Standardization of Lifetime Cumulative Dose Estimation for Re-Irradiated Patients Using Whole-Body Computational Phantoms

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Background

- Advances in radiation therapy have improved cancer survival, resulting in a growing number of patients receiving re-irradiation for recurrent disease or new primary tumors.
- Accurate assessment of lifetime cumulative dose to organs at risk (OARs) is critical for minimizing toxicity and guiding treatment decisions.
- We propose mapping patient dose distributions from multiple treatment courses onto standardized whole-body computational phantoms developed by the International Commission on Radiological Protection (ICRP).
- The ICRP phantom contains detailed representations of numerous OARs, enabling lifetime dose tracking across anatomies that extend beyond the field of view (FOV) of individual treatment-planning CT scans.
- This approach enables comprehensive lifetime dose accumulation within a common anatomical framework and may facilitate multi-institutional studies, toxicity modeling, and the development of standardized re-irradiation dose constraints.

Materials/Methods

- Synthetic CT datasets of the male and female ICRP reference phantoms were generated using the DICOMator extension in the graphics software Blender®.
- Hounsfield Unit (HU) values were assigned to each anatomical structure using tissue density and elemental composition data from ICRP Publication 145, followed by voxelization at 0.54 × 0.54 × 3.0 mm resolution.
- Dose distributions from a small cohort of thoracic re-irradiation patients were mapped onto the ICRP reference phantoms for preliminary evaluation in RayStation 2023B.

