependent X-ray Imaging



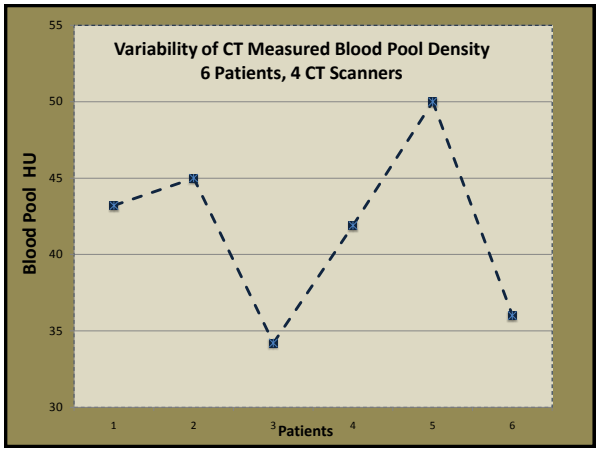



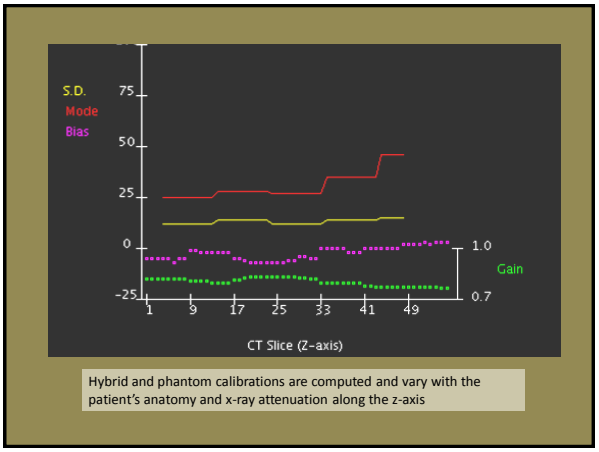



Water phantom Calibration

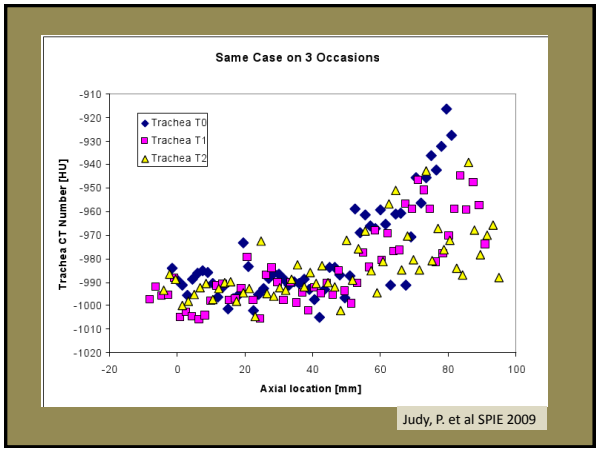
Problems:

* Idealized circular shape
* Homogeneous material
* Calibrated at center



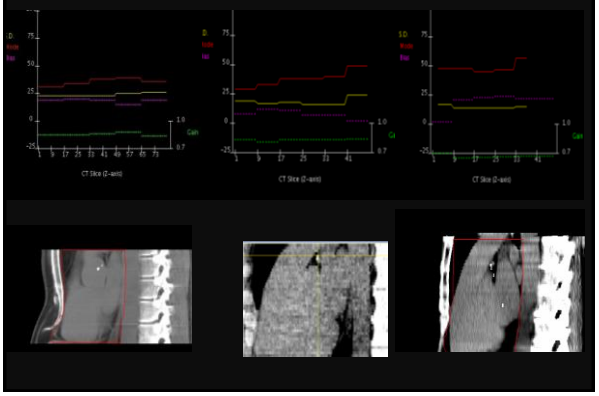




Hybrid and phantom calibrations are computed and vary with the patient's anatomy and x-ray attenuation along the z-axis



