# Geometric Feature Extraction and Spatial Relationship Analysis of HRCTV Relative to Organs at Risk in Cervical Cancer Brachytherapy with Intracavitary and Intracavitary-Interstitial Applicators


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## Introduction

The standard-of-care definitive treatment for locally advanced cervical cancer (LACC) is
external beam radiotherapy (EBRT) with concurrent chemotherapy, followed by high dose-rate (HDR) image-guided brachytherapy (IGBT).
This indispensable highly conformal internal radiation technique delivered in one of two strategies:
(1) intracavitary brachytherapy (IC), OR
(2) combined intracavitary-interstitial brachytherapy (IC/IS), also called hybrid applicators, which adds interstitial needles to improve conformality in topographically challenging tumors. Fig. 1
Current guidance for IC vs. IC/IS selection relies on HRCTV volume thresholds (30 cc, ≥ retroEMBRACE) and expert judgment, but volume alone fails to capture 3D geometric complexity and tumor-OAR spatial relationships critical for predicting needle number and placement.
creating substantial clinical consequences:
interstitial needles improve coverage in bulky or asymmetric disease BUT increase procedural complexity and patient risk
while defaulting to IC alone can undertreat tumors requiring interstitial coverage, compromising local control.
A standardized, objective framework is critically needed to guide applicator selection across institutions and experience levels, optimizing tumor dose while sparing critical organs—ultimately improving local control, reducing toxicity, and promoting equitable care quality.

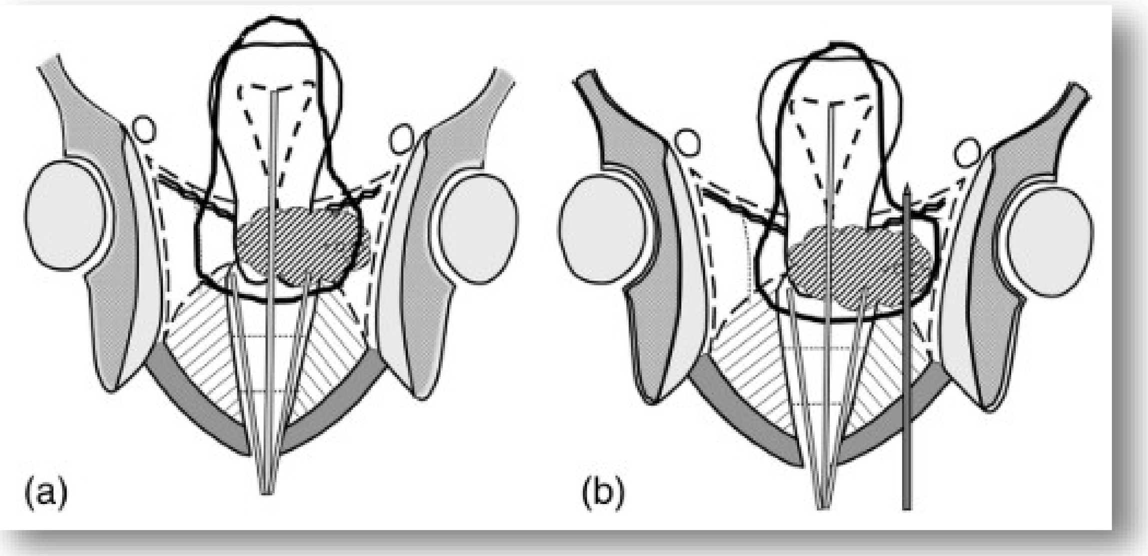


**Figure 1.** a) Conventional intracavitary brachy-therapy applicator (IC). Thick solid line represents the prescription isodose line. Tumor is the shaded structure extending left parametrium with suboptimal dose coverage.
b) Hybrid intracavitary-interstitial brachytherapy (IC/IS). The needle inserted to allow locally for optimal conformal dose coverage of the tumor (Murakami et al. BMC Cancer (2016)

## Methods and Materials

Complete post-implant first-fraction DICOM datasets from 81consecutive cervical cancer patients treated with IC or combined IC/IS brachytherapy were extracted from the Oncentra-Brachy TPS.
An in-house Python-based geometric analysis code computed slice-by-slice:
(1) Euclidean distances between the uterine tandem axis and the most distant HRCTV boundary (d_hrctv), and
(2) the shortest Euclidean distance between the tandem and the rectum (d_rec), bladder (d_blad), sigmoid colon (d_sig), and small bowel (d_smb) on corresponding axial slices.
(3) HRCTV volumes were also collected.
(4) Slice-by-slice ratios between d_hrctv and each OAR (R_rec, R_blad, R_sig, R_smb) were calculated, and the maximum ratio (R_max) and corresponding OAR were identified.
(3) All 41 IC/IS cases were replanned without interstitial needles, and dosimetric data were collected for IC plans, original IC/IS plans, and IC/IS plans replanned without needles.