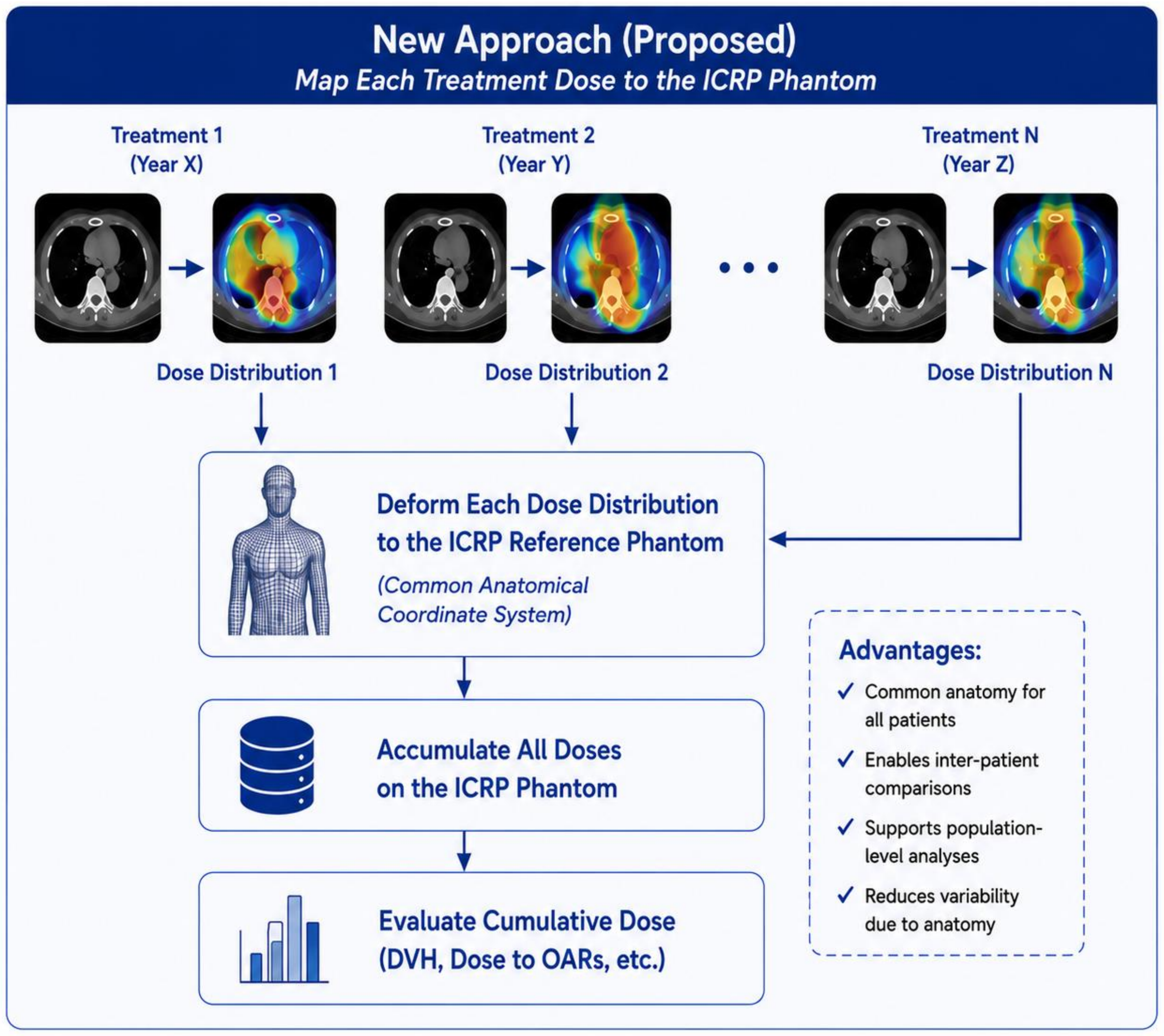
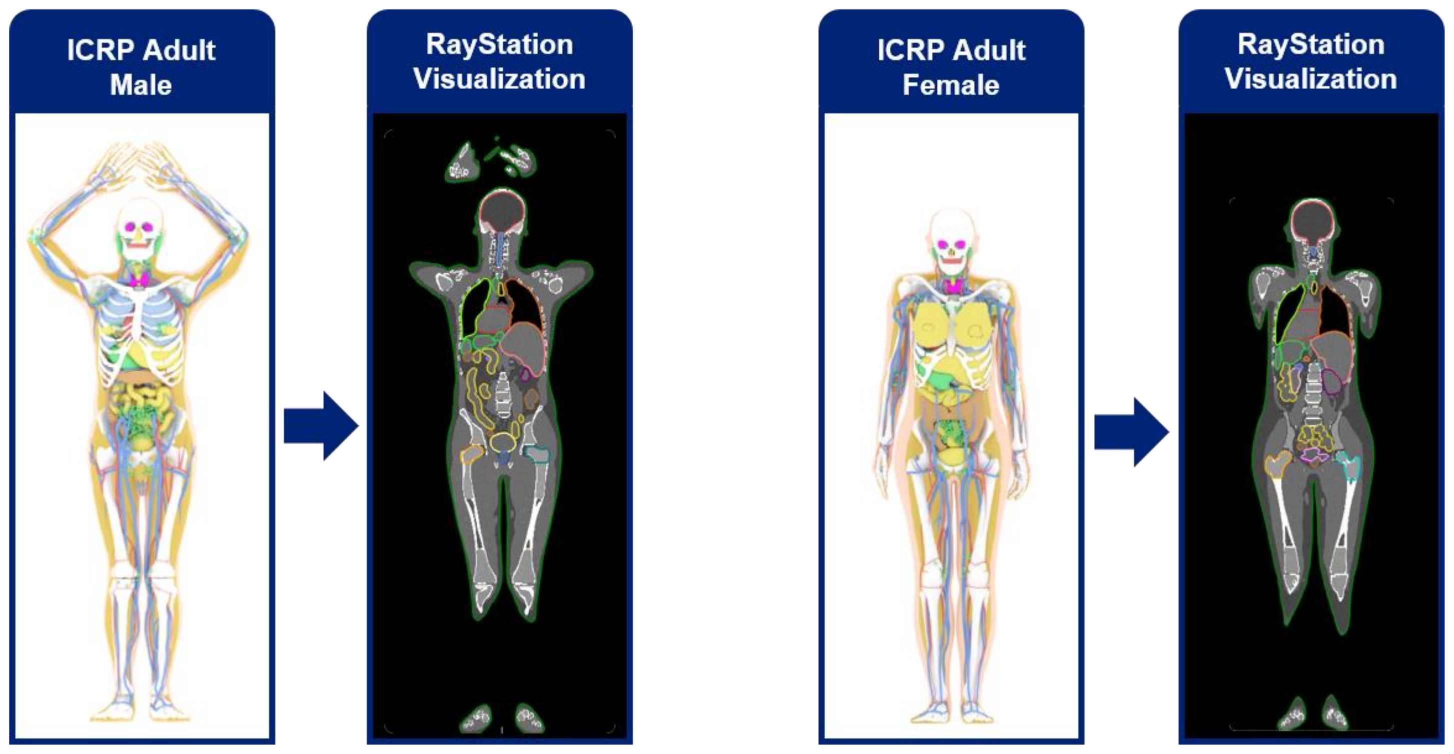


