Comparison of Contour-based, Image-based, and Contour-image-based Deformable Image Registration for Adaptive Re-planning

Kristofer KAINZ, Hualiang ZHONG, An TAI, Ergun AHUNBAY, and X. Allen LI

Department of Radiation Oncology, Medical College of Wisconsin, Milwaukee, WI 53226

JULY 12–16 2020 VIRTUAL JOINT AAPM | COMP MEETING
EASTERN TIME [GMT-4]

INTRODUCTION

- Adaptive-planning in the middle of the treatment course is a common clinical continency.
- Accurate deformable image registration (DIR) between the original-plan and re-plan images is essential for accurate region-of-interest (ROI) dose summation.
- The Jacobian determinant is a measure of DIR performance interior to the ROI, and the mean distance to agreement (MDA) and Dice similarity coefficient (DSC) both assess DIR performance along the ROI boundary.

PURPOSE

We compare deformable image registration techniques based upon contours only (C-DIR), image features only (I-DIR), and contours and images combined (CI-DIR), and determine which techniques are expected to provide reliable region-of-interest dose summation for adaptive re-planning.

METHODS

- Analyses were performed using original-plan and re-plan kVCT images from previously-treated pelvis cases with clinician-drawn ROIs on both sets.
- All DIRs were performed with preliminary rigid registration (RR) using a commercial DIR tool (MIM Software Inc., Cleveland, OH).
- For C-DIR and CI-DIR, the constraining ROIs were the bladder, colon, rectum, and small bowel.
- DIR quality assurance (QA) metrics included ROI Jacobian determinant (JD) distributions, along with changes in mean distance-to-agreement (ΔMDA) and Dice similarity coefficient (ΔDSC) relative to RR alone.
- ΔMDA < 0 and ΔDSC > 0 indicate improvement in DIR over RR alone.
- Lower standard deviation of JD (σ_J) within the ROI suggests more reliable dose summation interior to the ROI.
- MDA and DSC measure registration accuracy along the ROI boundary, and thus indicate the reliability of ROI maximum dose calculation.

CONTACT INFORMATION

Kristofer Kainz, PhD / kkainz@mcw.edu / 414-805-9761

RESULTS

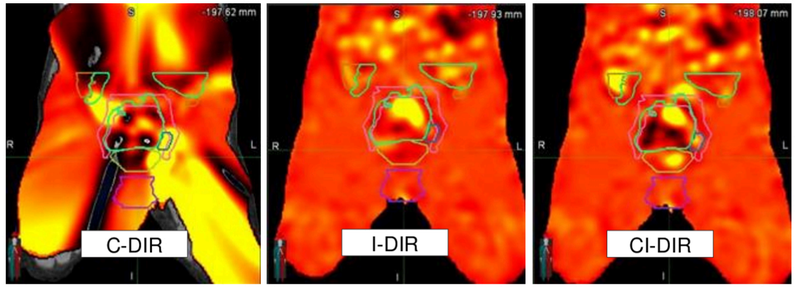

Figure 1: *shown for a pelvis patient are coronal projections of the Jacobian determinant (JD) map resulting from contour-based registration alone (C-DIR), image-based registration alone (I-DIR), and using both the constraining contours and image features (CI-DIR). All DIRs were performed using the MIM software. Orange regions indicate JD ≈ 1, yellow indicates JD > 1, and black indicates JD < 1. The colon and small bowel ROIs were edited so that the superior borders were aligned between the original-plan and re-plan kVCT images following rigid registration. The I-DIR and CI-DIR techniques exhibit less variation in JD throughout the image volume. One explanation for this is that the C-DIR algorithm, in optimizing registration along the surfaces of the constraining ROIs, allows large voxel displacements both exterior and interior to the constraining ROIs.*

Table 1: *for the pelvis patient depicted in Figure 1, and for each ROI considered, summarized for the C-DIR, I-DIR, and CI-DIR techniques are the standard deviation of JD within the ROI (σ_J), difference in mean distance to agreement between DIR and rigid registration alone (ΔMDA), and difference in Dice similarity coefficient between DIR and rigid registration alone (ΔDSC). ROIs utilized in C-DIR and CI-DIR are indicated in blue. σ_J is lower for I-DIR (p=0.0006) and CI-DIR (p=0.0002). For C-DIR, ΔMDA < 0 and ΔDSC > 0 (indicating improved ROI boundary mapping over rigid registration) for constraining ROIs; however, ΔMDA > 0 for all non-constraining ROIs except the mesorectum and sigmoid, and ΔDSC < 0 for all non-constraining ROIs except the mesorectum. For I-DIR and CI-DIR techniques, ΔMDA < 0 and ΔDSC > 0 for all ROIs.*