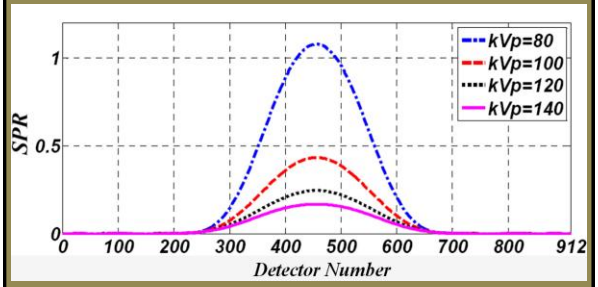

Judy, P. et al SPIE 2009

Automated Blood Pool Density and SD for Three Patient CT Scans



## Scattered Radiation with a 64 MDCT Scanner

21.5 cm Water phantom, without the bow-tie filter
SPRs after applying inverse software scatter corrections




A Akbarzadeh et al. Biomed Imaging Interv J 2010; 6(1):e3

## Blood as In vivo Tissue Reference

"There was **a small increase in whole blood specific gravity with increasing hematocrit, but it was not statistically significant over the 40-56 hematocrit range studied."**

Trudnowski RJ et al. Clin Chem 1974 ;20/5, 615-16

Normal variations of blood chemistry equate to approximately 2-4 HU

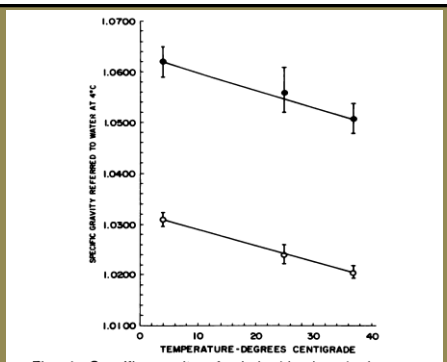
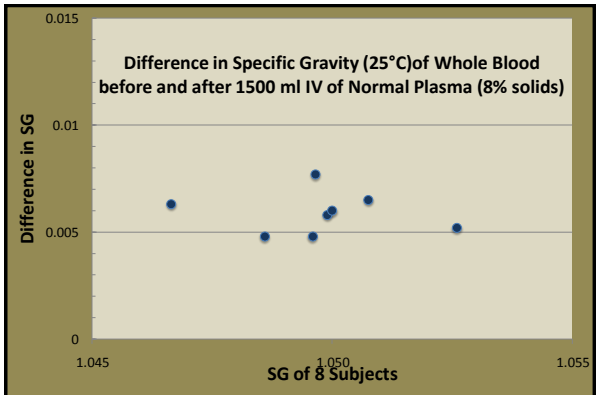



Fig. 1. Specific gravity of whole blood and plasma—healthy adults
*Abscissa:* temperature °C. *Ordinate:* specific gravity referred to water at 4 °C. ●, whole blood; O plasma

