Reproducibility and Accuracy of HU Assignments in CT Imaging

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ABSTRACT

Purpose: In Radiation Oncology, a crucial step for accurate patient treatment is converting Hounsfield Units (HU) from Computed Tomography (CT) scans into mass or electron density for dose calculations. However, several factors – like scan energy, metal artifact reduction (MAR) algorithm, and reconstruction kernel – can influence these values.

Methods: We compared HU values for 16 different density rods within a Gammex 467 tissue characterization phantom across multiple institutions in the Pacific Northwest. Our comparative analysis included several CT simulators. CT scans were examined with three parameters: scan energy, clinic, and machine type.

Results: Using a Python program, a parallel coordinate plot was generated to compare HU values for each rod as a function of the scan parameters. We also plotted HU values against mass density to investigate deviations from literature values, which were most pronounced for high-density (HD) structures (>400 HU) with HU values far from 0 HU. The magnitude of these deviations varied based on the specific scan parameters.

Conclusions: Our preliminary findings suggest that while HU assignments are relatively repeatable and accurate across CT scans in the -700 HU to 400 HU range, independent of scan parameter, reproducibility deviations and discrepancies from literature values were observed for HD structures. The relative balance between reproducibility and accuracy appears parameter dependent. These findings highlight the importance of local HU-to-mass density calibration and cautious use of HU values for high-density tissues in treatment planning. Further investigation with a larger dataset is recommended to confirm these trends.

Acknowledgements

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INTRODUCTION

CT scans are commonplace in the healthcare industry to visualize patient anatomy and aid in medical diagnosis and treatment. They are typically produced by:[1,3]

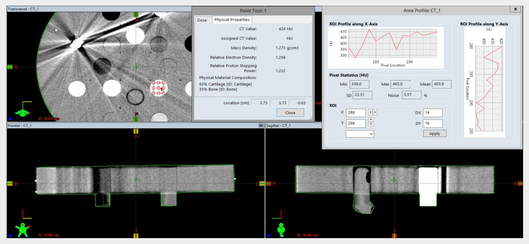
- Passing an x-ray beam through thin cross-sections of the body.
- Measuring photon attenuation with a detector array.
- Reconstructing images via back projection of the attenuation data.

Each voxel is assigned a Hounsfield Unit (HU) based on its degree of attenuation:[3]

$$HU(x,y,z) = 1000\frac{(\mu(x,y,z) - \mu_w)}{\mu_w}$$

HU values determine grayscale intensity and helps distinguish structures of different materials. A common practice in radiation oncology departments is associating HU values with a mass/electron density (CT-MD plot) required for dose calculations; that methodology is employed here for several plots. Ensuring reproducibility and accuracy of HU assignments is critical for reliable clinical use across imaging parameters.

Figure 1. A. Photo of the Gammex 467 Tissue Characterization Phantom.[2] **B.** Determination of the density for each Gammex Rod Type within the treatment planning system.



METHODS AND MATERIALS

CT scan reproducibility and accuracy were evaluated using the Gammex 467 Tissue Characterization Phantom (16 density rods).[2] HU values were measured within the treatment planning system or extracted from scanner reports across numerous radiation oncology clinics in the Pacific Northwest.

Three scan parameters were analyzed: scan energy, clinic, and machine type. For each parameter, standard deviation (SD) calculations served as a metric of reproducibility while mean error calculations determined accuracy. Parameters were assessed both jointly and independently.

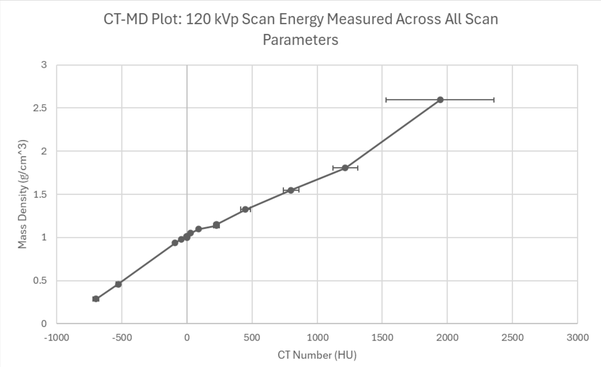
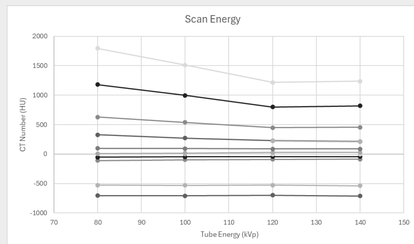


Figure 2. CT-MD plot demonstrating the variability in CT Number regardless of scan parameters.

