Evaluating the Geometric Accuracy Of Automatic Applicator Anchor Point Placement For Cervical Cancer HDR Brachytherapy Planning

F. Barrett[1], A. Tremblay[1], T. Meyer[2], P. McGeachy[2]

[1]Department of Physics and Astronomy, University of Calgary, Calgary, AB, Canada
[2]Arthur J.E. Child Comprehensive Cancer Centre, Cancer Care Alberta, Calgary, AB, Canada

Introduction

- Magnetic resonance imaging (MRI)-guided cervical high-dose-rate (HDR) brachytherapy requires accurate applicator reconstruction for treatment planning. Prior applicator reconstruction literature suggests uncertainty on the order of 1-2 mm may be clinically relevant [1,2].
- Manual placement of applicator anchor points is time-consuming and may introduce interuser variability. A fast and reproducible solution for identifying applicator anchor points could improve planning efficiency and standardization.
- In this work, a deep learning segmentation model was combined with a geometry-based registration pipeline to automatically localize three anchor points on the Venezia applicator and compare them with clinically used points.

Can automatic anchor point placement achieve geometric accuracy that is within a clinically acceptable margin of 2 mm?

Methods

- This retrospective study included 44 patients (127 MRIs) treated between Dec. 2023 and Dec. 2025 for cervical cancer with HDR brachytherapy using the Venezia (Elekta) applicator. The dataset was split into development (37 patients; 106 MRIs) and testing (7 patients; 21 MRIs) sets. All MRIs were post-insertion 3D axial T1 VIBE scans.

1. **Segmentation Model Development:**

   Several 3D deep learning segmentation architectures were used to predict an applicator mask based on MRI. Model selection and performance were based on Dice score during validation and testing.

2. **Automatic Applicator Registration and Anchor Point Extraction:**

   Predicted applicator masks were used to localize anchor points via registration. An applicator model from a library of configurations was digitized and matched using **Powell-based rigid registration**.

3. **Outcome Measurements:**

   Coordinate-wise differences and 3D Euclidean distances between automatic and clinically used anchor points were computed. **Bootstrap-derived 95% confidence intervals** (CIs) for the **3D Euclidean distance** of each anchor point were calculated and compared to a **2 mm clinical margin** motivated by prior brachytherapy applicator reconstruction literature [1-3].

Results

- **BasicUNet++** was selected for applicator mask prediction, achieving Dice values of 0.868 ± 0.065 for the tandem and 0.920 ± 0.032 for the ovoids; testing Dice was **0.846 ± 0.078** and **0.929 ± 0.017**, respectively.
- **Figure 1** showcases the registration workflow, where the predicted applicator mask was used to align the applicator model to patient-specific MRI anatomy and automatically extract the anchor points.
- **Chart 1** and **Table 1** show that automatic anchor placement achieved low geometric error relative to clinically used anchor points: mean coordinate-wise errors were < 1 mm and the upper extents of the **95% CIs for 3D Euclidean distance were < 2 mm for all anchor points**.

