Comparative Dosimetry of the Xoft Axxent Electronic Brachytherapy Skin Applicator at 50 kVp with Film, Chamber, and Diode in Various Backscatter Media

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Abstract

Purpose: The Xoft Axxent Electronic Brachytherapy Skin Applicator and miniature x-ray source delivers superficial dose to shallow depths using 50 kVp x-rays over small target areas (< 20 cm2). The Xoft Skin Applicator is a 25 mm SSD cone (1.0-5.0 cm diameter) with an embedded flattening filter which acts to both filter the low energy x-rays from the beam and to mitigate the radial inverse squares peak on a flat surface. **Method and Materials:** The relative depth and profile dose characteristics of the 35 mm diameter cone were measured in water and solid water using film (Kodak EDR2, GAFChromic EBT), ionization chambers (A16, RK, Marcus) and stereotactic diode (SFD). Correction factors for diode backscatter response and solid water density are derived by comparison. TG-45 beam profile metrics for penumbral transition width (PTW), field width, flatness and asymmetry were computed. A virtual SSD was computed using in-air diode measurements. The beam energy is defined using a TG-61 HVL approach at 25 cm distance. **Results:** The first and second HVL for this system are 1.4 mm and 2.5 mm. A VSSD of 22 mm was computed, differing from the nominal 25 mm SSD. PTWs, ranging from 0.4 to 5.0 mm, are directly related to the chamber size. Field widths from 38.8 to 42.0 mm correlated with chamber size; 38.2 mm width is expected at 2 mm depth. Flatness ranged from 2.0 to 9.6%, and asymmetry ranged from +/- 0.9 to 6.2%. A linear depth correction can be made solid water density of 1.13, while a non-linear depth dependant diode backscatter correction is required. **Conclusion:** The Xoft skin applicator provides depth doses similar to other 50kVp superficial systems. The dose profiles are similar to short SSD applicators. These comparisons provide the clinical physicist with options for measuring energy and beam characteristics.

Introduction

The Xoft Axxent Electronic Brachytherapy Skin Applicator and miniature x-ray source (figure 1) delivers superficial dose to shallow depths using 50 kVp x-rays over small target areas (< 20 cm2). The Xoft Skin Applicators are conically shaped with circular treatment diameters of 10, 20, 35, and 50 mm. Each applicator has a specially designed aluminum flattening filter which acts to filter the low energy x-rays from the beam and to mitigate the radial inverse squares peak on a flat surface. Previous studies (1) and AAPM Task groups (2) have examined the feasibility of routine measurements at these energies and have concluded that conducting and obtaining clear results is problematic. Depth doses, profiles and in-air measurements were conducted using a variety of measurement tools. The goals of this investigation are to 1) examine the response and suitability of several commonly available detectors for measuring the 50 kVp low energy radiation, 2) provide a baseline series of results for each detector, and 3) suggest possible detector specific corrections.

Materials and Methods

A 35 mm surface applicator assembly and Axxent 50 kVp controller and source were used to produce low energy x-rays (Xoft, Inc, Sunnyvale, CA). As the manufacturer recommends the use of a 0.5 mm poly-acrylic end cap at the end of the conical section of the surface applicator (figure 2), this end cap was used for all measurements. Prior to each measurement, the temperature-pressure corrected dose rate of each source was measured using the inherent well-chamber and electrometer provided with the Axxent system. Each measurement was then corrected for variation of that dose rate from the nominal dose rate (110,000 U). Xoft Axxent system has a 30 second ramp up period which delivers dose equal to 2 seconds of full dose. All measurements were corrected for this end-effect.

The relative depth and profile dose characteristics of the 35 mm diameter cone were measured at room temperature in water and Solid Water ™ using film (Kodak EDR2, GAFChromic EBT), ionization chambers (A16, RK, Marcus) and stereotactic diode (SFD). Correction factors for diode backscatter response and solid water density are derived by comparison. Beam profile metrics for penumbral transition width (PTW), field width, flatness and asymmetry were computed. A virtual SSD was computed using in-air diode measurements, using the empty water tank system.

