Uncertainty analysis of AI-generated contours for molecular radiotherapy dosimetry

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Objective

Absorbed dose calculations in molecular radiotherapy (MRT) dosimetry rely on *mass* and *energy* estimates which are impacted by contouring.

A method to calculate uncertainty in region localization using a deep learning contouring model (DLM) is proposed and compared to EANM guidelines.[1]

The effect of uncertainty on volume and activity estimates are calculated in a ^{177}Lu-DOTATATE case.[2]

Materials & Methods

- A DLM was pre-trained and fine-tuned on 22 PET/CT datasets to segment the liver, left kidney, right kidney and spleen (organs at risk [OARs]) on CT images.
- The DLM created activation maps indicating the presence of a tissue type at each voxel of the CT image.
- Results were assessed using SPECT/CT images at four time points (4TPs) of one patient from the SNMMI 2021 dosimetry challenge.[2]
- The DLM activation maps were used to create statistical shape models of uncertainty for the OARs that predicted region distribution for these organs on CT scans.
- Results were reviewed visually by a qualified radiographer.
- Uncertainty in volumes derived from the proposed AI pipeline were compared to the EANM guidelines.
- Volume uncertainties measured on CT were further propagated to the SPECT to calculate the corresponding distributions of Activity (MBq).

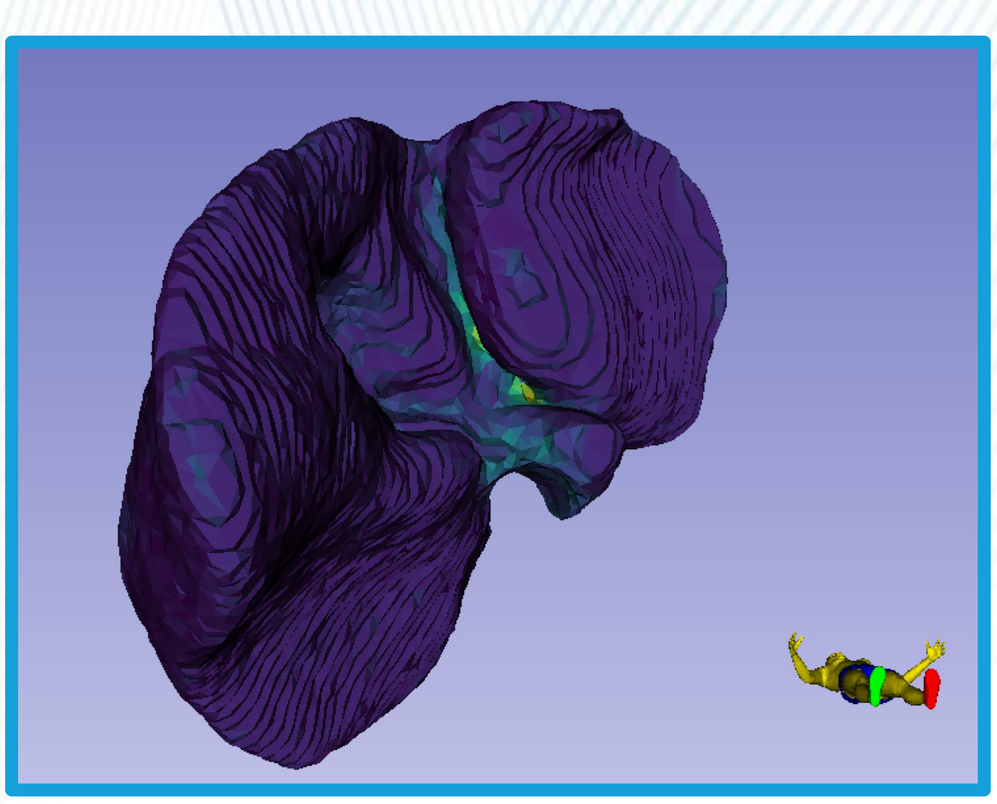

Figure 1: Mesh of the Liver with distance from 50% threshold to 95% threshold mesh. This scale is used to build a statistical model.

Results

- Qualitative assessment by the radiographer showed the uncertainty from the DLM was positively correlated with regions of ambiguity.
- Volumes of the OARs were seen to have a range of values (standard errors) over the 4TPs of 1983-2212 (29-36) ml, 240-260 (4.5-5.7) ml, 246-269 (2.8-6.0) ml and 241-295 (4.9-6.3) ml respectively.
- OARs were measured to have a coefficient of variation (COV) [%] of the volume over the 4TPs ranging from (1.5%-1.6%), (1.7%-2.1%), (1%-2.2%) and (1.8%-2.4%) respectively.
- The COV of volume calculated using the EANM analytical method were (0.61%-0.62%), (1.21%-1.23%), (1.21%-1.26%) and (1.18%-1.26%).
- The COV range for Activity over the 4TPs were (0.7%-1.3%), (1.6%-2.8%), (1.7%-2.5%), and (1.3%-2.1%).