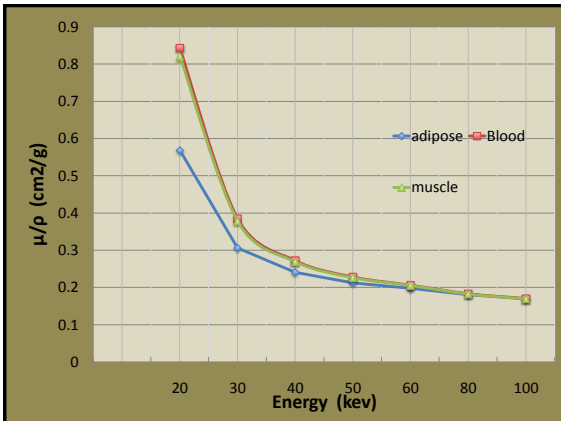


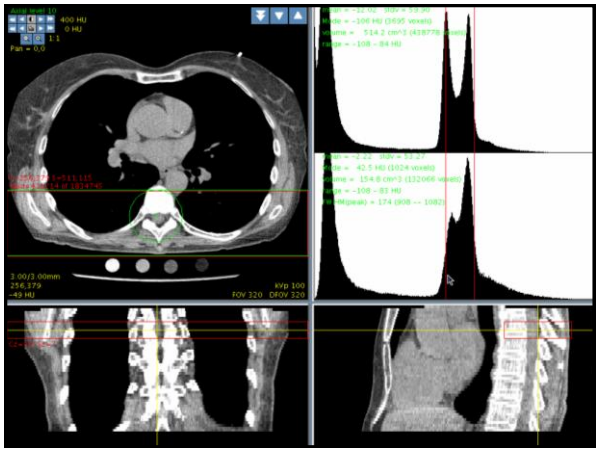

Phillips RA, The Rockefeller Institute for Medical Research, Dec 15,1945

## Development of Automated in vivo Tissue References

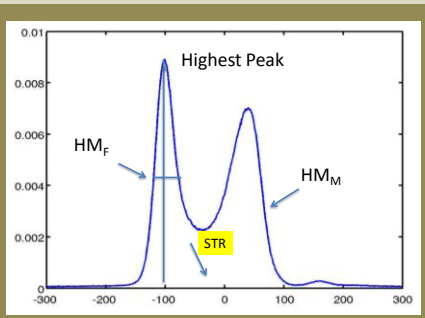
Requirements:

- Full body calibrations
- Fully automated
- Universal standard
- Better than water phantoms

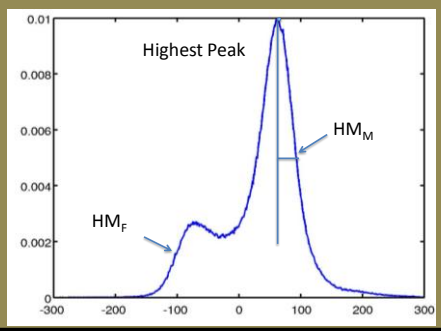


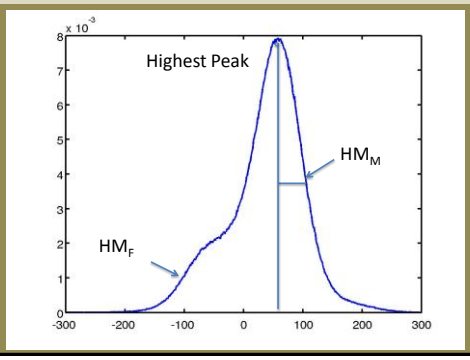
## Automatic Computation of Tissue Measures



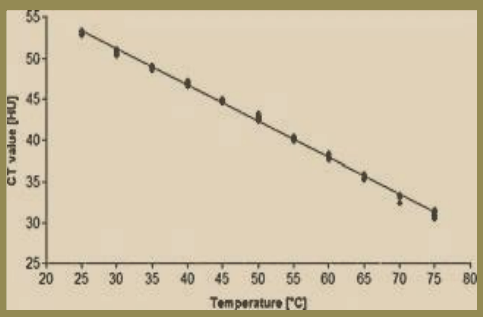
## Automatic Computation of Tissue Measures