Figure 1. Proposed workflow for dose accumulation from multiple treatment courses onto a standard reference phantom model.

Results



List of Current OARs

Bladder	Right Breast
Brain	Right Femoral Head
Carina	Right Kidney
Colon	Right Lens
Esophagus	Right Lung
External	Salivary Glands
Gall Bladder	Small Intestine
Heart	Spinal Canal
Left Adrenal	Spleen
Left Breast	Sternum
Left Femoral Head	Stomach
Left Kidney	Thymus
Left Lens	Thyroid
Left Lung	Trachea
Liver	Left Ovary (Female)
Pancreas	Right Ovary (Female)
Pituitary	Uterus (Female)
Rectum	Prostate (Male)
Right Adrenal	Testes (Male)

Figure 2. Conversion of the ICRP reference male (arms-up) and female (arms-down) phantoms into synthetic CT datasets and their corresponding visualization within RayStation 2023B. The OARs currently contoured in each phantom are also shown.

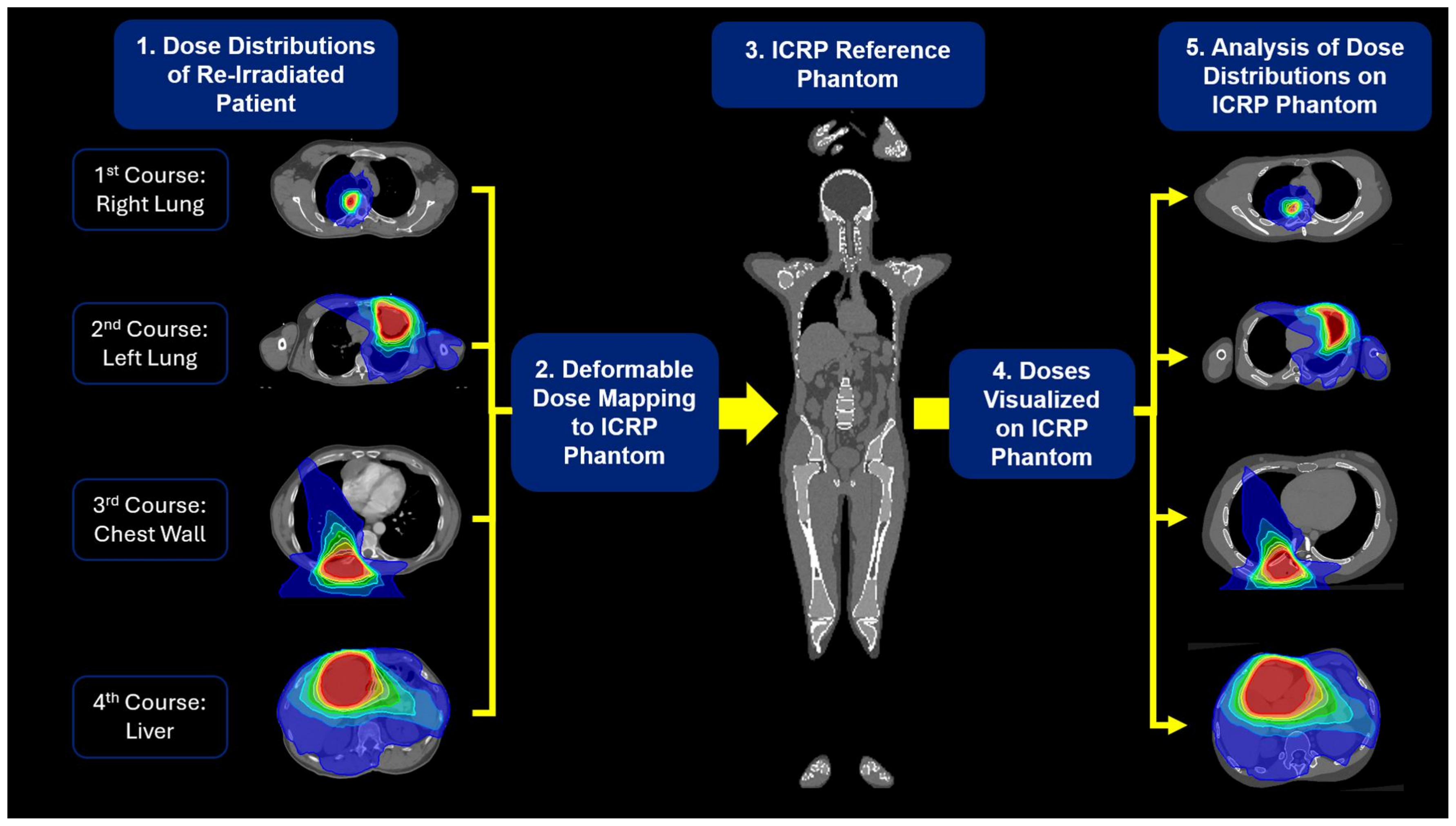
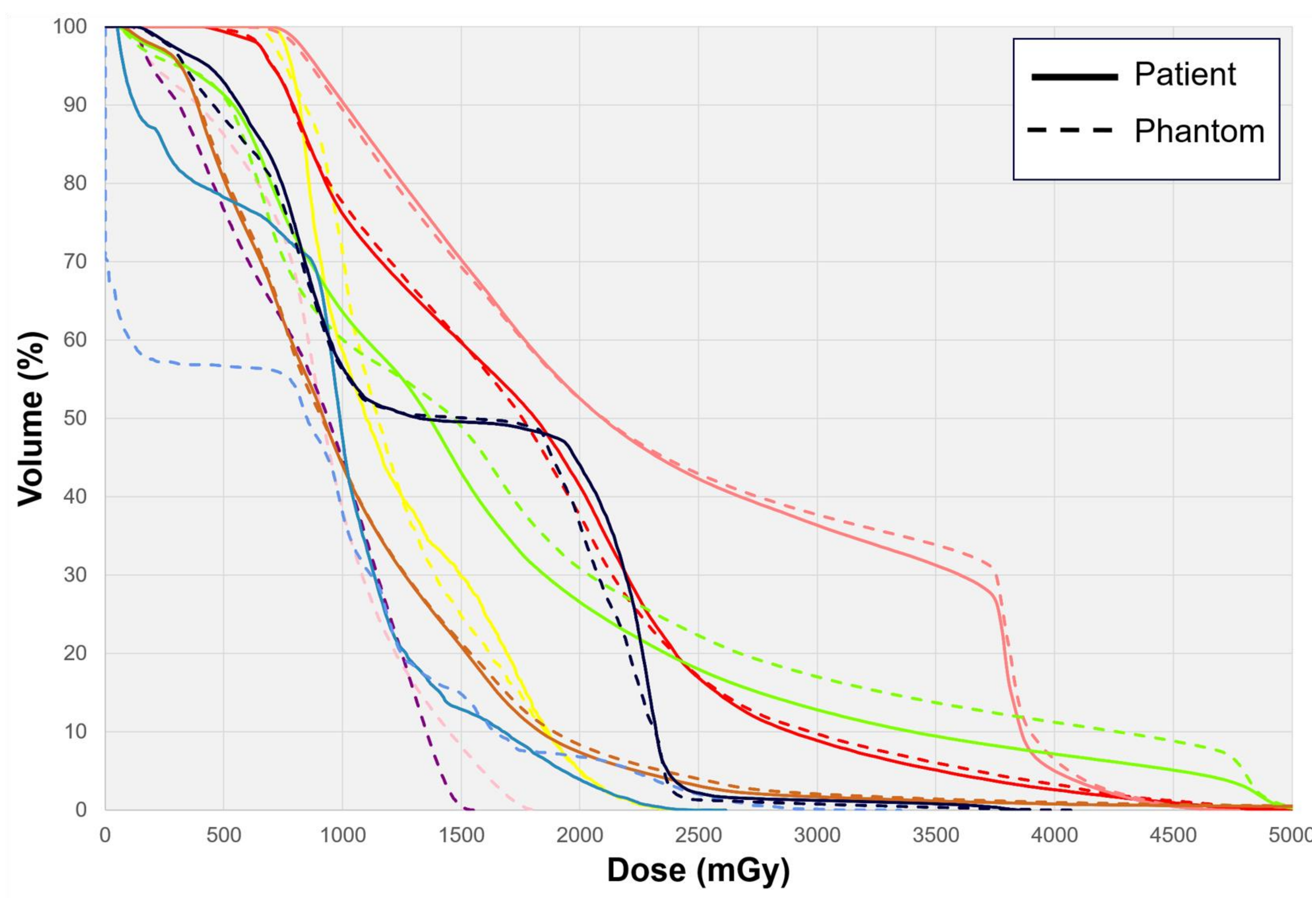