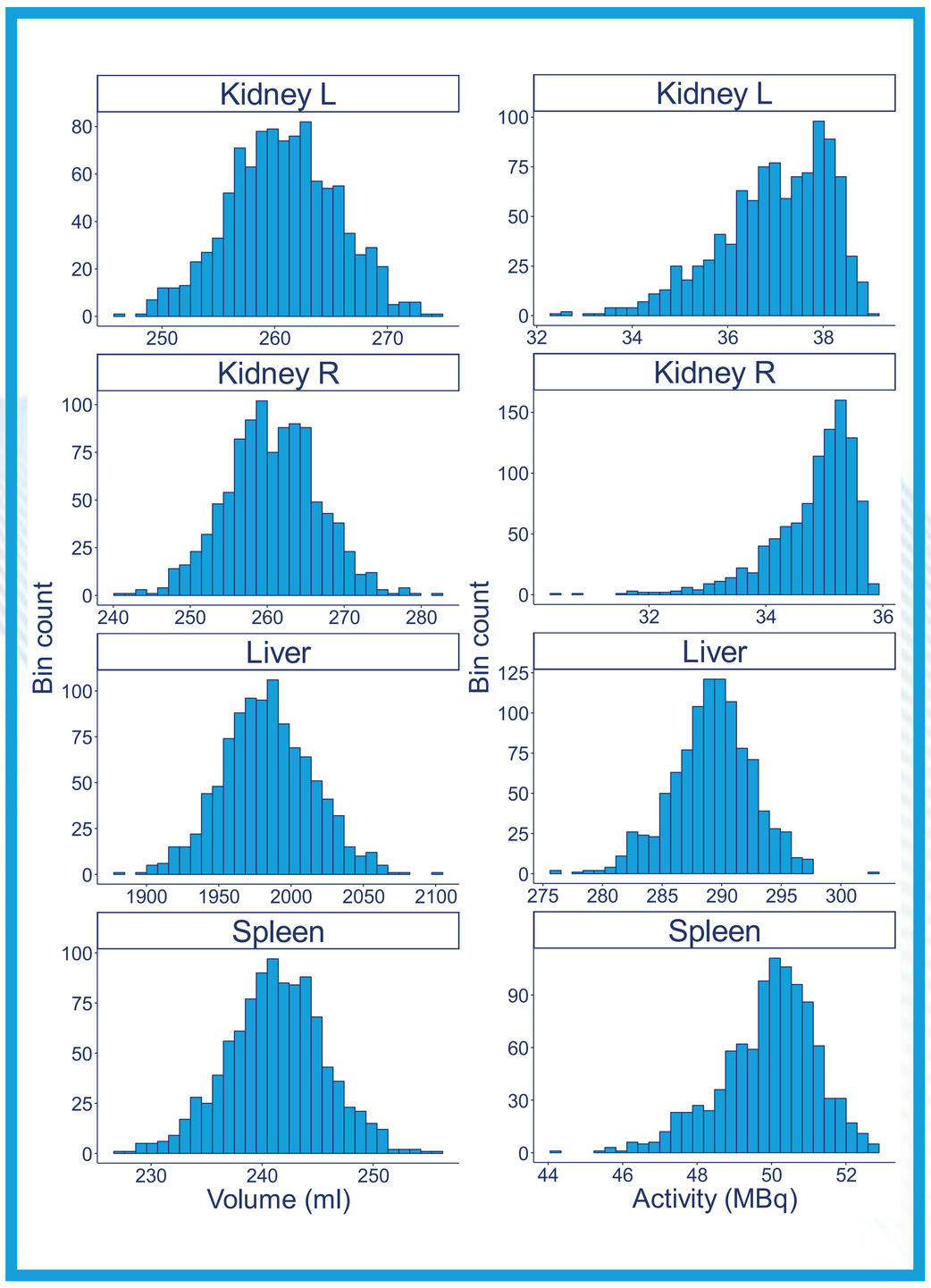

Figure 2: Histograms of the volumes (left) and activity (right) for the four structures for a single timepoint.

		Structures			
Timepoint	**Uncertainty measurement**	***Kidney L***	***Kidney R***	***Liver***	***Spleen***
1	COV	2.37	1.75	1.5	2.14
	COV EANM	1.26	1.26	0.61	1.2
2	COV	2.15	1.05	1.47	2.24
	COV EANM	1.27	1.22	0.62	1.18
3	COV	1.72	1.48	1.65	2.4
	COV EANM	1.23	1.25	0.6	1.23
4	COV	1.83	2.29	1.58	1.82
	COV EANM	1.23	1.23	0.63	1.26

Table 1: COV of the volume of four structures for each timepoint using the EANM method and our statistical DLM method

Conclusion

The localization uncertainty of OARs for MRT dosimetry was spatially inhomogeneous and the quantified uncertainty (COV) varied by OAR. Qualitatively, the uncertainty was low in regions with less ambiguity on the classification of voxels. Uncertainty from the EANM analytical approach was consistently lower than that using our approach.

The volume uncertainty measured using this DLM approach is still far smaller than that reported by Uribe et al.[2] Uncertainties calculated using a DLM will reflect variations in contouring technique in the training data, which is normally tightly controlled.

The uncertainty of localization of OARs combined with the inhomogeneity in Activity can result in shifts of Activity COV. The combined impact on absorbed dose estimates needs to be further evaluated.

References

1 Gear et al. (2018) doi: 10.1007/s00259-018-4136-7
2 Uribe et al. (2021) doi: 10.2967/jnumed.121.262748