2026 JULY 19–22 VANCOUVER, BC
JOINT AAPM | COMP MEETING

Post-Treatment Dosimetry Following Yttrium-90 Radioembolization: A Clinical Comparison of Nuclear Medicine and CT-Based Approaches

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ABSTRACT

Purpose: Present interim dosimetry analysis from a prospective, multi-center study (NCT05953337) comparing the mean absorbed dose (D_{mean}) derived from nuclear medicine (NM) and CT imaging of liver cancer patients undergoing yttrium-90-radioembolization (^{90}Y-RE) with radiopaque Eye90 microspheres®.

Methods: Twenty-seven patients were treated with Eye90 microspheres. Post-treatment, patients were imaged with CT and NM (SPECT [n=9], PET [n=18]) to measure the absorbed dose to the perfused volume (PV) and tumor (T). In NM-based dosimetry, D_{mean} was calculated using voxel S-values for PET and the local deposition method for SPECT. For CT, D_{mean} was calculated through calibration phantom analysis and convolution with a dose-voxel kernel. D_{mean} was compared using linear regression and Bland-Altman analysis. Correlation coefficients, percent difference ± standard error (bias), and 95% limits of agreement (precision) between D_{mean} are reported. For PV, D_{mean} was also compared to a ground truth, single compartment MIRD-based D_{mean}.

Results: When comparing D_{mean} from CT- and NM-based dosimetry to the MIRD-based D_{mean}, CT demonstrates significantly improved agreement. There is a very strong correlation between CT- and MIRD-based D_{mean} to PV (R^2=0.96). In NM, the correlation was far weaker (R^2=0.56). The MIRD-based D_{mean} was generally greater than both CT- or NM-based D_{mean}, particularly NM. For CT, bias and precision were 44±13% and 64%, respectively. For NM, bias and precision were 70±16% and 78%. When comparing D_{mean} between CT and NM, there was a moderate correlation between for PV (R^2=0.57) and a weak correlation for T (R^2=0.36). D_{mean} was generally greater in CT-based dosimetry relative to NM. For PV, bias and precision were 31±19% and 94%, respectively. For T, bias and precision were 10±21% and 104%.

Conclusion: For PV, CT-based dosimetry revealed that D_{mean} maintained a significantly stronger correlation with the MIRD-based D_{mean}, relative to NM. CT-based dosimetry had a reduced bias and improved precision relative to NM-based dosimetry.

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INTRODUCTION

Yttrium-90 (^{90}Y) radioembolization (RE) is a radiation-based embolic therapy where ^{90}Y-labeled microspheres are administered into the hepatic arterial vasculature to preferentially target liver tumours while sparing the surrounding liver parenchyma. Post-procedure nuclear medicine (NM) imaging (i.e., PET and SPECT) can provide reasonably reliable estimates of the mean absorbed dose (D_{mean}) but are limited in accuracy by poor noise and spatial resolution characteristics. CT imaging of radiopaque ^{90}Y microspheres (Eye90 microspheres®) may significantly improve dosimetry estimates due to its improved image quality.

METHODS AND MATERIALS

D_{mean} to the perfused liver volume (PV) was calculated for CT and NM-based imaging and compared to a MIRD-based ground truth using linear regression and Bland-Altman analysis. In MIM Software, D_{mean} was calculated using voxel S-values for PET and the local deposition method for SPECT.[1] For CT-based dosimetry, D_{mean} was calculated using an Eye90 calibration phantom and convolution of the subsequent activity distribution with a ^{90}Y dose voxel kernel.[2]

