# Sensitivity of the 50 kVp Xoft Axxent Skin Applicator to Flattening Filter Design, Source-Filter Position, Applicator Alignment and Surface Collimation


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## Abstract

**Purpose:** The Xoft Axxent Electronic Brachytherapy Skin Applicator and miniature x-ray source combination can be used for superficial skin or surface treatments. The applicator is a 25 mm SSD cone (1.0-5.0 cm diameter) with an embedded flattening filter. The applicator and source are decoupled, which could lead to variations in dose profile. Several potential problems are investigated for this system. **Method and Materials:** Dose profiles of the 35 mm diameter cone were measured in solid water using GAFChromic EBT film and in water using a stereotactic diode. Two flattening filter designs were examined. The effect of rotating the source or applicator independently, tilting the applicator with respect to the surface, modifying the source-filter distance, and skin collimation from 10 to 30 mm by means of tungsten aperture cutouts were examined. **Results:** The stepped disk filter design had flatness and asymmetry of 8.3% and 3.1%. The chamfered filter was 14.8% and 0.7% respectively. Rotation of the source and applicator produced a minimal change in flatness and asymmetry, with less than 2% change in flatness or asymmetry. The stepped-disk filter flatness changed by up to 7% with filter source displacement. Tipping the applicator off of the perpendicular axis by 6 degrees changed the symmetry by 14%. Beam profiles for cutouts ranging from 1.0 -3.0 showed little change in flatness and asymmetry, and the sharp edges of the PTW were retained. **Conclusion:** The stepped filter design is superior. The source-filter is sufficiently concentric to prevent profile shifts, but the dose is very sensitive to the filter-source distance, as predicted by the geometric model. Small tilts of up to 2 degrees, or a 1 mm gap on one side of the cone, can be tolerated. Skin collimation preserves both profile and penumbra. Research Sponsored by Xoft, Inc.


## Introduction

**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 (figure 2). 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. The overall sensitivity and of the surface applicator to small deviations in both manufacturing tolerances and setup tolerances were investigated. Four types of variations in use were investigated in this work.

1) The effects of surface collimation on the beam profile were examined.

2) The effects on the beam flatness and symmetry of two filter designs, a stepped filter and a chamfered filter, were examined by simple model, and by measurement.

3) The applicators are designed for use with any 'off-the-shelf' 50 kVp source, and the sources are routinely replaced. As the source and applicator are loosely coupled, small variations in distance and centering of the source relative to the flattening filter can occur. Additionally, the manufacturing tolerances of the source inside the source tube could also introduce similar variations to the source-flattening filter geometry. The effects of these deviations were examined.

4) The system is also intended to be placed directly over the treatment area, with an end cap, which is intended to create a flat surface. The effect of potential error in the conjunction of end cap and treatment surface were investigated.

## Materials and Methods

**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). The 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 profile dose characteristics of the 35 mm diameter cone were measured at room temperature in Solid Water ™ (Gammex RMI, Madison, WI) using GAFChromic EBT film (ISP, Wayne, NJ). Films were scanned using a Vidar DP-16x scanner (Vidar, Herndon, VA) and analyzed using ImageJ (NIH). Film exposures were allowed 24-36 hours to stabilize, and the red channel information was filtered out at scan time. 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.

A first order model to predict the variation of beam flatness and symmetry was created in Matlab (Mathworks, Natick, MA). This simplistic model examines the inverse squares effect of a spherical radiating source placed at varying distances from a chamfered flattening filter. The effect of the chamfered filter were modeled by a simple radial path-length beam attenuation (figure 4).

Beam profiles for two types of flattening filter (figure 3) were measured; a filter designed from a series of disks, and a chamfered conical filter. Film profiles using the chamfered filter were examined for sensitivity to an air-gap at the edge of the conical section. The effects of the relative positions of the source to the flattening filter were examined by introducing a gap between the source and the flattening filter. Beam profiles for several arbitrary shapes of surface collimator ('cutouts') were measured with the film system. Cutouts were fashioned using Xoft FlexiShield ™, which is a soft, flexible, tungsten impregnated polymer with an equivalent shielding of 0.5 mm lead.