Figure 3. Deformable mapping of dose distributions from four radiotherapy courses delivered to a single patient onto the ICRP male reference phantom. The availability of both arms-up and arms-down phantom configurations enabled position-specific dose mapping, with the second treatment course mapped through the arms-down phantom before transformation to the common arms-up reference atlas. This approach allows for improved accuracy in dose accumulation across treatment courses acquired under differing patient setups.



DVH Metrics (mGy)	D99		Average		D1	
OARs	Patinet	Phantom	Patinet	Phantom	Patinet	Phantom
Carina	736	682	1243	1255	2225	2216
Heart	540	588	1811	1812	4477	4571
Left Kidney	-	131	-	924	-	1731
Right Kidney	-	131	-	856	-	1463
Liver	777	746	2408	2430	4396	4429
Left Lung	104	91	1636	1759	4912	4930
Right Lung	124	122	1063	1082	3711	3992
Spinal Canal	55	0	955	744	2244	2664
Sternum	205	195	1494	1439	3301	2779

Figure 4. Cumulative dose–volume histograms (DVH) for selected critical structures following dose accumulation on the patient's fourth CT scan and the ICRP reference phantom. Because both kidneys were outside the FOV of the patient CT, kidney dose could not be assessed, demonstrating the advantage of whole-body reference phantoms for comprehensive lifetime dose evaluation.

Conclusion

- A standardized phantom-based dose accumulation framework was developed to address the lack of consistent methods for estimating cumulative lifetime OAR dose in re-irradiation, enabling meaningful comparisons across patients, institutions, and treatment platforms.

References

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[2] Dawson RJ, Baggett JM, Dinwiddie LE, et al. The UF/MSK adult mesh-based computational human phantom library: applications to organ dosimetry in computed tomography. *Phys Med Biol*. 2025;70(23):10.1088/1361-6560/ae1dc5. Published 2025 Nov 21. doi:10.1088/1361-6560/ae1dc5