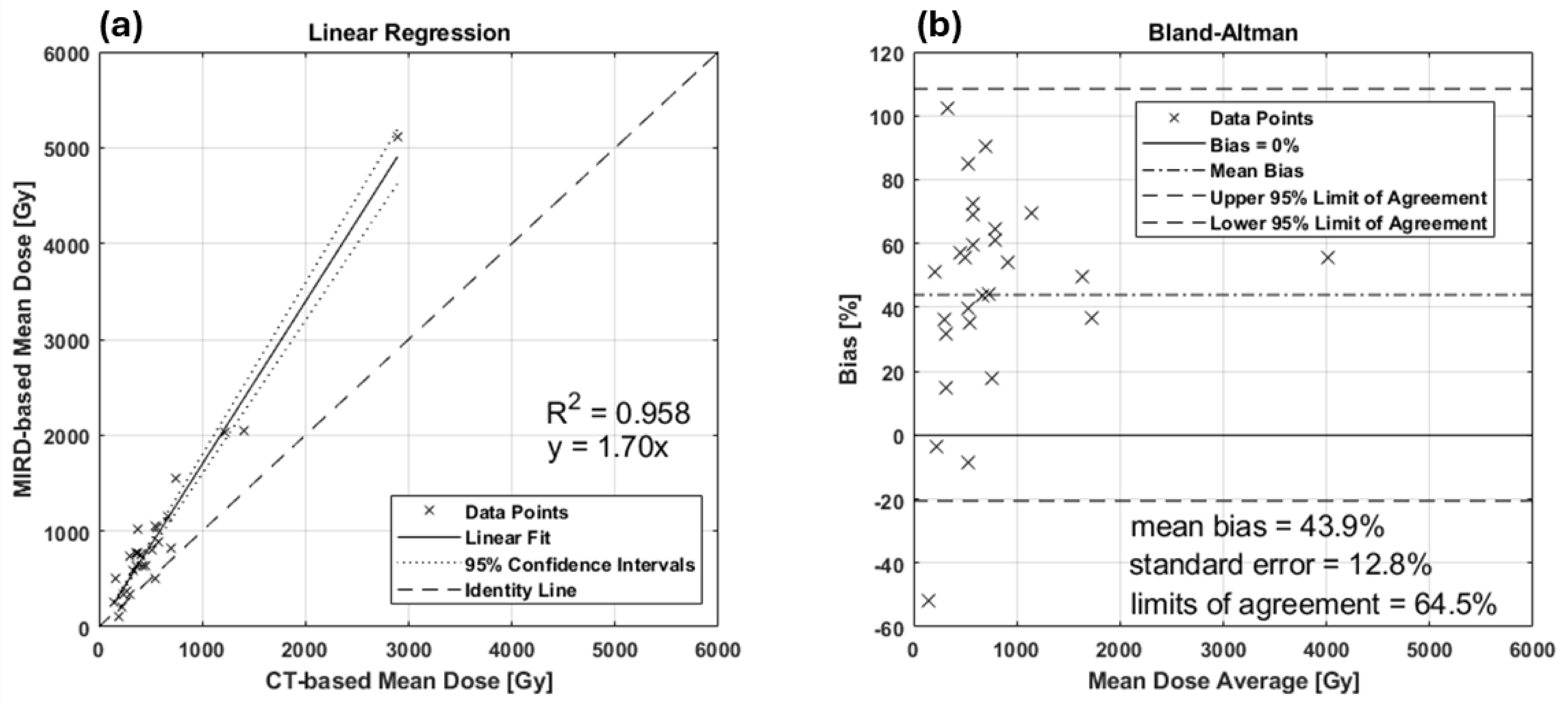

Figure 1. Dosimetry comparison for the perfused liver volume. (a) Linear regression demonstrating the relationship between the MIRD-based mean dose and the CT-based mean dose. (b) Bland-Altman analysis on the average of the MIRD- and CT-based mean dose.