The beam energy was defined using a modified TG-61 HVL approach at 25 cm distance (figure 3). Measured in-air diode response compared to inverse squares response for VSSD=22 mm over the first 60 mm (or useful region) of the beam.

Measurements were made at room temperature using the following detectors and devices were used:

- Scanditronix RFA-200 water tank
- Scanditronix RK ionization chamber (4 mm diam, 10 mm length, effective depth 1.7 mm)
- Scanditronix SFD p-Si Stereotactic diode detector (0.6 mm diam, effective depth 0.55 mm)
- Standard Imaging Exradin A16 ionization chamber (0.33 mm diam, effective depth 1.6 mm)
- Gammex RMI “Solid Water”, varying thickness, 15x15 cm square, minimum 15 cm backscatter.
- GafChromic EBT Film, with appropriate dose-density curve correction
- Kodak EDR2 film, with appropriate dose-density curve correction
- PTW Markus 23343, 5.4 mm diameter, 2.3 mg.cm2 entrance window.
- Vidar DP16 Film Scanner with ImageJ (NIH) film analysis softwar, scanned at 600 DPI
- Varying thickness of 99.9 % pure aluminum (0.1 mm to 2.0 mm), GammexRMI
- Standard Imaging Max 4000 Electrometer.

For water tank measurements, significant care must be taken to properly align the source assembly directly above the detector and to contact the end cap assembly tank.

For film and chamber measurements, the physical setup requires only that the end cap be firmly in contact with the top plate. Film exposures were allowed 24-36 hours to stabilize.

Relative calibration curves were developed for each film series by exposing film to 1, 2, 4, 8, 16, 32, 48, 64, 96 and 128 total seconds (with an additional 2 seconds added to each exposure to account for end-effect). GafChromic EBT film has a known variation with orientation relative to the film scanner light source, and care was taken to always scan the film in the same direction, for both calibration curves and subsequent measurements.

Fig 1. The Xoft Skin-Surface applicators shown here are available in four sizes, 10 mm, 20 mm 35 mm and 50 mm in diameter. The lightweight (150 g) applicators are comprised of steel and aluminum. The Xoft Axxent ™ 50 kVp source is inserted in the tube source and rests at the tip of the conical section just above the a flattening filter. (images courtesy Xoft, Inc).

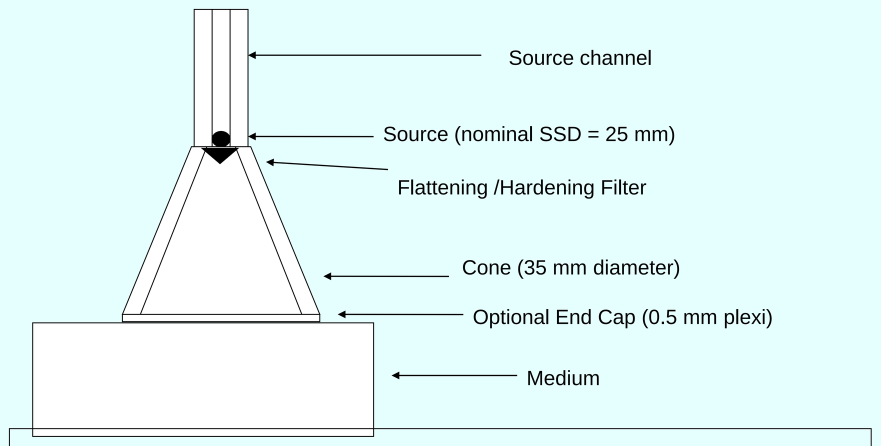

Fig 2. The Xoft Surface applicator and source assembly, with plastic end cap and measurement configuration. Various media were used, including water, and solid Water. A 1.4 mm Aluminum flattening filter is used to flatten out the beam in the central section, as dose to the surface would otherwise have variable doses due to both radial spectra and varying SSD. The end cap is used clinically to produce a consistently flat surface to treat.