## Automatic Computation of Tissue Measures




## HU Values vs. Temperature of Water




Falone, BG et al Med. Phys. 9(5), 1982

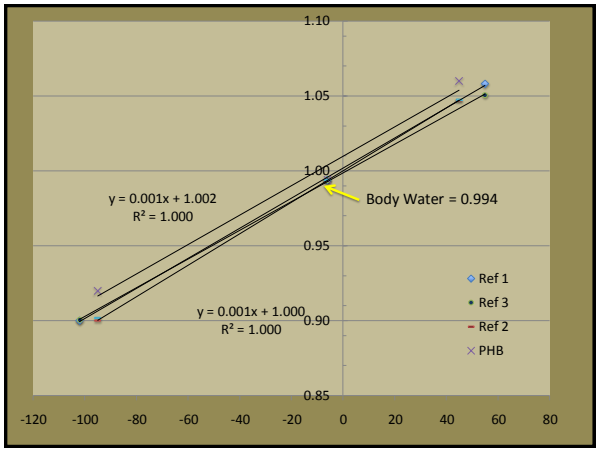
## Body Water CT Number 37°C

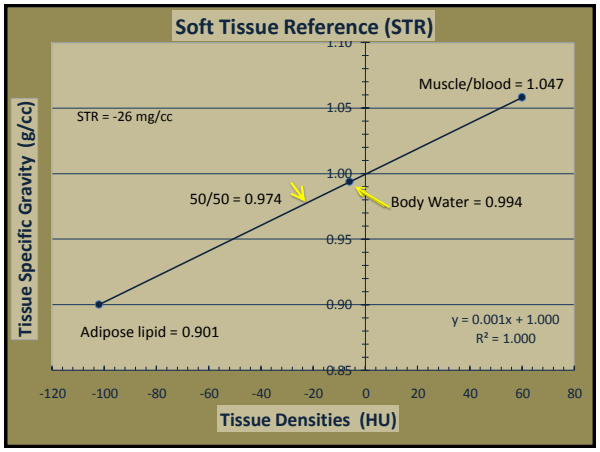
Water Density Decreases with Increasing Temperature - 0.45 HU/°C

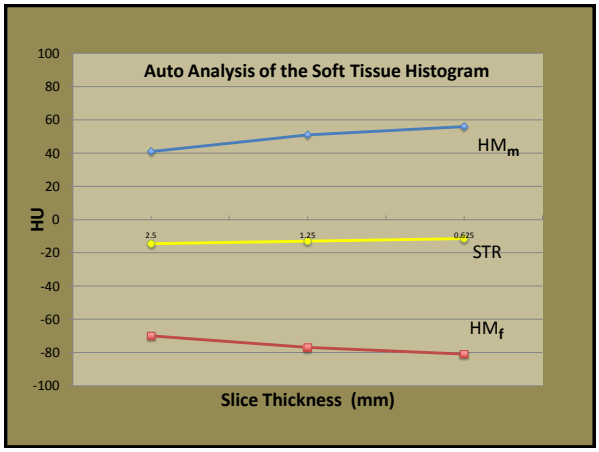
Body - Room Temperature = 37° - 20°C = 17°C

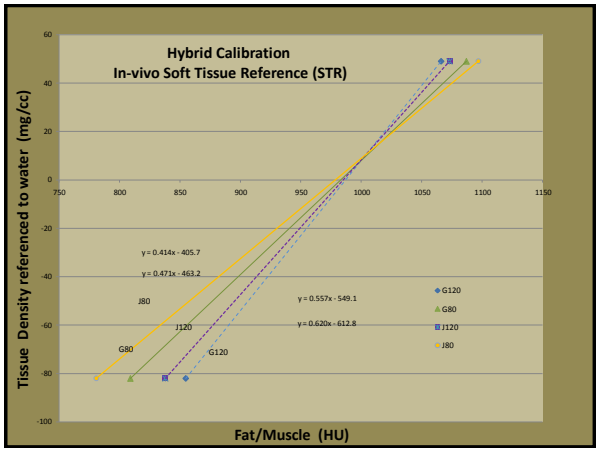
$\triangle$ HU = 0.45 x 17 = 7.6 HU

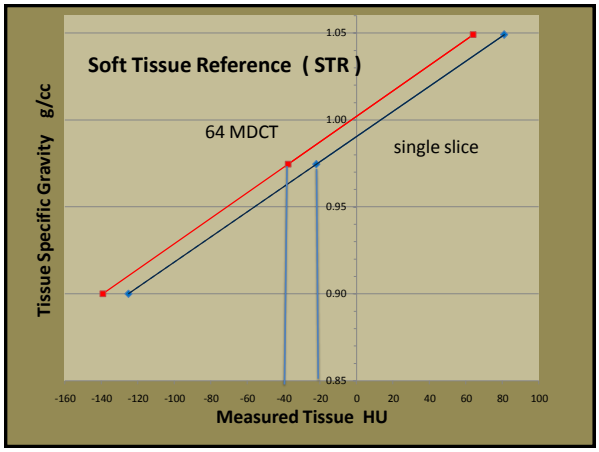
Mahnken AH et al, Int J Clin Pract, 65 (S. 171), 2011


y = 0.001x + 1.002
R² = 1.000
Body Water = 0.994
y = 0.001x + 1.000
R² = 1.000
Ref 1
Ref 3
Ref 2
PHB

