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MASSACHUSETTS GENERAL HOSPITAL | RADIATION ONCOLOGY

Using TG-132 digital phantoms to compare registration results between the MIM Maestro™ and Raystation™ systems

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INTRODUCTION

- ❑ AAPM Task Group 132 published their report on quality assurance for image registration algorithms in May 2017[1]
  - Online resources included digital phantoms to assist in performing QA tests outlined in the report
- ❑ Physicists recommended to implement TG-132 for all of their clinical registration systems
  - Some vendors provide resources[2] to assist users
  - Most systems have built-in analysis tools for QA

AIMS

- ❑ Learn about registration options and commissioning tools for our systems: MIM Maestro 6.7[3,4] & Raystation 5.0[5]
- ❑ Implement TG-132 recommended QA in both systems
  - Compare rigid registration results with expected
  - Compare deformable registration results between the systems using available metrics
- ❑ Gain better understanding of the operation and limitations of registration software in clinical use

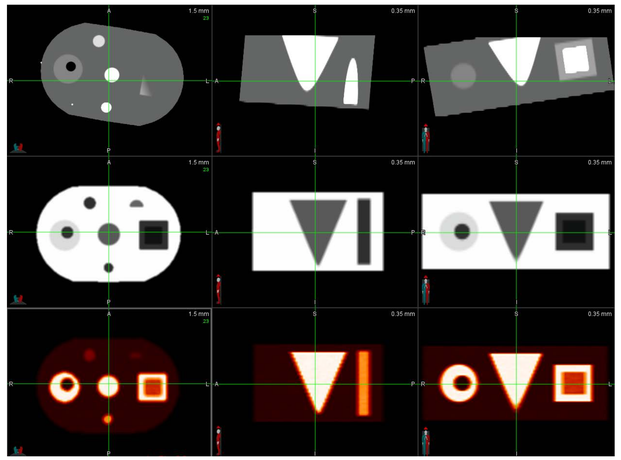
METHOD

- ❑ **TG-132 virtual phantoms were downloaded & imported**
  - Geometric phantom with 5 modalities (CT, T1/T2-MR, PET, CBCT) and known offsets, translation and rotation
  - Anatomic pelvis phantom: 4 modalities with known offsets (CT, T1/T2-MR, PET) and one deformed CBCT
  - Two 4D-CT inhale (0%) and exhale (50%) phases
- ❑ **Additional resources:**
  - POPI data[6]: Five 4D-CT lung images with 100 landmarks
  - Pukala data[7]: 10 H&N start and end of treatment CTs
    - Deformation vector field (DVF) available for purchase
- ❑ **Rigid registrations:**
  - Compare registration results to known offsets
  - Raystation: perform with and without external contour
- ❑ **Deformable registrations:**
  - If DVF available, compare deformation voxel-by-voxel
  - If landmark points available, compute target registration error (TRE) for those points
  - If contours available, compute Dice Similarity Coefficient (DSC) and contour centroid TRE
- ❑ **Compare results obtained on same images between MIM and Raystation**

RESULTS – RIGID

- ❑ TG-132 recommended criteria is error < 0.5*voxel dimension
  - Translation only: both systems failed criteria for CT-to-PET
  - Translation and rotation: MIM failed criteria for all modalities, Raystation failed criteria only for CT-to-PET registration
    - Rotations in MIM off by ~1°, causing larger translation errors
  - Using external contours in Raystation to guide registration gave worse results for intermodality registrations
    - External contour generation relies on intensity levels and may be less accurate for non-CT images
- ❑ Sample of results shown in table below, where Raystation results are for registration without external contours

Reference Image	Target Image	MIM Error (mm)			Ray Error (mm)		
		x	y	z	x	y	z
CT	CT	0.15	-0.08	-0.01	-0.1	-0.2	0.0
CT	T2 MR	-0.35	0.41	-0.06	-0.3	-0.5	-0.4
CT	PET	-0.93	1.07	-0.63	-1.1	-1.3	-0.4
rotated CT	CT	0.07	2.13	-2.09	-0.1	0.2	0.1
rotated CT	T2 MR	-0.34	2.81	-2.00	-0.3	-0.2	-0.8
rotated CT	PET	-1.32	3.24	-1.87	-1.4	-0.7	-0.7