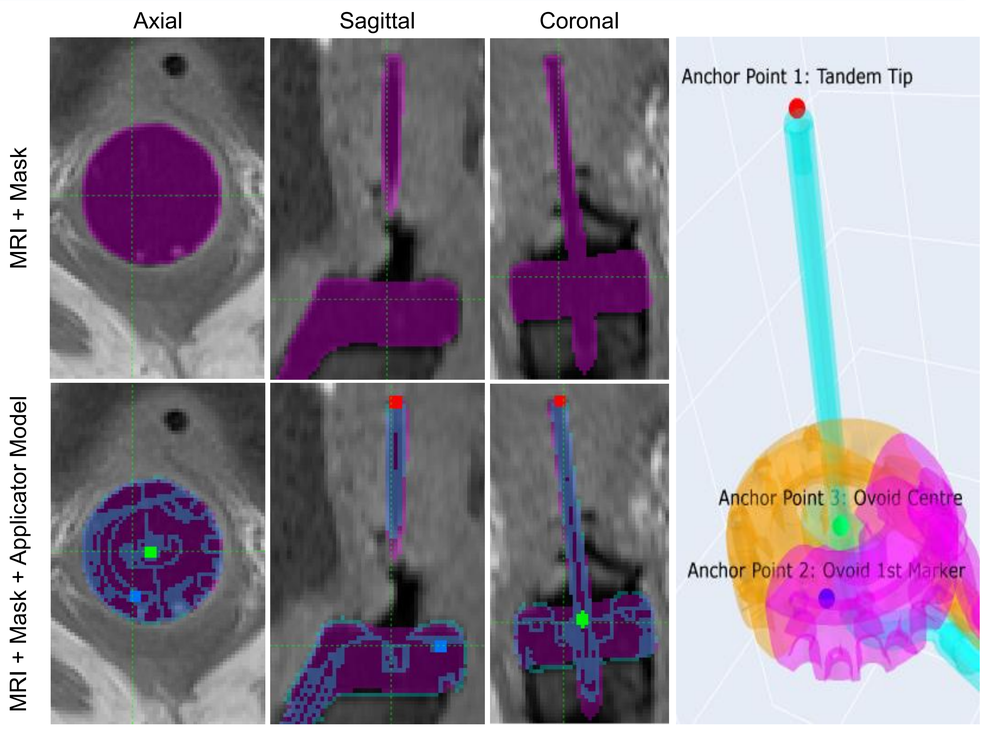

Figure 1. *Example applicator mask prediction and anchor point extraction workflow from a testing-set MRI. On the right, an applicator render is shown with three anchor points used for applicator placement: 1) Tandem Tip, 2) Ovoid 1st Marker, and 3) Ovoid Centre shown in red, blue, and green, respectively. On the left, the top row shows axial, sagittal, and coronal MRI slices with the predicted applicator mask, and the bottom row shows the registered digital applicator model with its anchor points (a comparison with the clinical anchor points is shown in Chart 1).*

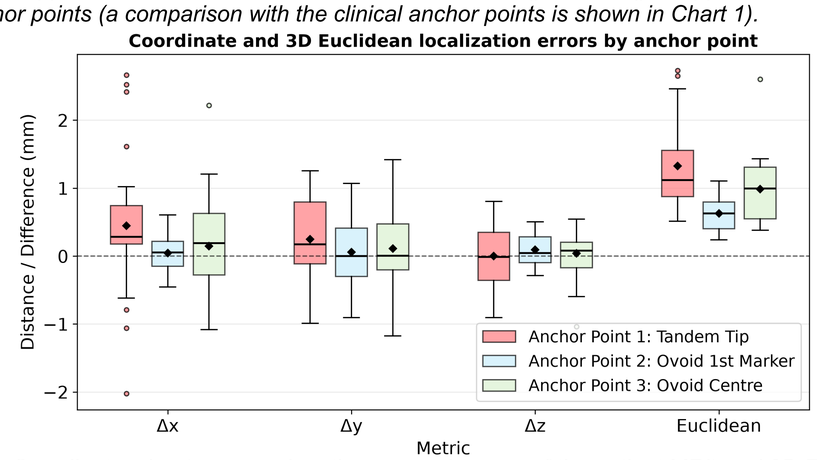

Chart 1. *Coordinate-wise (measured on the x, y, and z axes of the patient MRI) and 3D Euclidean localization errors between automatic and clinically used anchor points across the testing set. Diamonds and lines indicate means and medians, respectively. Boxes represent the interquartile range with whiskers extending to 1.5x the interquartile range and outliers shown as points.*

3D Euclidean Distance	
Anchor Point	**95% CI [mm]**
1: Tandem Tip	1.05 to 1.62
2: Ovoid 1st Marker	0.51 to 0.75
3: Ovoid Centre	0.78 to 1.22

Table 1. *Bootstrap-derived 95% confidence intervals (CIs) for the 3D Euclidean localization error between automatic and clinically used anchor points in the testing set. The upper extents of all three anchor point CIs were below 2 mm.*

Discussion

- Automatic anchor point placement achieved **high consistency** with those placed during planning for cervical HDR brachytherapy, with **95% CIs for Euclidean distance below 2 mm** for all anchor points, supporting geometric accuracy within a clinically acceptable margin.
- The **2 mm margin** was motivated by prior cervical brachytherapy literature on applicator reconstruction uncertainty, dwell position uncertainty, and interobserver variability [1-3], although these studies do not investigate anchor point placement directly.
- Due to the interpretive nature of this benchmark, it should be taken as a **clinically motivated surrogate** rather than a validated anchor point-specific threshold.
- Overall, these results support automatic anchor point placement as a promising tool to improve efficiency and standardization in cervical HDR brachytherapy planning.

Conclusion

Automatic anchor point placement of the Venezia applicator achieved geometric accuracy within a 2 mm margin, supporting its potential use as a support tool for cervical HDR brachytherapy treatment planning.

Contact Information

Fletcher.Barrett@cancercarealberta.ca

More Info

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References

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