Statistical analyses were performed using SAS-9.4.

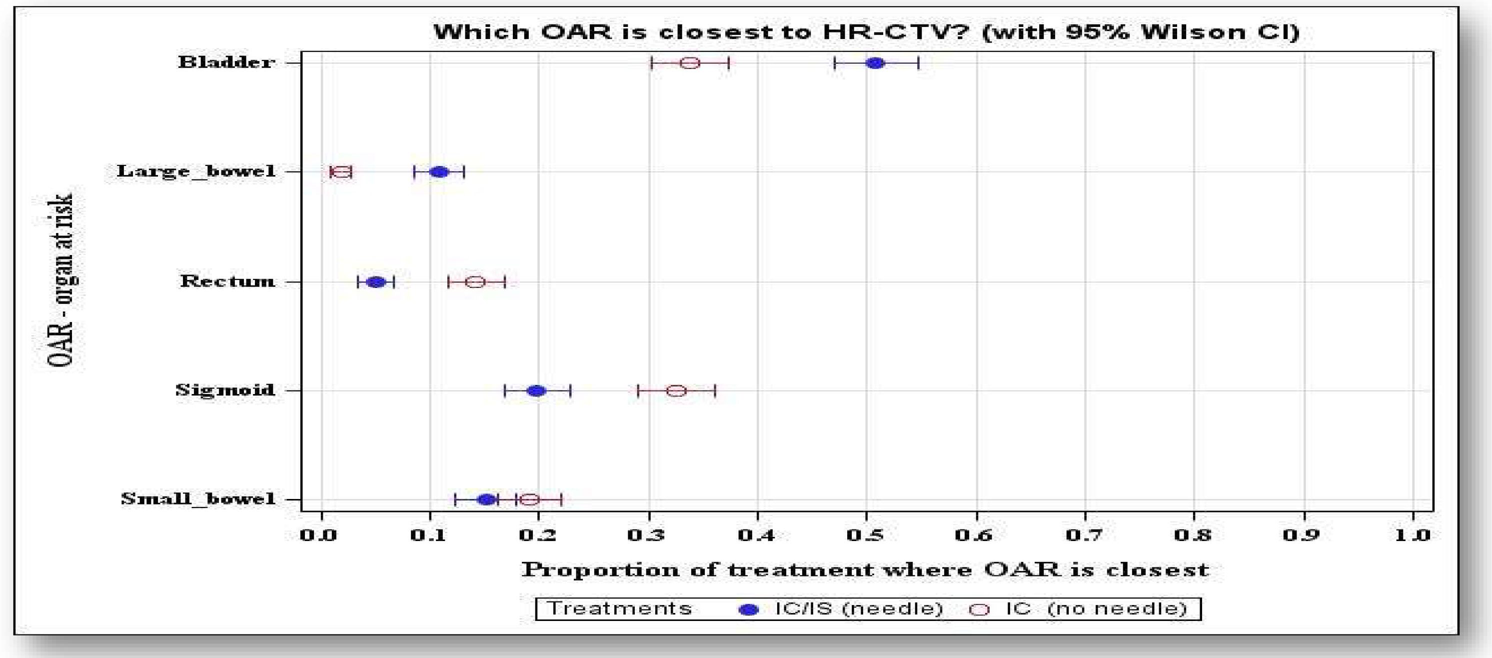


**Figure 2.** Which OAR is closest to HRCTV? (with 95% Wilson CI)

## Results

Mann-Whitney and two-sample t tests demonstrated:

- R_rec, R_blad, R_sig, R_smb, and R_max statistically significant different between IC and IC/IS patients for all ratios ($p<0.0001$).

Univariate Logistic Regression showed:

- IC/IS patients are on average 2.2 times more likely to have R_max>1 and 7.8 times to have R_max>2
- Bladder is statistically significantly the closest OAR to HRCTV (50% in IC/IS, and 33% in IC patients)
- No statistically significant difference in HRCTV volume was observed between IC and IC/IS patients ($p=0.35$).
- 29% of patients who demonstrated greater D2cc reduction with ICIS had HRCTV volumes <30 cc.