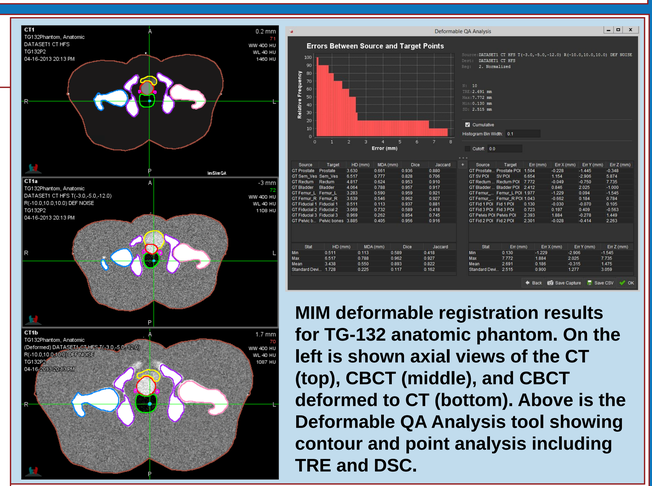
TG-132 geometric phantoms, axial, sagittal and coronal views. On top is the rotated CT phantom, middle is T2 MR, and bottom is PET (shown in MIM system). All images have voxel size 0.7 x 0.7 x 3 mm³.

RESULTS – DEFORMABLE

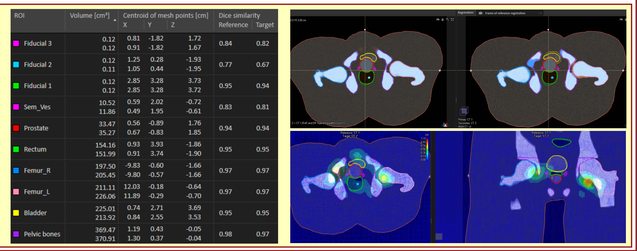
- ❑ DVF not freely available for any of the available data
  - H&N DVFs available through Oncology Systems Ltd (OSL)
  - TG-132 phantom DVF available but in OSL proprietary format
- ❑ Manually contoured organs on TG-132 images to compute DSC
- ❑ Used POPI data with landmarks for TRE analysis
  - Deformed 50% (exhale) to 0% (inhale) phase, and reverse
- ❑ Both systems have tools to assist with deformable registration QA
  - MIM tools are quantitative: given a set of reference points or contours, calculates either TRE or DSC, Hausdorff distance, Mean Distance to Agreement, and Jaccard distance
  - Raystation provides excellent visualization of DVF, but quantitative tools not as well developed as MIM
    - DSC calculated for contours; TRE calculated but incorrectly
    - More detailed information available through Python scripting
- ❑ Both systems performed similarly as shown in the table below

Reference Image	Target Image	MIM TRE	Ray TRE	MIM DSC	Ray DSC
TG-132 anatomic	TG-132 deformed	2.7 ± 2.5	2.0 ± 1.4	0.89 ± 0.12	0.90 ± 0.10
POPI 50%	POPI 0%	1.1 ± 1.2	1.7 ± 1.5		
POPI 0%	POPI 50%	1.1 ± 1.1	1.4 ± 1.2		

Raystation deformable registration results for TG-132 anatomic phantom. Displays are of a side-by-side comparison of deformable (top left) and rigid registration (top right), and axial and coronal heat maps of the DVF, showing largest deformation around the femurs. Also shown is the ROI Geometry Statistics tool, providing contour centroids and DSC.



MIM deformable registration results for TG-132 anatomic phantom. On the left is shown axial views of the CT (top), CBCT (middle), and CBCT deformed to CT (bottom). Above is the Deformable QA Analysis tool showing contour and point analysis including TRE and DSC.



CONCLUSIONS

- ❑ TG-132 phantoms for rigid registration easy to use
  - But no guidance on how to interpret a failed test
- ❑ TG-132 deformation phantoms less useful without DVF
  - MIM handles DVF in DICOM format, but Raystation does not import or export DVF in DICOM format
    - Manual contours simplest way to judge performance
  - POPI data with landmarks was useful and easy to use
  - All deformable phantoms tested CT-CT or CT-CBCT, no phantoms for intermodality deformable registration
- ❑ User education improved registration results
  - Learning about specific tools and options for guiding and evaluating the deformation improved registration results in both systems for this user
- ❑ May be challenging for a solo physicist in a small clinic to implement TG-132 for their registration systems
  - Still helpful to go through the exercises to increase awareness of system options and limitations

REFERENCES

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