JULY 19–22 VANCOUVER, BC 2026
JOINT AAPM | COMP MEETING

Learning Pelvic Anatomy: A Deep Learning Approach to Deformable Registration for Gynecologic Radiotherapy

Adriel Ngo[1,2]; Tsz Him Shek[2]; Naiyuan Liu[1,2]; Jan P. Seuntjens, PhD[1,2]; Monica Serban[1,2]
[1]University of Toronto, Canada [2]Princess Margaret Cancer Centre, Toronto, Canada

ABSTRACT

Purpose: To develop and validate a female pelvis-specific deep learning deformable image registration (DIR) framework optimized for longitudinal CT imaging, enabling accurate dose accumulation and cumulative dose assessment in gynecological radiotherapy.

Methods: Patients treated with pelvic radiotherapy between 2018 and 2024 were retrospectively identified. Patients with at least two CT scans were included, resulting in a dataset of 655 CT scans from 276 patients.

DIR was performed using a modified Voxelmorph framework. The model was adapted specifically for female pelvic anatomy, incorporating organ-aware supervision through auxiliary segmentation masks. A semi-supervised model was trained for intra-patient registration using paired CT scans.

Results: Our optimized registration model achieved a mean DICE score of 0.74, a mean Distance to Agreement of 3.25 mm, a Jacobian determinant of 0.002, and was driven by uterus, rectum, and urinary bladder segmentations.

Conclusion: This study presents the first deep learning-based DIR framework specifically optimized for female pelvic CT imaging.

CONTACT

Adriel Ngo
University of Toronto
Toronto, Canada
Adrielnissi.ngo@uhn.ca

INTRODUCTION

In radiotherapy for female pelvic cancers, radiation dose may be delivered in a series of fractions. This results in anatomical variations over time between treatment planning and delivery[1]. Dose accumulation across treatment fractions requires accurate segmentation and registration of patient anatomy.

Registration of female pelvic anatomy is particularly challenging due to large deformation of hollow organs including bladder and rectum, deformation of uterus and bladder in opposite directions due to organ sliding, and tumor growth or shrinkage during treatment[1].

The aim of our study is to develop and validate a female pelvis-specific deep learning deformable image registration (DIR) framework optimized for longitudinal CT imaging, enabling accurate dose accumulation and cumulative dose assessment in gynecological radiotherapy.

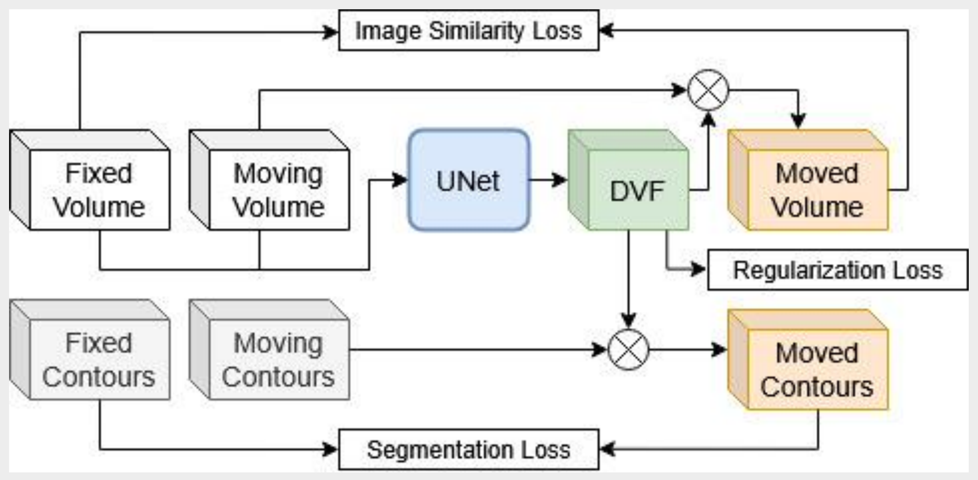

Figure 1. Voxelmorph Architecture

METHODS AND MATERIALS

Patients treated at the Princess Margaret Cancer Centre between 2018 and 2024 for gynecological (cervical, endometrial, anal, rectal, vaginal) cancers were retrospectively identified, resulting in 655 paired CT scans from 276 patients. Segmentations from 116 pairs of CT scans (152 scans, 66 patients) were manually refined to ensure consistent organ delineations.