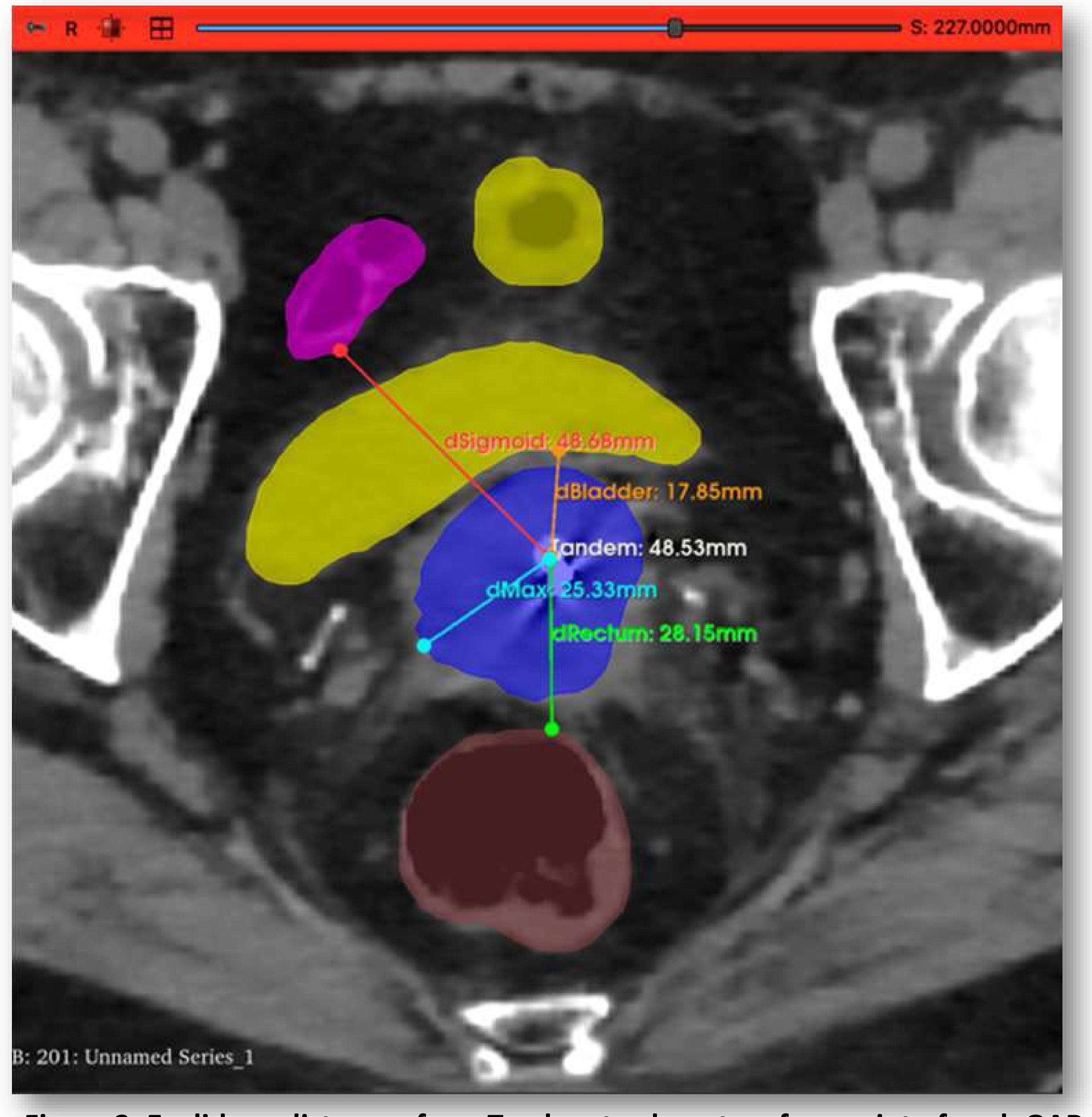


**Figure 3. Euclidean distances from Tandem to closest surface point of each OAR and furthest edge of HRCTV**

## Discussion

Our findings suggest that HRCTV volume alone may be insufficient to characterize the geometric complexity that influences applicator selection in cervical cancer brachytherapy. Although larger HRCTV volumes have previously been associated with greater benefit from interstitial needle supplementation, we observed no significant difference in HRCTV volume between patients treated with IC and IC/IS applicators. In contrast, all HRCTV-to-OAR distance ratios differed significantly between the two groups, indicating that the spatial extension of the target relative to adjacent critical structures may provide clinically relevant information beyond volume alone.
Patients treated with IC/IS applicators were more likely to have an R_max greater than 1, suggesting that the HRCTV extended farther from the tandem than the nearest surrounding OAR on the corresponding axial slice. This geometric relationship may represent situations in which intracavitary loading alone cannot adequately cover the lateral or asymmetric target without increasing dose to an adjacent OAR. The bladder was identified as a particularly important limiting structure, highlighting its potential influence on the decision to incorporate interstitial needles.
These results support the development of objective, patient-specific geometric criteria to supplement clinical examination, imaging findings, and HRCTV volume during applicator selection.

## Conclusions

The discriminative ability of any single HRCTV volume threshold was limited, indicating that HRCTV size alone is insufficient to determine the need for interstitial needle placement to meet OAR constraints without compromising target coverage.

We parameterized and quantified distance-based geometric features and characterized spatial relationships between the HRCTV and surrounding OARs, distinguishing patients treated with IC from those treated with combined IC/IS brachytherapy.

These geometric measures may better predict benefit from IC/IS applicators than HRCTV volume alone.

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