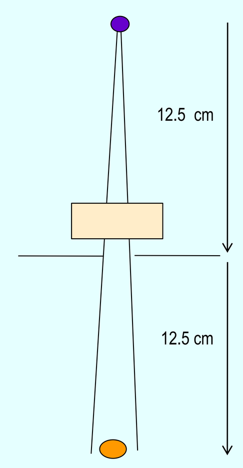

Fig 3. Beam energy characterization is made with ‘good geometry’, where the detector 25 cm from the source, and with a small window aperture through lead just large enough to irradiate the . Varying thickness of high grade aluminum were placed above the aperture until a 1st and 2nd HVL were obtained.

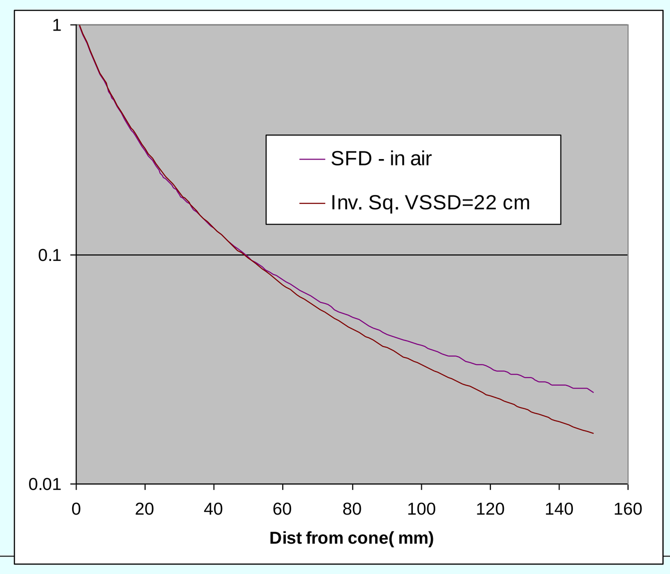

Fig 4. Measured in-air diode response compared to inverse squares response for VSSD=22 mm over the first 60 mm (or useful region) of the beam.

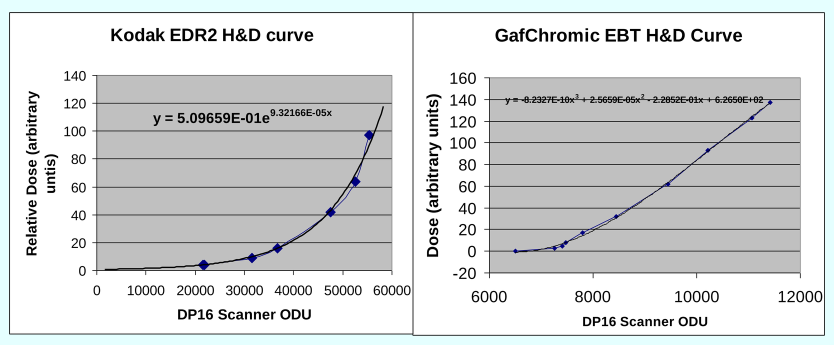

Fig 5 (a, b). Film calibration curves (H&D) relating scanner ODU to dose. In this case, dose is an arbitrary unit, meaning it is provided in incremental seconds of delivery time, normalized by the temp-press corrected air-kerma strength of the source used. The actual dose rate is not germane to these relative measurements in this investigation.

Results:

HVL: The first and second HVL for this system were measured at 1.4 mm and 2.5 mm (HC= 0.56), where the manufacturer suggested ranges are: 1.45 -1.60 mm Al and 2.5 – 2.7 mm Al (HC = 0.59).