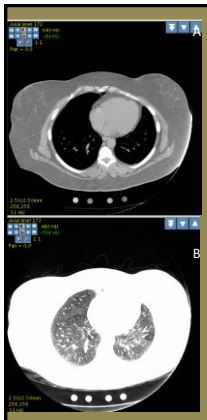

Soft Tissue Reference (STR)
Tissue Specific Gravity (g/cc)
Tissue Densities (HU)
Muscle/blood = 1.047
STR = -26 mg/cc
50/50 = 0.974
Body Water = 0.994
Adipose lipid = 0.901
y = 0.001x + 1.000
R² = 1.000


Auto Analysis of the Soft Tissue Histogram
HU
HMm
STR
HMf
Slice Thickness (mm)


Hybrid Calibration
In-vivo Soft Tissue Reference (STR)
Tissue Density referenced to water (mg/cc)
Fat/Muscle (HU)
y = 0.414x - 405.7
y = 0.471x - 463.2
y = 0.557x - 549.1
y = 0.620x - 612.8
G120
G80
J120
J80

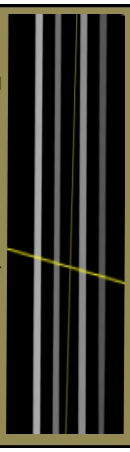


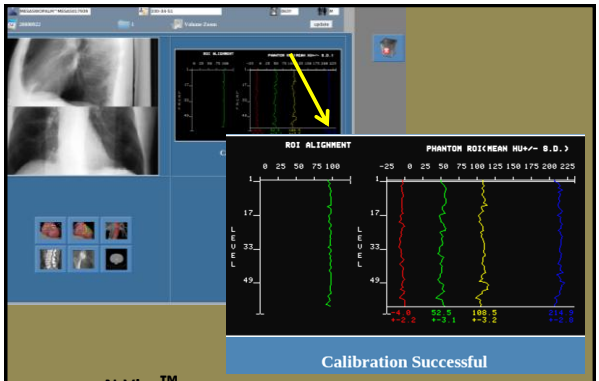

An always in place calibration phantom pad contains reference calcium hydroxyappitte samples incased within a CT couch pad was present in all scans.




No artifacts were observed from the small samples which would interfere with other exams

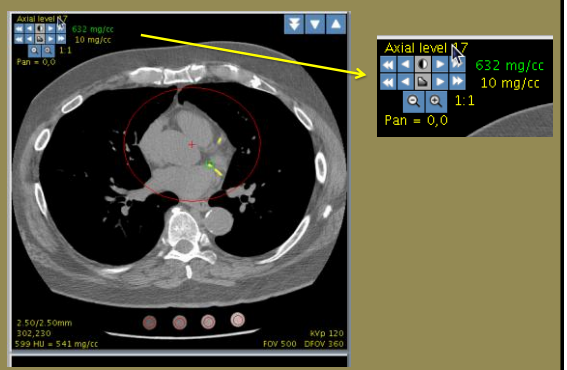
The calibration pad length of 125 cm extends to cover the torso






N-Vivo™ Applications and Calibration Screen

Ben Arnold
Image Analysis, Inc




**Automated Calibration in the Gram scale**

Ben Arnold
Image Analysis, Inc

## Patient, CT Technique, and Scanner Specific Dual Thresholds

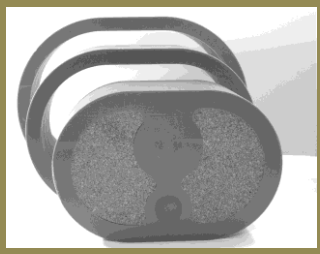
The thresholds equations are:

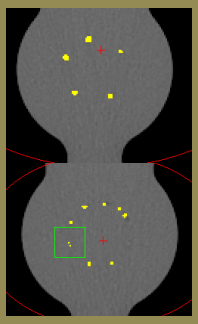
$$HiThreshold = C_1 \times BP(z) + C_2 \times SD(z) + C_3$$

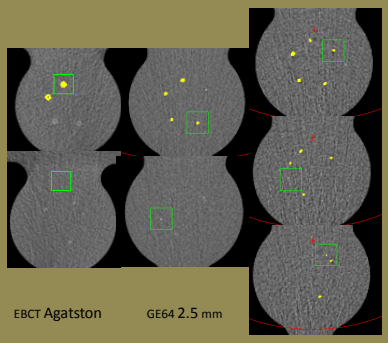
$$LoThreshold = C_4 \times BP(z) + C_5 \times SD(z) + C_6$$

Constants Cs, SD, and BP are computed with calibrated voxels from the muscle/blood along the z-axis.