Segmentations from TotalSegmentator[2] and Ethos therapy *(Siemens Healthineers[3]),* were used train a custom nnUNet[2] segmentation model for female pelvic and abdominal organs, including uterus and rectum.

Intra-patient affine registration was first performed using ANTs. Images were subsequently resampled to 1.5 mm3 isotropic spacing, cropped to the T12 vertebrae and below the lower pelvic bone, and zero padded to a uniform matrix size of 352 x 288 x 400 voxels.

DIR was performed using a Voxelmorph[4] framework (Figure 1). A semi-supervised model was trained with CT images at 3 mm resolution and organ segmentations at 6 mm using image similarity, segmentation, and regularization loss metrics.

All models were trained with 5-fold cross-validation (80% Train, 10% Validation, 10% Test) using NVIDIA L40S 48GB VRAM GPUs.

RESULTS

Our optimized registration model achieved a mean DICE score of 0.74, a mean Distance to Agreement (DTA) of 3.25 mm, and a Jacobian determinant of 0.002 in the test set of validated delineations. Metrics per organ are shown in Table 1.

Best performance was obtained using a weighted loss combination of Normalized Cross Correlation (weight = 1.0), DICE Similarity Coefficient (weight = 0.2), and L2 regularization (weight = 0.1). DICE score was driven by uterus, rectum, and urinary bladder segmentations.

Qualitative registration results for four sample patients are shown in Figure 2.

The model was trained for 400 epochs at a learning rate of 1.0e-3 using the Adam optimizer.

Table 1. Overall and per organ metrics for DIR model

Metric	Overall Mean (SD)	Bladder Mean (SD)	Rectum Mean (SD)	Uterus Mean (SD)
DICE	0.738 (0.091)	0.772 (0.132)	0.614 (0.150)	0.672 (0.270)
DTA (mm)	3.252 (0.333)	3.252 (0.333)	3.56 (1.48)	2.81 (0.994)