Parameter Comparison Table			
Rod Type	CT Number (HU) - Machine Type	CT Number (HU) - Clinic	CT Number (HU) - All Scan Energies
LN-300 Lung	-701.8 ± 17.3	-692.2 ± 18.0	-704.7 ± 5.7
LN-450 Lung	-522.0 ± 10.2	-523.9 ± 10.63	-530.6 ± 4.1
AP6 Adipose	-91.9 ± 5.3	-93.81 ± 11.6	-95.4 ± 9.8
BR-12 Breast	-45.7 ± 6.2	-45.0 ± 7.4	-47.4 ± 4.9
CT Solid Water	1.1 ± 12.3	-0.1 ± 7.4	N/A
CT Solid Water	-5.0 ± 6.3	-0.1 ± 8.1	N/A
CT Solid Water	-1.7 ± 8.4	0.2 ± 9.0	N/A
CT Solid Water	-2.4 ± 6.7	5.1 ± 17.1	N/A
Water Insert	1.4 ± 9.4	0.7 ± 6.1	2.0 ± 0.8
BRN-SR2 Brain	27.8 ± 5.3	27.7 ± 6.1	20.5 ± 10.2
LV1 Liver	85.7 ± 6.8	87.2 ± 8.8	92.0 ± 4.4
IB Inner Bone	215.0 ± 15.4	218.3 ± 19.2	259.9 ± 52.1
B200 Bone Mineral	221.0 ± 11.8	222.7 ± 12.0	253.9 ± 46.6
CB2-30% CaCO3	436.5 ± 19.0	438.8 ± 25.6	517.5 ± 84.4
CB2-50% CaCO3	783.2 ± 30.0	789.3 ± 41.5	948.8 ± 178.2
SB3 Cortical Bone	1181.7 ± 46.3	1197.6 ± 72.8	1439.0 ± 272.6
Mean Error (HU)	7.6 ± 11.6	7.0 ± 11.0	N/A
Average SD (HU)	13.5 ± 10.9	17.6 ± 17.3	56.2 ± 85.6