VSSD: As shown in figure 4, a VSSD of 22 mm was computed, differing from the nominal 25 mm SSD. A VSSD could be useful for predicting dose rate or output factors if this applicator requires an air gap.

Film Calibration curves: As shown in figure 5(a) and (b) the calibration curves for EDR2 and GAF EBT are noted, along with the exponential or polynomial fits. As this data was compared relatively, the dose units are arbitrary. However, it is of interest to note that these arbitrary units actually range up to 5 Gy, and a very linear dose-film response is noted in the 1-5 Gy range for GAF EBT film.

Depth Doses: The depth doses normalized to 2 mm depth are shown in figure 5. The depth doses for this applicator show a 1st HVL in water of 8.0 mm and 2nd HVL of 9.6 mm. It is important to note that after this applicator was investigated, some small modifications were made to the flattening filter design which could soften or harden the beam. The depth doses measured with the A-16 and RK matched within 1%, whereas the depth doses measured with SFD (in water) and PTW in Solid Water) required corrections.

SFD Detector correction: The raw SFD data underestimates th dose at depth and a depth based correction is required, similar to that noted by Li(3). A comparison of the correction modeled in EGS4 by Li is shown in figure 6 for similar energies (a 50 kVp endo-rectal therapy unit). The measurement based correction differs significantly from that noted by Li, and can be attributed to the difference in the size of diodes used (0.6 mm diameter vs. 2.5 mm diam).

Solid Water depth correction: A 13% per mm depth correction is necessary to match the solid water data points measured with the PTW parallel plate chamber to the RK or A-16 chambers (figure 5). This correction is a linear first order translation of the depth distance, and is applied to the x-axis of a depth dose, and does not include the effects of inverse squares.

Profiles: Surface profiles at 2mm deep for SFD diode, RK chamber, A16 chamber, EDR2 film and GAF EBT film are shown in figure 7. The profile metrics for each are noted in table 1. The PTWs, ranging from 0.4 to 5.0 mm, correlated with chamber size. Field widths from 38.8 to 42.0 mm correlated with chamber size; 38.2 mm width is expected at 2 mm depth. Flatness ranged from 2.0 to 9.6%, and asymmetry ranged from +/- 0.9 to 6.2%. Full profiles for both SFD diode and RK chamber are shown in figures 8 and 9. The differences in the penumbra can be attributed to detector size, but the flatness and asymmetry differences are most likely due to small errors in the applicator-water surface setup. Beyond the penumbra, the SFD has been shown to fall-off due to the angular response of this type of detector. (Li,(2)). An isodose style reconstruction of the RK data (figure 8) is shown in figure 9. This plot also shows a clinically useful range (inside the 70% isodose region).

Discussion:

As clearly noted in TG-61, water based measurements of low energy x-rays are difficult to perform. A 1/2 mm gap in the applicator media interface would introduce a 2% error in the asymmetry. The choice of detector will also influence the results, as the chamber size correlates with the PTW. However, very small detectors (such as the SFD) which can more precisely measure the penumbra show depth responses and angular variance. The ease of use of film and solid water, if appropriately calibrated and density corrected provide high spatial resolution, but are limited in the range of use. In order to achieve good signal over the central aperture, the dose beyond the penumbra will be below the linear H&D range. These peripheral doses, below 10%, may not be of routine clinical use, however. Comparing the two types of film, besides having a highly linear response at this energy, GAF EBT will also eliminate processor artifact.

The method proposed by TG-61 to measure HVL is not possible with this system. The wide angular aperture of the cone, and short SSD, will result in a room full of scattered x-rays that overwhelmed the signal from the aperture. AS this system is designed to be used at an SSD of 2.5 cm, at 100 cm, the signal would be reduced by 3+ orders (from nC to pC). Even at 25 cm, the signal will be reduced by a factor of 100, but the off-aixs x-rays can be effectively blocked by a 25 cm x 25 cm sheet of 2 mm lead.