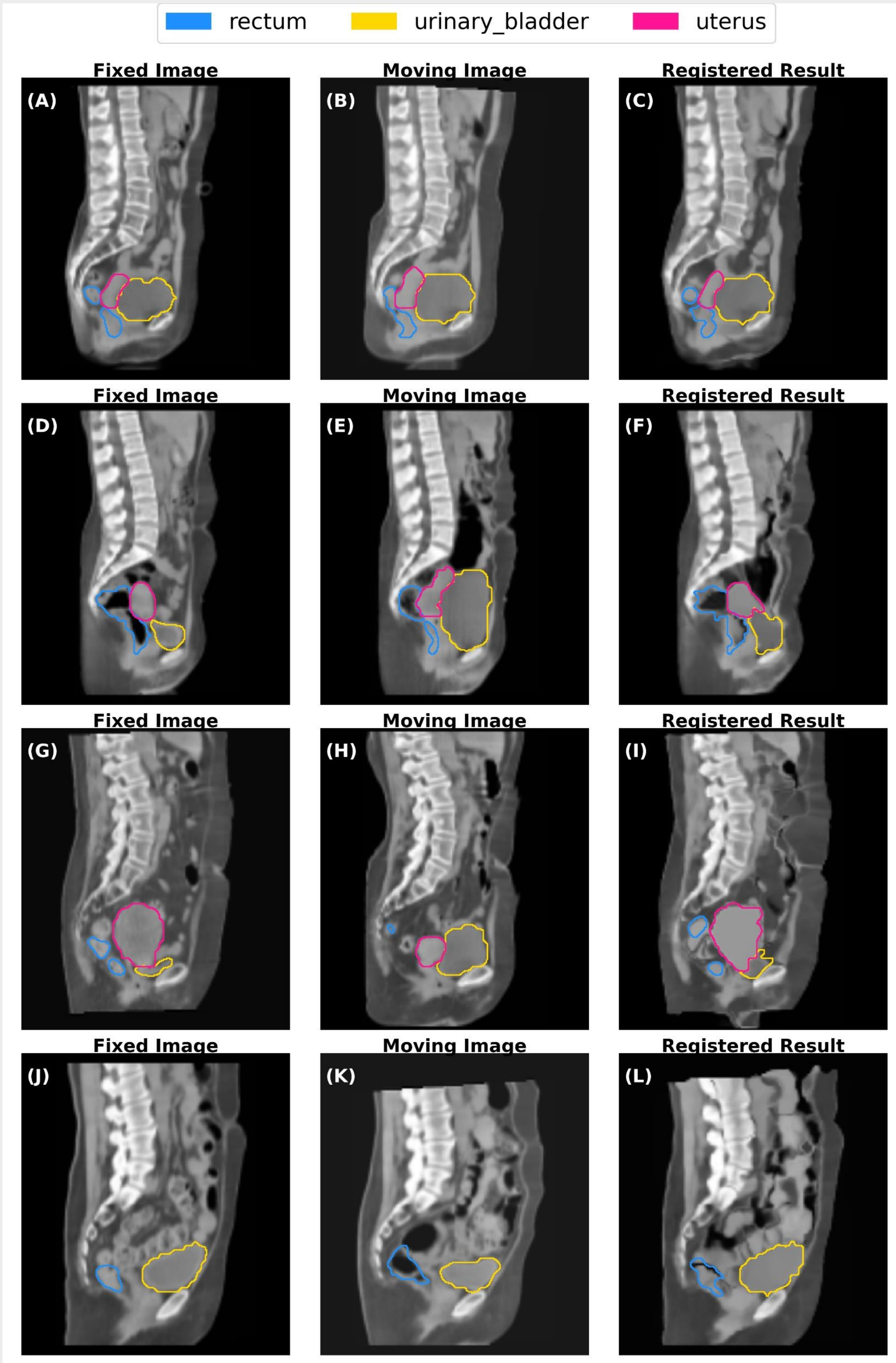

Figure 2. Registration results for four sample cases. *Patient 1* (A: Fixed, B: Moving, C: Registration result) example with minimal anatomy differences; *Patient 2* (D: Fixed, E: Moving, F: Registration result) example with significant bladder volume distance; *Patient 3* (G: Fixed, H: Moving, I: Registered) example with significant uterus volume difference; *Patient 4* (J: Fixed, K: Moving, L: Registration result) example of patient with surgically removed uterus prior to imaging.

DISCUSSION

The Jacobian determinant of 0.002 shows the model's ability to create smooth, physiologically realistic deformation fields without folding. Low mean square error (0.003) and high normalized cross-correlation (0.98) show improvement in image similarity after registration. DICE and Distance to Agreement showed the highest fidelity urinary bladder, with worse performance for rectum.

Figure 2 demonstrates the model's ability to retrieve large deformations in both the bladder and uterus, as well as successful deformation in cases with surgical resection. Figure 3 shows registration results and a resultant Deformation Vector Field.

Our results highlight the importance of dataset curation and high-quality contours for relevant organs at risk in driving complex image registration for pathological female pelvic anatomy.

