PTCOG-AO 2025
HONG KONG
NOV 7-9
PTCOG-AO

Theme: Physics
Abstract No: PTCOG-AO2025-ABS-0067
Abstract Title: Deep Learning-Based 4DCT Deformable Image Registration and Carbon-Ion 4D Dose Calculation

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Background / Aims:

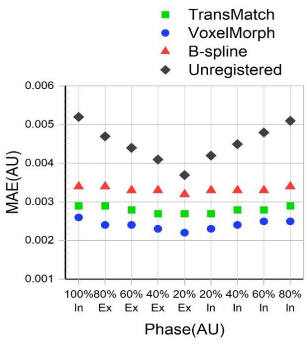
- Respiratory motion deforms anatomical structures and compromises dose accuracy in carbon-ion therapy.
- Deep learning–based deformable image registration (DIR) enables faster and more accurate motion quantification compared to conventional methods.
- This study applies **deep learning–based DIR** to **4DCT** registration and integrates the resulting deformation vector fields (DVFs) into **carbon-ion 4D dose calculations** to improve registration **speed** and **accuracy**.

Subjects and Methods:

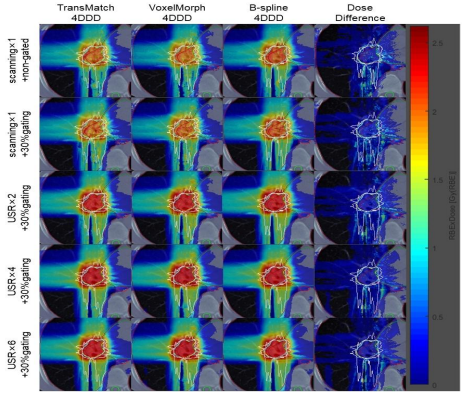
- A total of **150** clinical lung 4DCT datasets were collected, with 120 for training, 20 for validation, and 10 for testing.
- Two deep learning-based DIR models, **TransMatch** and **VoxelMorph**, were used for registration and compared with the conventional **B-spline** DIR method.
- Registration performance was evaluated using **MAE**, **DVF** magnitude, and **runtime**.
- The resulting **DVFs** were applied to **carbon-ion 4D dose calculations** for further comparison.

Result:

- In terms of **registration accuracy**, the average MAE between warped and fixed images was **0.0036 for VoxelMorph**, **0.0039 for TransMatch**, and **0.0045 for B-spline**, indicating that both deep learning models achieved higher accuracy than the conventional method.
- For **registration speed**, **VoxelMorph averaged ~0.3 s**, **TransMatch ~1.2 s**, and **B-spline ~771 s** per image pair, demonstrating that deep learning models improved efficiency by nearly three orders of magnitude.
- In **carbon-ion 4D dose calculations**, the choice of registration method significantly **affected** the final dose distribution under different motion scenarios.



Registration accuracy comparison



Carbon-ion 4D dose calculation results