It should also be noted that the flattening filter-assembly used was an earlier prototype, and the manufacturer has since improved the design to reduce the overall flatness and symmetry.

Conclusion:

The Xoft skin applicator provides depth doses similar to other 50 kVp superficial systems. The dose profiles are similar to short SSD applicators. Film measurements in Solid Water, when appropriately calibrated and adjusted for density can provide an easy to use method for verifying the relative dose distributions at this energy. An adjustment to the TG-61 specified method for measuring the HVL must be made. As compared to film, The choice These comparisons provide the clinical physicist with options for measuring energy and beam characteristics of the Xoft Surface Applicators.

References:

1) Ma, C.-M., et.al,. “AAPM Protocol for 40-300kV xray beam dosimetry in radiotherapy and radiobiology:, Med Phys 28 (60, June 2001. (aka TG-61).

2) Li, X. A, Ma, C.M., Salhani, D.: Relative dosimetry measurement for kilovoltage x-ray units, Med. Phys. 24, 1044, 1997.

3) Li, X. A., Salhani, D., Ma, C.M., Agboola, O.: Dosimetry of a kilovoltage x-ray unit for an endocavitary radiotherapy, Med. Phys. 24, 1199, 1997.

This research was sponsored in part by Xoft, Inc.

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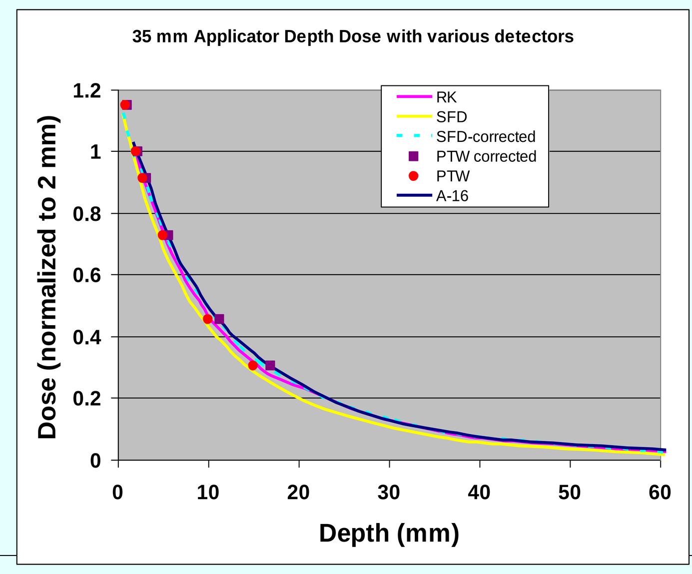

Fig 5. Relative depth dose for A16 chamber (in water), RK chamber (in water), SFD diode (in water) with and without depth dependant backscatter correction, and PTW Markus chamber with and without a correction for Solid Water Density.

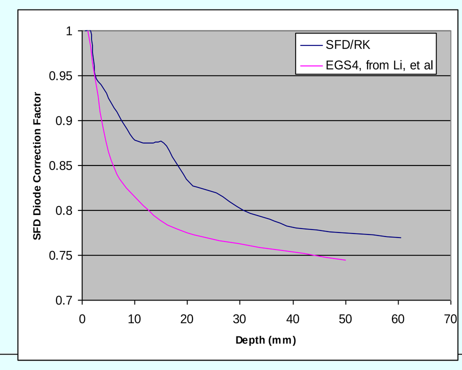

Fig 6. SFD diode correction factors computed from the comparison of the relative depth doses, in water, of the 0.6 mm diameter SFD diode vs. the 4 mm diameter RK chamber depth dose. A comparative correction predicted by Li, et al, is shown, for a larger volume diode (2.5 mm diameter), (but larger diode) at 50 kVp endo-rectal therapy system.

