An Evaluation of Deformable Image Registration Algorithms for MRI-to-CT Registration in Gynecologic Brachytherapy with Applicator-Induced Deformation

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

Brad Stiehl, PhD[1]; Indrin J. Chetty, PhD[1]; Tiffany Phillips, PhD[1]; Jennifer Steers, PhD[1]; Mitchell Kamrava, MD[1]; Hualiang Zhong, PhD[2]
[1]Cedars-Sinai Medical Center, [2]Medical College of Wisconsin

ABSTRACT

Purpose: Accurate deformable image registration (DIR) between magnetic resonance imaging (MRI) and computed tomography (CT) remains a significant challenge in gynecologic brachytherapy, particularly between images acquired with and without a brachytherapy applicator in place. This study evaluated the performance of commercially available intensity- and contour-guided algorithms and in-house finite element method (FEM)–based algorithms for MRI-to-CT DIR.

Methods: Seven DIR approaches were evaluated, including three intensity-based methods: Demons, B-spline, and multimodality (MM) registration; one contour-guided approach: contour-constrained (CC) registration; and three FEM-based approaches: hybrid FEM initialized from MM registration, hybrid FEM initialized from CC registration, and contour-based FEM (CB-FEM). MRI images acquired without an applicator were registered to CT simulation images acquired with applicator in place. Registration accuracy was assessed using contour-based analysis of three organs at risk: bladder, rectum, and bowel-sigmoid. Quantitative evaluation used Dice similarity coefficient (DSC), mean distance to agreement (MDA), and 95th percentile Hausdorff distance (HD95).

Results: CC registration demonstrated the highest overall geometric accuracy, with average DSC, MDA, and HD95 of 0.77, 5.49 mm, and 20.72 mm, respectively. Intensity-based methods showed intermediate performance, with average DSC values of 0.52–0.59 and HD95 values of 28.76–34.90 mm. FEM-based methods showed variable but improved performance compared with the prior hybrid implementation, with average DSC values of 0.56–0.61 and HD95 values of 27.95–31.39 mm. Across all evaluated organs, CC registration achieved the highest DSC and lowest HD95.

Conclusion: Contour-guided DIR provided the best overall MRI-to-CT registration performance for gynecologic brachytherapy cases with applicator-induced deformation. Intensity-based methods demonstrated intermediate accuracy, while FEM-based methods showed variable but improved performance compared with the prior hybrid FEM implementation. These findings support the value of anatomic constraints for MRI-informed CT planning and motivate further refinement of applicator-aware biomechanical methods for reliable contour propagation and future dose accumulation.

CONTACT

Brad Stiehl
Cedars-Sinai Medical Center
bradley.stiehl@csmc.edu

INTRODUCTION

MRI-guided adaptive brachytherapy is central to modern gynecologic radiation therapy because MRI provides superior soft-tissue visualization for target and organ-at-risk (OAR) delineation. However, same-day MRI with the applicator in place is not available in many clinical workflows.

When an MRI is acquired before applicator placement and a CT is acquired with the applicator in situ, MRI-to-CT registration is challenging because the image sets differ by both modality contrast and applicator-induced anatomic deformation.

Deformable image registration (DIR) may allow MRI-defined anatomy to inform CT-based brachytherapy planning and enable dose accumulation efforts. However, intensity-based methods may be limited by MRI-to-CT intensity differences, while biomechanical methods require accurate modeling of organ deformation and boundary conditions.

Study Objective: To evaluate intensity-based, contour-guided, and finite element method–based MRI-to-CT DIR algorithms for gynecologic brachytherapy cases with applicator-induced deformation.

METHODS AND MATERIALS

Study cohort:

- 15 retrospective gynecologic HDR cases
- Applicators: 7 multi-channel cylinders, 3 single-channel cylinders, 5 tandem-and-ring
- Fixed image: CT with applicator
- Moving image: MRI without applicator

Registration workflow:

- MRI datasets were deformably registered to the corresponding CT simulation datasets
- MRI organ-at-risk contours were propagated to CT and compared with CT reference contours

Seven MRI-to-CT DIR methods:

- Intensity-based: Demons, B-spline, multimodality (MM)
- Contour-guided: contour-constrained (CC)
- Biomechanical: hybrid FEM (hFEM (CC), (MM)) and contour-based FEM (CB-FEM)

Evaluation Metrics:

- DSC for volumetric overlap
- MDA for average surface agreement
- HD95 for worst-case boundary discrepancy

RESULTS

Table 1. Overall mean evaluation metrics by algorithm

Algorithm	DSC	MDA (mm)	HD95 (mm)
Demons	0.52 ± 0.07	5.49 ± 1.26	34.90 ± 6.80
B-Spline	0.57 ± 0.06	5.52 ± 1.17	28.76 ± 7.35
MM	0.59 ± 0.02	5.57 ± 1.21	30.03 ± 6.78
CC	0.77 ± 0.03	5.49 ± 0.60	20.72 ± 5.18
hFEM (MM)	0.58 ± 0.04	5.55 ± 1.23	29.84 ± 5.31
hFEM (CC)	0.61 ± 0.03	5.42 ± 1.08	27.95 ± 9.38
CB-FEM	0.56 ± 0.01	5.46 ± 1.15	31.39 ± 14.72

Figure 1. Overall mean evaluation metrics by algorithm

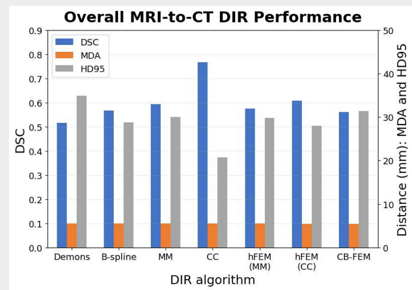


Figure 2. Mean evaluation metrics by algorithm across evaluated OARs

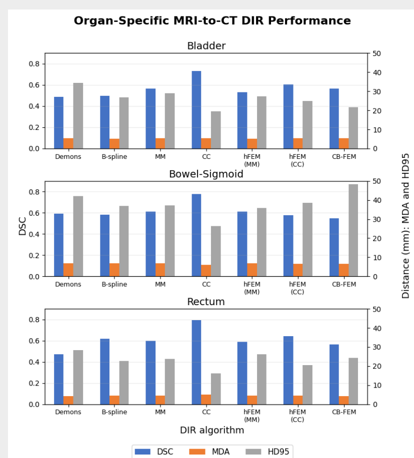
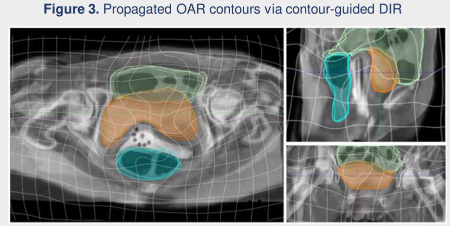


Figure 3. Propagated OAR contours via contour-guided DIR



DISCUSSION

Contour-guided DIR showed the best overall MRI-to-CT DIR performance, with the highest average DSC and lowest HD95 across bladder, bowel-sigmoid, and rectum. This demonstrates the value of anatomic constraints for multi-modality and applicator-induced deformation.

Intensity-based methods showed intermediate performance. Demons, B-spline, and multimodality registration produced similar average surface agreement, but lower overlap and higher HD95 than contour-guided DIR, suggesting that image information alone is less robust for this MRI-to-CT applicator-deformation problem.

FEM-based methods showed variable performance across initialization strategies and organ sites. hFEM initialized from contour-guided DIR achieved the strongest FEM-based performance overall, while CB-FEM and hFEM initialized from multimodality registration showed similar but slightly lower accuracy.

These results suggest that biomechanical correction may be useful, but are dependent on the driving registration, boundary conditions, and organ deformation model.

CONCLUSIONS

- Contour-guided DIR was the most reliable approach for MRI-informed CT planning in this applicator-deformation cohort.
- Intensity-based methods provided moderate performance, while FEM-based approaches remain promising but require further refinement.
- All DIR-propagated contours require clinical review before treatment planning or dose accumulation.
- Future work will investigate leveraging applicator-aware biomechanical modeling for target volume deformation and dose accumulation efforts.

REFERENCES

1. Zhong H et al. Phys Med Biol. 2007;52:4721-4738.
2. Zhong H et al. Phys Med Biol. 2012;57:3499-3515.
3. Brock KK et al. Med Phys. 2017;44:e43-e76.
4. Tait LM et al. Brachytherapy. 2016;15:333-340.
5. Dyer BA et al. Brachytherapy. 2019;18:378-386.
6. Rigaud B et al. Phys Med Biol. 2019;64:115023.