Quantitative Automated Source Position Assessment for HDR Gynecologic Brachytherapy Using Applicator-Specific 3D-Printed Phantoms

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INTRODUCTION

- Annual applicator quality assurance (QA) is essential for source positioning for dose delivery in HDR gynecologic (GYN) brachytherapy.
- This study introduces an applicator-specific, 3D-printed phantom combined with a quantitative, automated, image-based method to measure source position displacement.
- The objective is to develop a reproducible annual QA methodology that enables direct, numerical assessment of source positioning while minimizing operator-dependent variability.

METHODS AND MATERIALS

- **Applicator Sample**:
  - Selected a sample of 24 HDR GYN Elekta applicators: Geneva, Venezia, Utrecht, and Fletcher (Elekta)
- **Applicator- Specific 3D Printed Phantoms**
  - Designed a customized 3D- printed phantom for each applicator set to ensure reproducible applicator placement (Fig A)
  - Incorporated applicator-specific slots with a fixed geometry for Gafchromic film placement for each phantom
  - Maintained a known and consistent distance between the applicators and the film plane

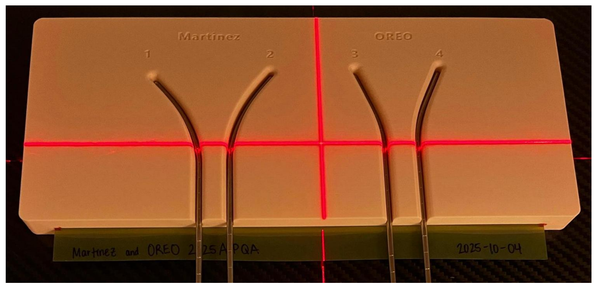

Figure A: Customized 3D phantom for Endometrial Double Tandem, with a secure housing for EBT-3 film

- **Quantitative Automated source position analysis**
  - Inserted applicators into their designated phantom slots
  - Placed four disposable X-SPOT skin markers at the film corners as registration fiducial markers (Fig B)
  - Performed Autoradiography and CT imaging for each applicator set
  - Irradiated the EBT-3 film with an HDR Ir-192 source for Autoradiography
  - Inserted Radiopaque CT markers into each applicator for CT acquisition
- Developed a MATLAB-based GUI to automatically register scanned film image with the corresponding CT image using a four-point registration algorithm

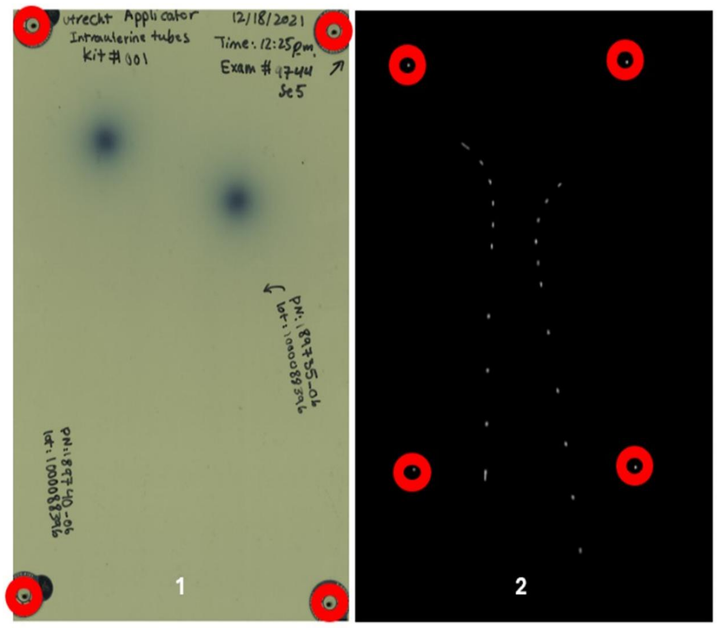

Figure B: From left to right: 1) Scanned image radiated EBT3 film image with four landmark BBs shown in red circles, 2) on the right: CT image with four landmark BBs shown in red circles

