

APPLICATION OF THE TG-43 DOSIMETRY PROTOCOL TO ELECTRONIC BRACHYTHERAPY SOURCES



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ABSTRACT

Purpose: AAPM Task Group No. 43 report recommends a brachytherapy dosimetry formalism for interstitial brachytherapy sources containing radionuclides. Recently, small x-ray sources have been developed that offer the prospect of electronic brachytherapy. Xoft microTube has developed a micro-miniature x-ray brachytherapy source. The purpose of this project was to characterize the microTube within the TG-43 dosimetry framework.

Materials and Methods: Experimental and calculative techniques were used to characterize the microTube dose distribution and, subsequently, determine the TG-43 dosimetry parameters. Experiments used radiochromic film, ionization chambers and an x-ray spectrometer for ascertaining depth-dose curves in air and water, air-kerma strength, angular dose distributions, x-ray energy spectra, and half-value layers. Calculations employed the MCNP (v.4C) radiation transport code. Since the TG-43 air kerma strength definition is based upon measurements using the NIST WAFAC, the formalism required broadening to accommodate beam current as it relates to source strength.

Results: After manipulating the dose distributions with the geometry function, the measured radial dose function compared favorably with that determined using MCNP. With the microTube operating at 40 kVp and 0.30 mA, the air kerma strength exceeded 800 Gy cm² h⁻¹ or approximately twice that of a 10 Ci ¹⁹²Ir source. Altering operating potential (i.e. kVp) permitted perturbation of the radial dose function and 2D anisotropy function.

Conclusion: Dose distributions in water for the Xoft microTube have been measured and calculated, and the TG-43 dosimetry parameters have been obtained. Thus, the source may now be properly used *in vivo*.

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INTRODUCTION

- In 1995 the AAPM Task Group No. 43 published a set of guidelines for calibration of interstitial brachytherapy sources that are in common use today.¹ These guidelines were recently updated to revise several definitions and provide consensus data sets for low-energy brachytherapy seeds that meet AAPM dosimetric requirements.²
- These guidelines for radionuclide sources apply equally well to the Xoft microTube electronic brachytherapy source with two minor modifications:
 - Air kerma strength must be normalized to beam current because the source dose rate can be easily varied by changing the beam current.
 - Anisotropy can be described using the point-source approximation for the geometry function because the apparent source size is about 1 mm.
- One salient difference between description of the Xoft microTube and a radionuclide-based seed is that the air kerma strength and radial dose function may be selected at the time of treatment by the clinician. Hence the source dosimetric parameters need to be determined for a selection of operating voltages.
- Source characterization in this paper will concentrate on 40 kVp operation.

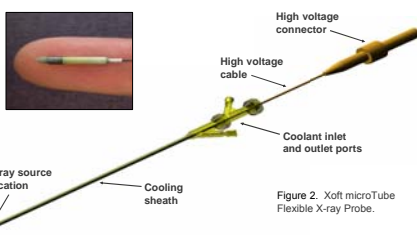
METHODS

- Objective:** To characterize within the TG-43 framework a new electronic brachytherapy source, which is based on a miniature x-ray tube.
- Instrument:** Xoft microTube flexible x-ray probe operated at 40 kVp with a beam current range from 0.1 - 0.3 mA.
- Design:** X-ray probe output was bench tested in air, water and solid water and characterized by Monte Carlo modeling.
- Data Collection:** Parameters measured included:
 - Depth-dose curves in water (PTW Model 34013 Soft X-ray Chamber 0.005 cm³ with a Standard Imaging MAX 4000 electrometer).
 - Air kerma strength using the seven-position technique (Precision Radiation Measurements Model LE-0.8 Low Energy Ionization Chamber).³
 - X-ray spectrum (high purity Ge gamma ray spectrometer at the UW RCL)
- Modeling:** Monte Carlo modeling of the microTube was calculated using MCNP v.4C with the DLC-200 library
- Endpoint:** TG-43 dosimetry parameters were extracted from these measurements in a form that is consistent with parameters from standard radionuclide brachytherapy sources.

DEVICE DESCRIPTION

- Electronic high dose rate brachytherapy delivers ionizing radiation to the tumor bed using a fully electronic system.
- The Xoft microTube Flexible X-ray Probe consists of a disposable, micro-miniature X-ray source (Figure 1) integrated into a cooled, flexible, disposable probe (Figure 2).
- Fluid circulating within the cooling sheath allows a higher source power dissipation, hence higher dose rate, without thermal damage to the source or surrounding structures.
- X-rays of 50 keV maximum energy are produced at the tip of the retractable probe, which can be pulled back for accurate dose delivery as in current HDR afterloaders.
- The X-ray source can be intensity modulated to mimic penetration and/or dose rate characteristics of many different radionuclides, including HDR ¹⁹²Ir, ¹²⁵I and ¹⁰³Pd.
- Control variables are source operating voltage (penetration depth), beam current (dose rate), dwell time and dwell position.
- The Xoft microTube Flexible X-ray Probe can be inserted directly into tissue or into one or more lumens of an intracavitary or interstitial brachytherapy applicator, which is inserted during surgery (e.g. lumpectomy) or as an outpatient procedure up to five weeks later.
- This X-ray source is potentially appropriate for any accessible body cavity or excised tumor bed such as with breast cancer or gynecologic cancers.
- The initial application of the Xoft microTube Flexible X-ray Probe has been for the conservative treatment of breast cancer utilizing a balloon-based Partial Breast Irradiation System. See Poster #140 at this meeting.