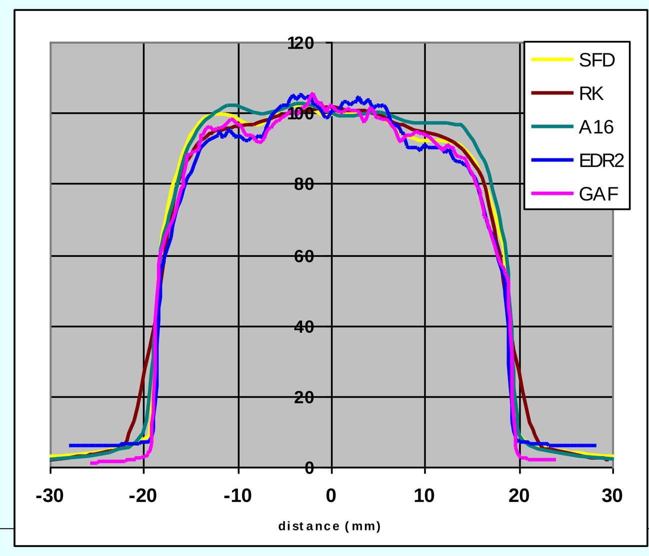

Fig 7. Dose profiles at 2 mm depth for SFD diode, RK chamber, A16 chamber, EDR2 film and GAF EDT film.

	Left PTW (mm)	Right PTW (mm)	FWHM (mm)	Flatness (%)	Asymmetry (%)
GAF	0.4	2.0	38.8	8.3	3.1
EDR2	1.1	0.4	38.4	8.8	0.9
RK	5.0	4.2	41.0	6.2	-3.4
A-16	2.6	2.1	42.0	2.0	1.5
SFD	2.3	2.2	40.0	9.6	-6.2

Table 1. 80-20 Penumbral Transition Width (PTW), Field width (FWHM), Flatness and Symmetry (TG-45) for GAF film, EDR2 film, RK chamber, A-16 chamber, and SFD diode at 2 mm depth.

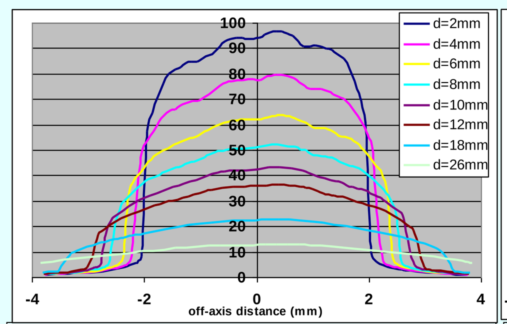

Fig 8. Full profile set using SFD diode, uncorrected

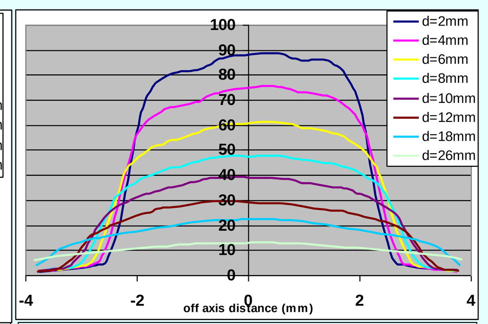

Fig 9. Profile set using RK chamber.

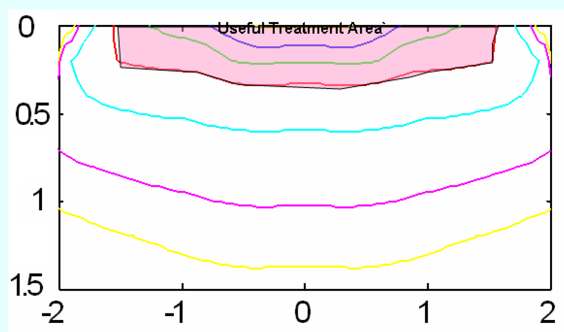

Fig 10. Isodose profiles based on fig (9), showing possible useful treatment area