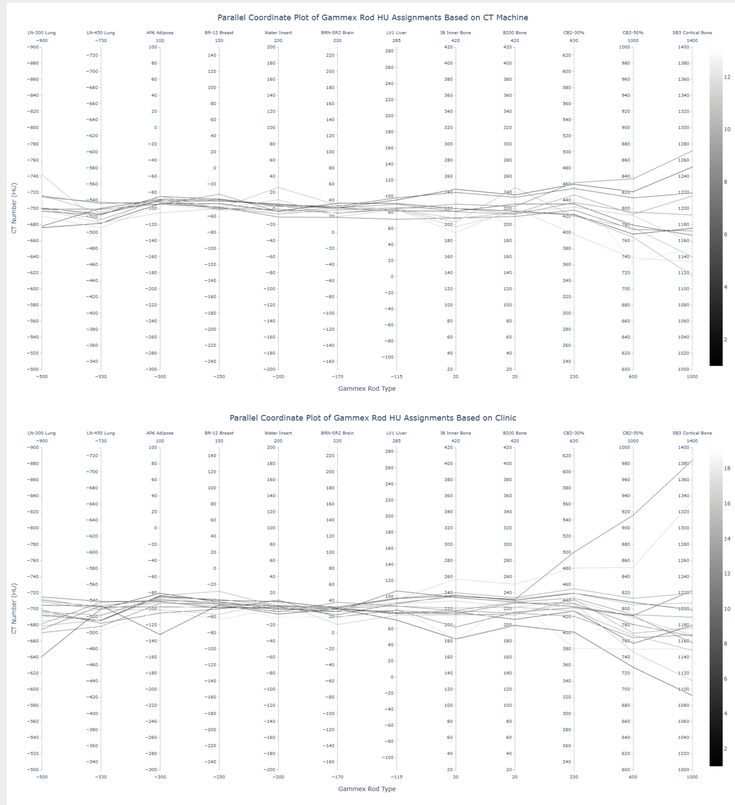


Figure 3. (Top) A table summarizing statistical analysis of dataset. (Bottom) CT Number as a function of scan energy plot. (Right) Two parallel coordinate plots evaluating variability in CT Number for machine type (top) and clinic type (bottom).

RESULTS

Data blending and statistical analysis revealed greater HU deviation with increasing distance from 0 HU (CT calibration baseline). High-density (HD) materials (>400 HU) showed the largest variability across parameters. It was also observed that the scans for each parameter were generally more accurate than reproducible.

Key Observations:

- **Scan Energy**: Average SD across all plugs (56.2 HU) was ~73.2% higher compared to other scan parameters. B200 Bone Mineral, CB2-30%, CB2-50%, and SB3 Cortical Bone Gammex phantom rods scanned with 80 kVp and 100 kVp tube energies exhibited the most deviation in HD region.
- **Clinic & Machine**: Deviations are relatively minimal, but it can be observed that individual clinics demonstrated a larger deviation among HU assignments (17.6 HU) compared to machine type (13.5 HU). Mean error was approximately the same for both parameters (7.6 HU ~ 7.0 HU).
- **Reproducibility and Accuracy Near 0 HU:** Structures with HU values in the range -700 HU to 400 HU showed high reproducibility and accuracy regardless of scan parameter for 120 kVp. Average SD across all parameters = 9.6 ± 9.4 HU and Average Mean Error across all parameters = 8.0 ± 12.2 HU.
- **Reproducibility and Accuracy Beyond -700 HU to 400 HU Range**: For CB2-30%, CB2-50%, and SB3 Cortical Bone Gammex phantom rods, a noticeable decrease in reproducibility was observed. Average SD across all scan parameters = 73.4 ± 76.7 HU and Average Mean Error across all scan parameters = 8.9 ± 8.7 HU; however, most SD was caused by scan energy across all parameters.

DISCUSSION AND CONCLUSIONS

The current analysis suggests support for consistent CT scan reproducibility and accuracy regardless of machine type or clinic, especially within the -700 HU to 400 HU range, for a 120 kVp scan energy. Beyond 400 HU, visual deviations in HU assignment for machine type and clinic were observed. Such deviations and their explanations for HD materials are common in the literature.[3] However, the underlying cause(s) of the deviations present in this current analysis are unclear.

It was also observed that the CT Number was relatively consistent across scan energies, until reaching ~200 HU, just before the threshold for HD structures. Deviations in scan energy may be explained by the relationship between scan energy and mass attenuation coefficient.[3]

Future directions of this analysis include:

- Expanding limited data set to reinforce suggested results and outlined data trends.
- Consideration of other scan parameters' (e.g. metal artifact reduction algorithm, reconstruction kernel, FOV, slice thickness, scan protocol, etc.) impact on CT scan reproducibility and accuracy.
- Application of relevant statistical analysis schemes to construct independent accuracy and variability metrics for individual parameters present in the dataset.

REFERENCES

1. L.E. Romans, *Computed Tomography for Technologists (A Comprehensive Text)*, 1st Edition (Wolters Kluwer Health | Lippincott Williams & Wilkins, 2011).
2. Gammex, Tissue Characterization Phantom Model 467 User's Guide, 1st Edition (Gammex, 2004).
3. J. T. Bushberg, J. A. Seibert, E. M. Leidholdt Jr., and J. M. Boone, *The Essential Physics of Medical Imaging*, 3rd. ed. (Lippincott Williams & Wilkins, Philadelphia etc., 2012).

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