Figure 1. X-Ray Source – Scaled to Size



RESULTS

- The x-ray source geometry was simulated as shown in Figure 3. Elements included in the model were the x-ray anode and substrate, x-ray source wall materials, and x-ray source cooling water jacket. Details of the cooling sheath were not included in all calculations because substituting the polymer components for a water jacket of equivalent dimensions did not alter the calculated depth-dose curves or angular distributions.
- Depth-dose curves have been calculated for the x-ray probe immersed in air, water, Solid Water™ and breast tissue (as defined in ICRU Report No. 44, 1989). In all cases, the model started with an electron beam striking the anode surface to generate x-rays that were then emitted by transmission through the substrate.
- Calculated depth-dose curves in water compare favorably with results published for ¹⁹²Ir, ¹²⁵I and ¹⁰³Pd as shown in Figure 4, 4.4. Because the source operating voltage can change, the Xoft microTube can mimic each of these isotopes for depths ≥ 1 cm. It has the additional advantage that the dose rates can be significantly higher than ¹⁹²Ir or ¹⁰³Pd seeds.

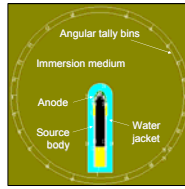


Figure 3. MCNP model geometry for angular distribution calculations. The surrounding medium can be air, water or tissue.

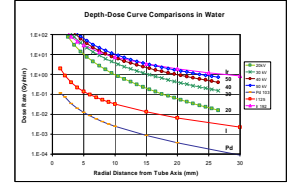


Figure 4. Comparison of calculated depth-dose curves for standard brachytherapy seeds compared to the Xoft microTube with operating voltages of 20-50 kVp.

- Source output was measured in air for an operating voltage of 40 kVp with 0.10 mA of beam current over a distance range from 10 to 40 cm in seven steps. Air kerma strength was then calculated using the formalism described by Stump, et al³ to be 27,000 cGy cm² h⁻¹.
- Air kerma strength normalized for beam current is 270 cGy cm² h⁻¹ μA⁻¹ at 40 kVp.**
- Depth-dose curves were measured in water for x-ray probe (SN 252) by translating a submerged PTW 34013 miniature ionization chamber that was encased in a thin water-light polymer sleeve.
- The depth-dose curve measured in the axial direction was 74% of the calculated value with a standard deviation of 7.3%. The depth-dose curve measured in the radial direction was 62% of the calculated value with a standard deviation of 2.4% (Figure 5). These deviations can be the result of uncertainty in the distance measurement between the source and ionization chamber and also a result of uncertainty in the actual anode thickness compared to the value used in the model.

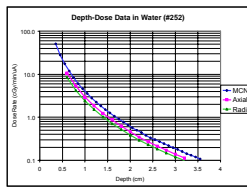


Figure 5. Measured depth-dose curves in water in the axial and radial directions agree with calculated values to within 25 and 38%, respectively.

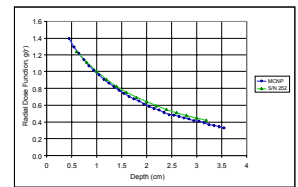


Figure 6. Measured radial dose function for 40 kVp inferred using the point-source approximation agrees with the calculated function to within 8% at a depth of 3 cm.

- From the depth-dose curves, a radial dose function was calculated using the point-source approximation that agreed with the modeled value to better than 8% over the depth range from 0.6 to 3.2 cm (Figure 6). The increasing difference between these radial dose functions is probably the result of using the DLC200 cross-section library for the Monte Carlo modeling.
- The point-source approximation was used because the apparent source length is approximately 1.0 mm. The line source approximation was not required because the deviation between point-and-line source approximations was less than 3% at all angles for distances of 0.3 cm or greater, i.e. for all distances outside of the cooling sheath.

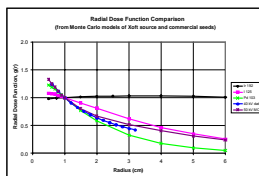


Figure 7. Measured radial dose function for 40 kVp in comparison to those of standard brachytherapy isotopes.

- The measured radial dose function for operation at 40 kVp lies between those of ¹⁰³Pd and ¹²⁵I as shown in Figure 7. The higher rfd at distances below 1 cm results from the broad x-ray spectrum emitted by the source in comparison to the discrete gamma ray line spectrum emitted by the isotopes.
- Measured dose rate constant was 0.53 cGy h⁻¹ U⁻¹ at 40 kVp. For comparison, consensus values are 0.69 for ¹⁰³Pd and 0.94 - 1.04 for ¹²⁵I.
- The calculated anisotropy function above 40 kVp is reasonably independent of voltage and distance from the source.
- Comparison of calculated and measured anisotropy data will be reported at the 46th AAPM meeting in July.

CONCLUSIONS

- Dosimetric parameters of the Xoft microTube Flexible X-ray Probe, a new electronic brachytherapy source based on a miniature x-ray tube, can be characterized within the updated TG-43 protocol with very minor modifications.
- Initial measurements have been done to compare actual and calculated source performance. Measured source performance agrees with predictions to better than 30% for operation at 40 kVp. Measurements are in progress to characterize a greater number of sources.
- The measured microTube x-ray source operating at 40 kVp had an air kerma strength of approximately 810 Gy cm² h⁻¹ when scaled to a beam current of 0.3 mA, which is twice that of a 10 Ci ¹⁹²Ir source. The measured dose rate constant at 40 kVp was 0.53 cGy h⁻¹ U⁻¹.
- Preliminary measurements confirm that the Xoft microTube Flexible X-ray Probe can be a high dose rate brachytherapy source with tunable depth-dose characteristics.

ACKNOWLEDGEMENTS

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