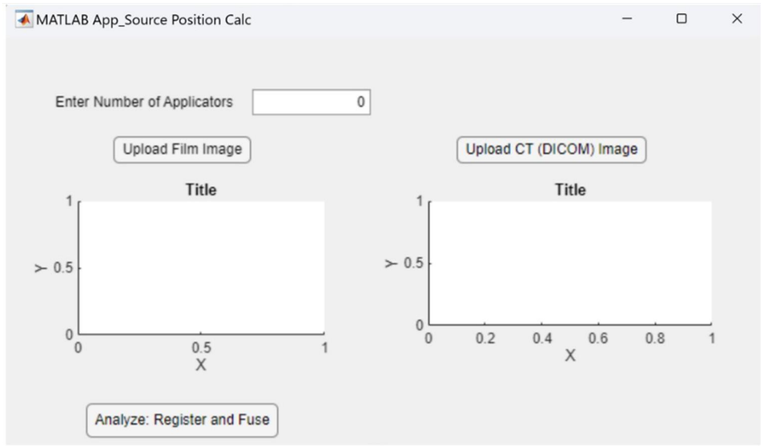

Figure C: MATLAB-based GUI for automatic source position calculation

- **Analysis**:
  - Calculated source position displacement quantitatively in two dimensions
  - Computed the distance between the center of the radiation (Fig D.1) and the center of the CT marker (Fig D.2)
  - Reported the displacement as pixel-based distances relative to the expected source path
  - Converted the displacement to actual distance in physical units (mm)

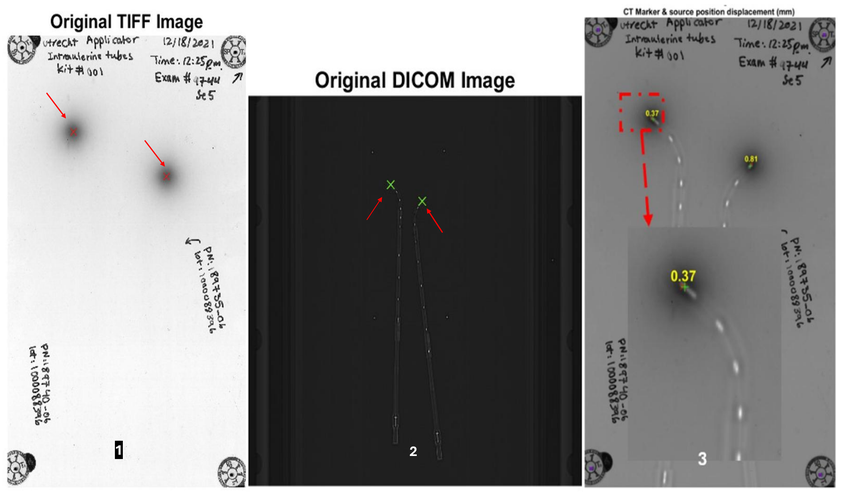

Figure D: From left to right: 1) Analyzed scanned film image to find the center of the radiation shown in red "X"; 2) Analyzed CT image to find the center of the CT marker shown in green "X"; 3) Registered images with source position displacement illustrated

RESULTS

- Quantitative analysis yielded a mean measured source displacement of 0.26 ± 0.01 mm across all 24 applicators.
- The automated calculation produced consistent numerical measurements across repeated applicator geometries, demonstrating high measurement reproducibility.

Calculated source displacement values (mm ± 0.01)

Applicator	Min	Mean	Max
Geneva	0.02	0.33	0.68
Utrecht	0.02	0.35	0.70
Venezia	0.02	0.17	0.42
Fletcher	0.05	0.24	0.46
Total	0.11	**0.26**	0.82

CONCLUSIONS

- The proposed QA approach enables fully quantitative, automated calculation of source position displacement using applicator-specific 3D-printed phantoms and image registration.
- By providing direct numerical measurements rather than qualitative assessment, this method reduces operator dependence and improves reproducibility, supporting its use for routine annual QA of HDR GYN brachytherapy applicators.
- **Future Directions**:
  - Future studies include further design and testing with automated source position assessment on various applicators

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