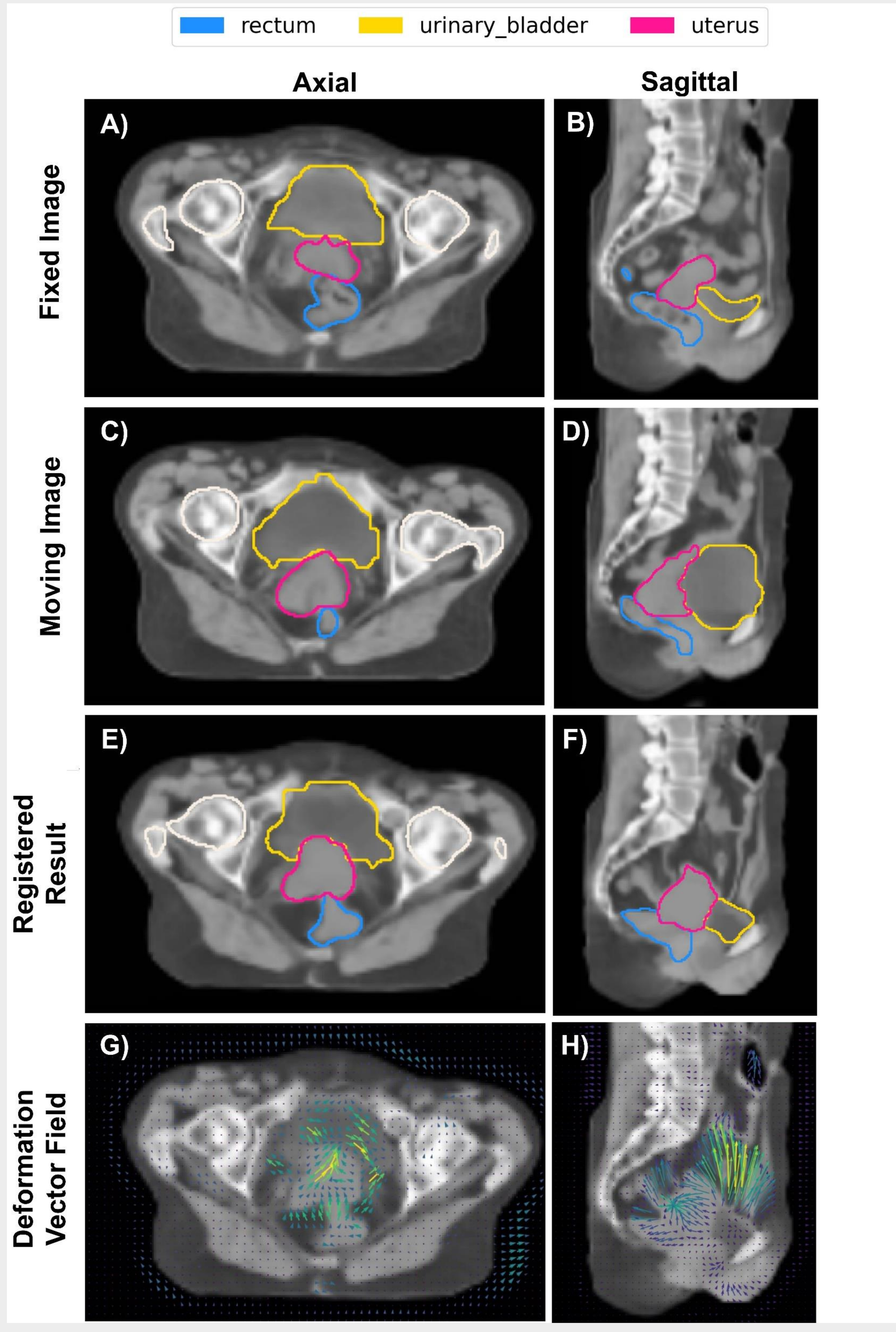

Figure 3. Sample registration result showing axial and sagittal views. Fixed image (A, B); Moving image (C, D); Registration result (E, F); Deformation Vector Field (G, H).

CONCLUSIONS

This study presents the first deep learning-based DIR framework specifically optimized for female pelvic CT imaging. By tailoring dataset curation, model hyperparameters, and training strategy to female anatomy, this approach enables robust longitudinal registration across treatment plans.

REFERENCES

1. Ghose S, Holloway L, Lim K, Chan P, Veera J, Vinod SK, et al. A review of segmentation and deformable registration methods applied to adaptive cervical cancer radiation therapy treatment planning. Artificial Intelligence in Medicine. 2015 Jun;64(2):75–87. doi:10.1016/j.artmed.2015.04.006
2. Wasserthal J, Breit HC, Meyer MT, Pradella M, Hinck D, Sauter AW, et al. TotalSegmentator: Robust Segmentation of 104 Anatomic Structures in CT Images. Radiology: Artificial Intelligence. 2023 Sep 1;5(5):e230024. doi:10.1148/ryai.230024
3. Varian Medical Systems. Ethos therapy: intelligent structures: deep learning algorithms for target and OAR segmentation [Technical Brief]. Palo Alto (CA): Varian Medical Systems; 2020 Jul [cited 2026 Jul 8].
4. Balakrishnan G, Zhao A, Sabuncu MR, Guttag J, Dalca AV. VoxelMorph: A Learning Framework for Deformable Medical Image Registration. IEEE Trans Med Imaging. 2019 Aug;38(8):1788–800. doi:10.1109/TMI.2019.2897538