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

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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

BMD Phantom calibration for single slice CT scanner

\[ y = 0.99x + 6.19 \]

\[ R^2 = 1.00 \]

Phantom Calibration

CT Values  HU

Phantom Densities  mg/cc

250
200
150
100
50
0

-25
-50
-75
-100
-125
-150
-175
-200
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
Variability of CT Measured Blood Pool Density
6 Patients, 4 CT Scanners

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

Same Case on 3 Occasions

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

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. O, whole blood. C, plasma

Phillips RA, The Rockefeller Institute for Medical Research, Dec 35, 1945

Difference in Specific Gravity (25°C) of Whole Blood before and after 1500 ml IV of Normal Plasma (8% solids)
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

FM

FM

HM

Highest Peak

HU Values vs. Temperature of Water

Body Water CT Number

37°C

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

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

\[ HU = 0.45 \times 17 = 7.6 \text{ HU} \]


An always in place calibration phantom pad contains reference calcium hydroxyapatite 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.
The thresholds equations are:

\[
\text{HiThreshold} = C_1 \times BP(z) + C_2 \times SD(z) + C_3
\]

\[
\text{LoThreshold} = C_4 \times BP(z) + C_5 \times SD(z) + C_6
\]

Constants $C_s$, $SD$, and $BP$ are computed with calibrated voxels from the muscle/blood along the z-axis.
Example Coronary calcium score

Agatston Score = 0

Auto/Calibrated Mass = 0.7 mg
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

<table>
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<th>HU Scale</th>
<th>GU Scale</th>
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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?”