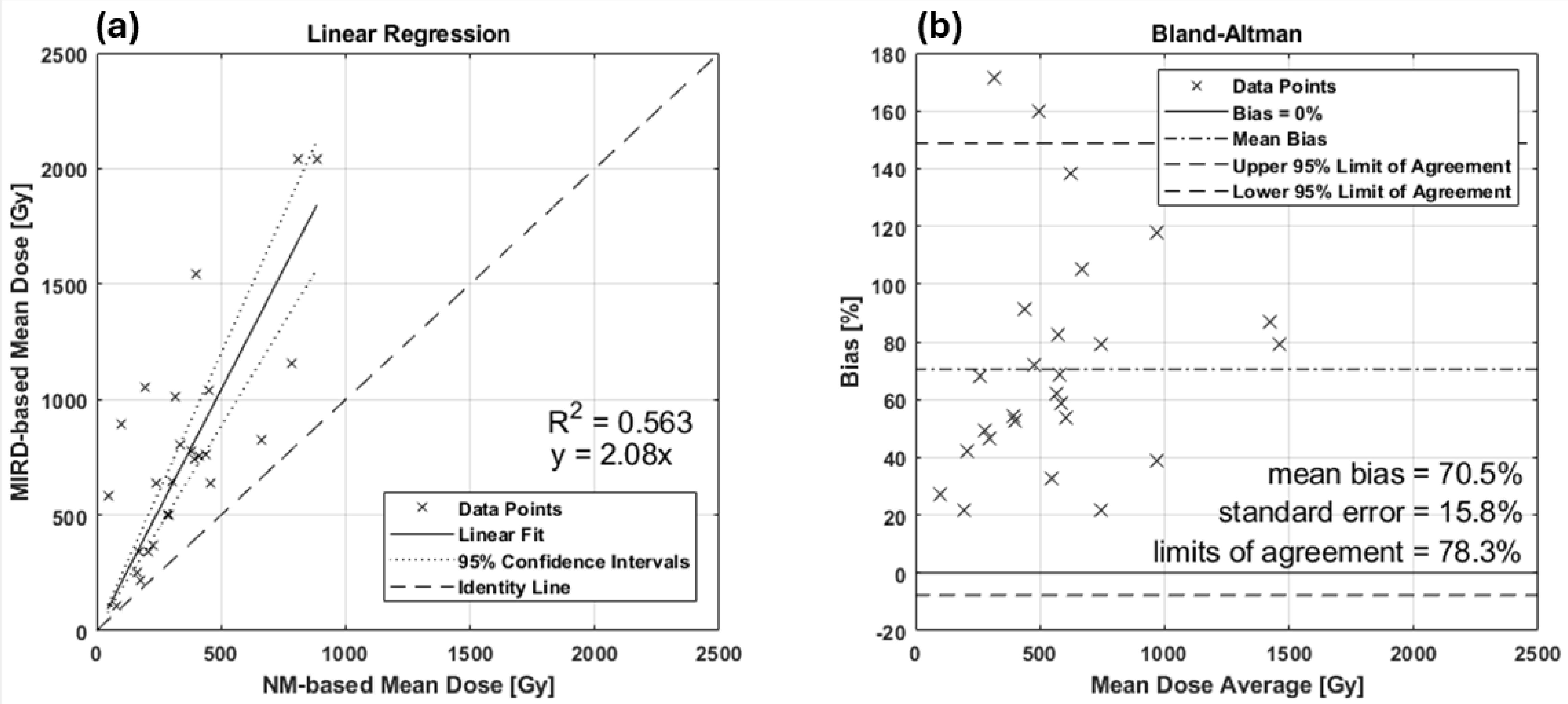

Figure 2. Dosimetry comparison for the perfused volume. (a) Linear regression demonstrating the relationship between the MIRD-based mean dose and the NM-based mean dose. (b) Bland-Altman analysis on the average of the MIRD- and NM-based mean dose.

RESULTS

Linear regression and Bland-Altman plots are provided in **Figure 1** for a CT-based D_{mean} comparison to a MIRD-based ground truth estimate of D_{mean} in PV. These plots are provided in **Figure 2** for a NM-based D_{mean} comparison to a MIRD-based D_{mean}. The data shows a very strong correlation between CT- and MIRD-based D_{mean} to PV (R^2=0.96). In NM, the correlation was far weaker (R^2=0.56). CT-based dosimetry also had a reduced bias and improved precision relative to NM-based dosimetry. **Figure 3** shows coronal images of the post-procedure CT fused with CT- and PET-based dose distributions. The CT-based dose is spatially correlated with the CT voxel enhancement from microsphere uptake. The PET-based dose distribution suggests regions outside of the tumour volume received a dose exceeding 1,000 Gy. This indication is false, however, and can be attributed to respiratory motion during image acquisition which 'smears' the ^{90}Y activity in the direction of respiratory motion.