## CaHA microsphere phantom



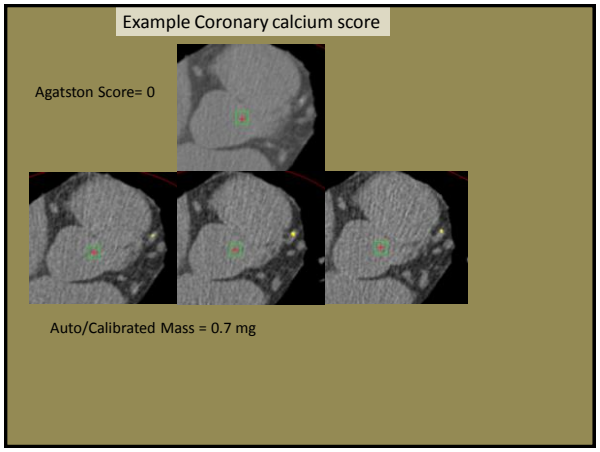


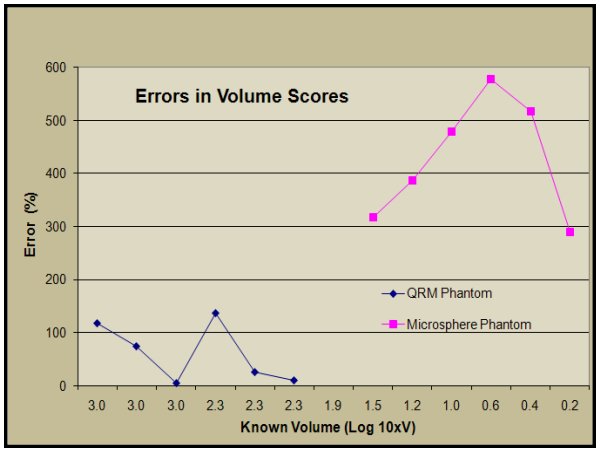


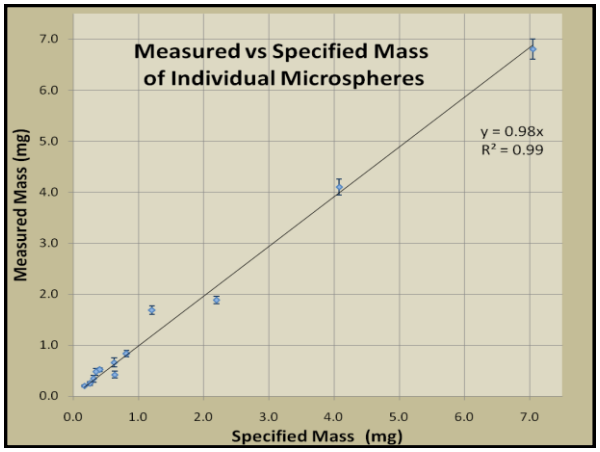
EBCT Agatston

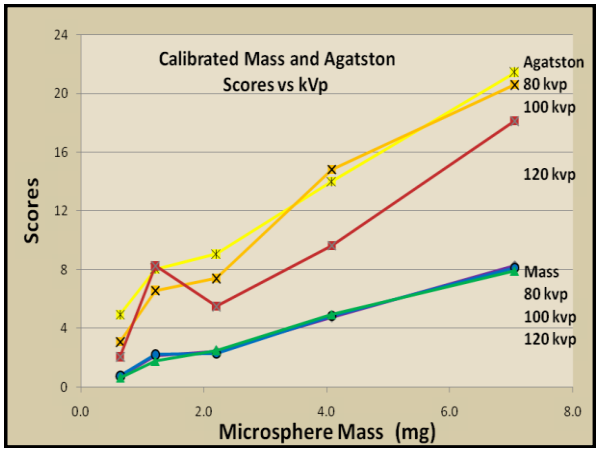
GE64 2.5 mm

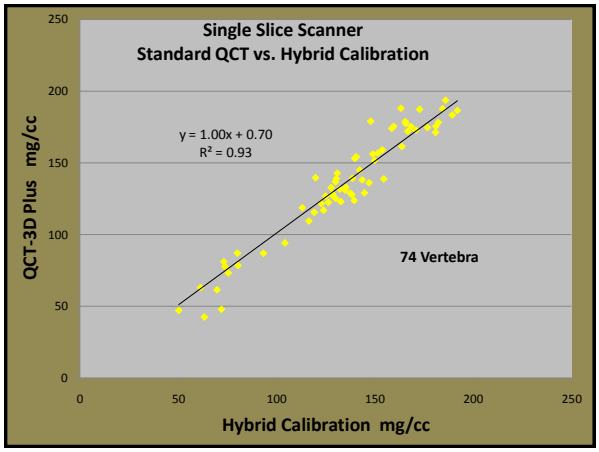
GE64 .62 mm Auto-calibrated

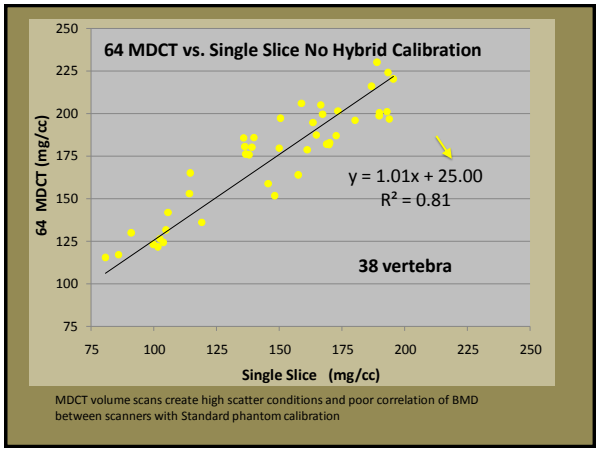

Example Coronary calcium score
Agatston Score= 0
Auto/Calibrated Mass = 0.7 mg


Errors in Volume Scores
Error (%)
600
500
400
300
200
100
0
QRM Phantom
Microsphere Phantom
3.0 3.0 3.0 2.3 2.3 2.3 1.9 1.5 1.2 1.0 0.6 0.4 0.2
Known Volume (Log 10xV)


Measured vs Specified Mass
of Individual Microspheres
y = 0.98x
R² = 0.99
Measured Mass (mg)
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0.0 1.0 2.0 3.0 4.0 5.0 6.0 7.0
Specified Mass (mg)


Calibrated Mass and Agatston
Scores vs kVp
Agatston
80 kvp
100 kvp
120 kvp
Mass
80 kvp
100 kvp
120 kvp
Scores
24
20
16
12
8
4
0
0.0 2.0 4.0 6.0 8.0
Microsphere Mass (mg)




MDCT volume scans create high scatter conditions and poor correlation of BMD between scanners with Standard phantom calibration

## The Gram Scale
## Why?

1. More consistent images for specific patients
2. Calibration without the use of a water phantom
3. Image voxels in density units for quantitative measurements
4. Potential for better standardization among CT scanners

## The Gram Scale

| | Air | Fat | Body Water | Water | Muscle | Bone |
|---|---|---|---|---|---|---|
| HU Scale | -1000 | -100 | | 0 | 55 | 3000 |
| Density | 0 | 0.901 | 0.994 | 1 | 1.047 | 1.85 |
| Gram Scale | -1000 | -100 | -6 | 0 | 47 | 1850 |

## The Gram Scale

HU Scale -1000 0 3000

STR

GU Scale -1000 -26 0 1000

Density (mg/cc) = 1000 + GU

## Conclusions and Comments:

MDCT HU values are not reliable for many applications

In vivo tissues may provide improved calib (blood/muscle, fat, air)

Automated Hybrid calibrations appear possible in background

A new density scale is proposed, " The gram Scale"

" Could we, should we, consider converting from the HU scale?"