ROI	σ_J			ΔMDA (mm)			ΔDSC		
	C-DIR	I-DIR	CI-DIR	C-DIR	I-DIR	CI-DIR	C-DIR	I-DIR	CI-DIR
anus	1.02	0.31	0.32	12.835	-6.308	-4.357	-0.592	0.412	0.287
bladder	1.46	0.30	0.36	-6.997	-5.361	-6.670	0.326	0.296	0.311
colon	1.40	0.38	0.77	-2.456	-2.396	-2.653	0.142	0.275	0.189
L inguinal LN	0.58	0.09	0.11	16.834	-1.896	-1.358	-0.790	0.146	0.104
mesorectum	1.41	0.46	0.62	-2.116	-5.319	-3.102	0.144	0.433	0.211
pelvic LN	1.05	0.36	0.47	1.433	-2.624	-1.129	-0.088	0.172	0.060
R inguinal LN	0.39	0.08	0.08	11.676	-1.540	-0.608	-0.614	0.118	0.047
rectum	1.68	0.56	0.69	-5.895	-7.860	-8.227	0.397	0.621	0.580
sigmoid	0.75	0.96	0.79	-2.416	-2.566	-4.703	-0.004	0.240	0.184
small bowel	0.65	0.49	0.42	-3.741	-3.548	-3.897	0.290	0.180	0.299
vulva	0.86	0.20	0.19	10.637	-1.875	-1.176	-0.518	0.147	0.081

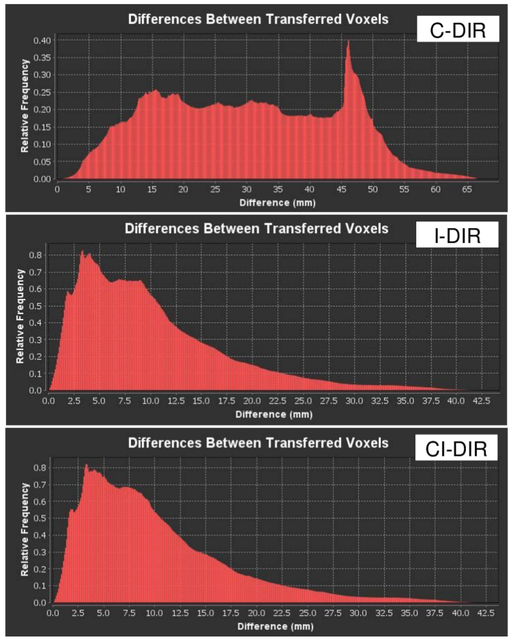

Figure 2: *shown for the patient depicted in Figure 1 are distributions of the distance displacements of all voxels in the moving image of the DIR, for C-DIR (top), I-DIR (middle), and CI-DIR (bottom). Note the overall increased displacement among voxels for C-DIR relative to I-DIR and CI-DIR; the distribution of distance differences between transferred voxels was μ = 31 mm and σ = 15 mm for C-DIR, compared with μ = 12 mm and σ = 7 mm for the I-DIR technique and μ = 13 mm and σ = 7 mm for the CI-DIR technique.*

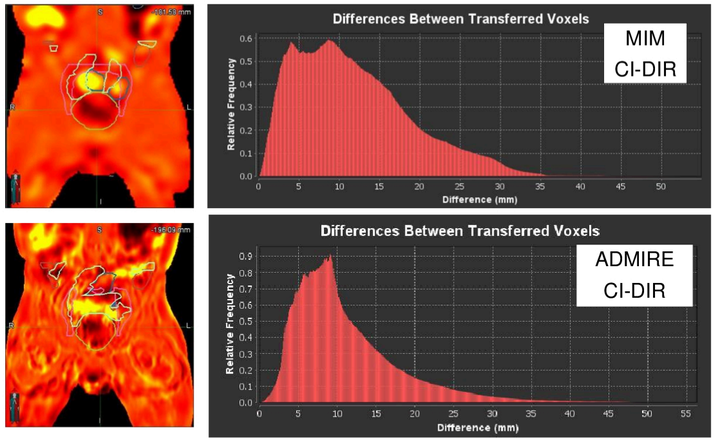

Figure 3: *shown for a different pelvis case are the Jacobian distributions and voxel displacement distance histograms for two different CI-DIR algorithms: the registration in the top frame used the MIM software, and the bottom frame used the ADMIRE software (Elekta, Inc.). Although ADMIRE apparently exhibits more local deformations within the JD map, the mean and standard deviation of the voxel displacements are similar; μ and σ are approximately 13 mm and 7 mm for MIM CI-DIR, and approximately 11 mm and 7 mm for ADMIRE CI-DIR.*

CONCLUSIONS

- C-DIR exhibits large JD variations (high σ_J) throughout the imaged volume; σ_J is smaller for I-DIR and CI-DIR. This suggests that I-DIR and CI-DIR exhibit less severe deformations within the ROIs and are thus expected to lead to better ROI dose summation.
- ΔMDA < 0 for only the constraining ROIs, mesorectum, and sigmoid for C-DIR, whereas for I-DIR and CI-DIR ΔMDA < 0 for all ROIs considered.
- For C-DIR, ΔDSC > 0 for only the constraining ROIs and mesorectum, whereas for I-DIR and CI-DIR ΔDSC > 0 for all ROIs. This suggests that I-DIR and CI-DIR provide better ROI surface propagation.
- Based upon the JD, ΔMDA, and ΔDSC DIR QA metrics, I-DIR and CI-DIR are expected to provide more reliable dose summations than C-DIR, and thus are recommended for adaptive re-planning.

ACKNOWLEDGEMENTS

This work is partially supported by MCW Fotsch Foundation and by Manteia Med.