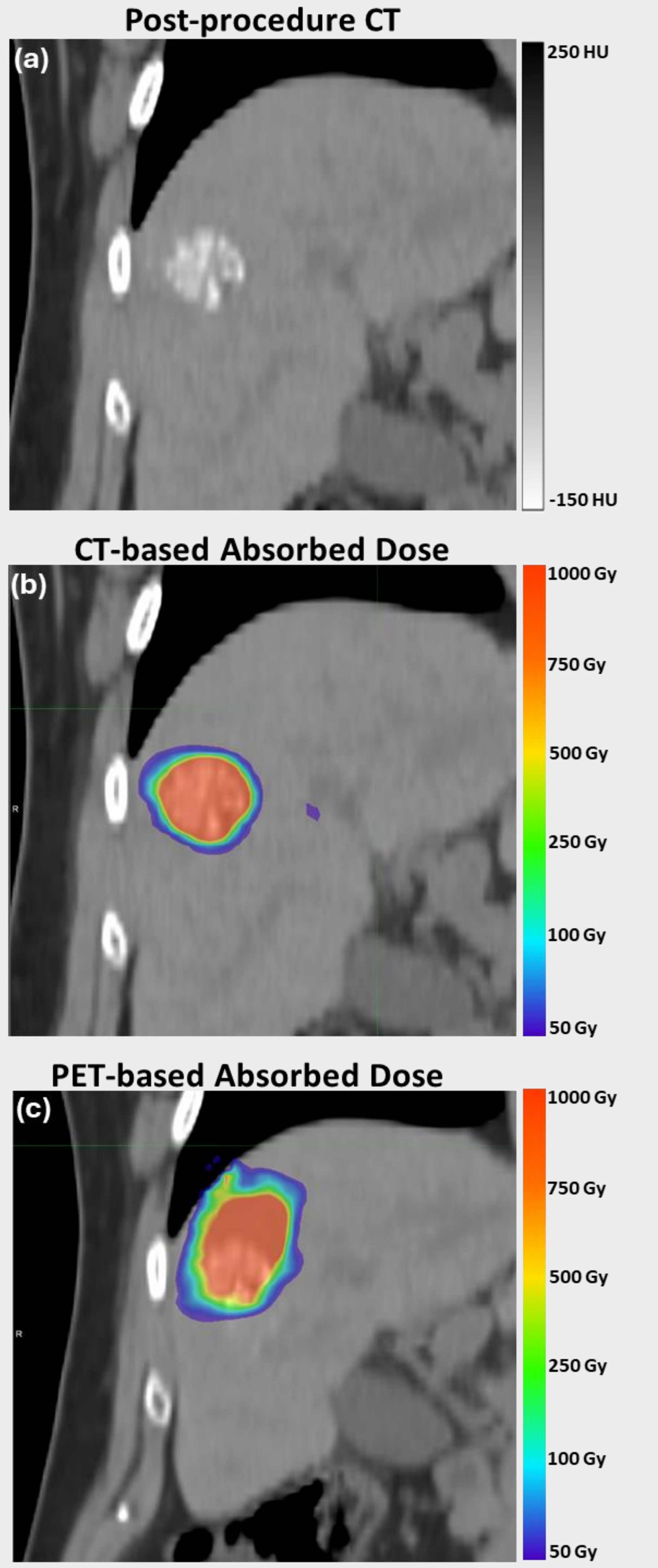

Figure 3. (a) Post-procedure CT showing Eye90 microsphere uptake in the tumour. (b) The post-procedure CT fused with the CT-based absorbed dose distribution. (c) The post-procedure CT fused with the PET-based absorbed dose distribution.

DISCUSSION

The benefits of a CT-based approach to post-treatment dosimetry in ^{90}Y-RE include improved visualization of the dose distribution, reduced partial volume effects, a better representation of dose heterogeneity, and the mitigation of respiratory motion effects. These benefits, relative to NM imaging, provide the means to perform precision dosimetry and extract more accurate dose metrics used to refine the understanding of the dose-response relationship, which could ultimately improve future patient outcomes.

CONCLUSIONS

CT-based dosimetry in ^{90}Y-RE revealed that D_{mean} to PV maintained a significantly stronger correlation with the MIRD-based D_{mean}, relative to NM. CT-based dosimetry also had a reduced bias and improved precision relative to NM-based dosimetry.

REFERENCES

1. Henry, E. Courtney, et al. Medical Physics 51.9 (2024): 6034-6045.
2. Henry, E. Courtney, et al. EJNMMI Physics 9.1 (2022): 21.