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).

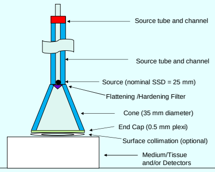


Fig 3. The Xoft Surface applicator and source assembly, with plastic end cap and measurement configuration. Solid Water and GaCfhromic EBT film were used to measure the flatness and symmetry with varying flattening filters and surface collimators. Measurement setup errors were investigated by tilting the source tube/channel to create a gap on one side of the cone/end cap assembly at the media surface.

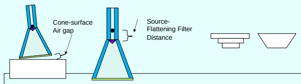


Fig 4. Two potential errors are A) the introduction of an air-gap at the surface of the cone caused by tipping the applicator assembly away from the orthogonal to the surface, and B) a variation in the source-flattening filter distance caused either by incomplete insertion of the source tube into the applicator, or by variations in the manufacture of the source. Two types of flattening filter, a stepped disk, and a chamfered cone were examined

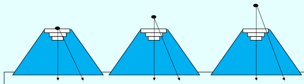

Fig 5. The effect on a radial profile caused by a variation in the source-flattening filter distance (SFFD) can be predicted by inspection of the geometry. As the source moves away from the filter, the radial path will pass through different thicknesses of the flattening filter.

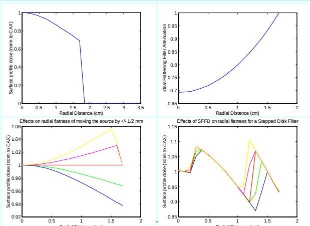


Fig 6. a) Computation of the effect of inverse squares on the radial profile due to increasing SSD. b) An 'ideal' flattening filter was computed by inverting the missing dose in 6(a).

c) From top to bottom, the SFFD was perturbed by 0.5 (yellow), 0.25, 0, -0.25 and -0.5 mm (blue) from the ideal location. Moving the source closer to the ideal flattening filter lowers the dose at the edges of the profile, as the x-rays must pass through more attenuation than the ideal. Moving the source away from the filter causes the 'horns'.

d) A similar effect is noticed with a stepped filter, except that the ideal SSFD will also have a ringing effect introduced by the abrupt filter edges.

## Results

**SFFD Model:**

As shown in figure 6 (a), the an increase in source-surface distance will reduce the dose by 31% at the edges of the applicator (in this case, the 35 mm cone). To counteract this inverse squares effect, the ideal flattening filter design (fig 6(b)) would invert this and reduce the dose at the central axis by the same amount. The predicted dose would be ideally flat (fig 6(c), red line). Moving the source closer to the filter by 0.5 mm (blue line) is predicted to reduce the dose by 7% at the edges, due to the increased material those x-rays would pass through (relative to the ideal). Moving the source away from the filter by 0.5 mm (yellow line) would raise 6% 'horns' at the edge of the profile. An extension of this model from the ideal filter to a stepped disk set (figure 6(d)) shows similar behavior with +/- 4% variation from the zero-error SFFD (red line). The zero-error model of the stepped disk filter, however, begins with a +/- 10% variation due to the edges of the disks.

**SFFD Measurements:**

The zero SFFD profile has an inherent flatness error of +/- 6% as noted in figure 7. Decreasing the SSFD dropped the shoulders by an additional 4%, where increasing the SFFD raised the shoulders by 6%. The full-width-half maximum of the increased FSSD also increased by 2 mm on each side, while introducing a sloped effect at the shoulders.

**Stepped vs. Chamfered Filter:**

The stepped disk filter design had flatness and asymmetry of 8.3% and 3.1% as noted in figure 8. The chamfered filter was 14.8% and 0.7% respectively.

**Surface Gap Effects:**

Tipping the applicator off of the perpendicular axis by 6 degrees changed the symmetry by 14% as compared to the perpendicular applicator as noted in figure 9. A 6 degree tip would be caused by a 3.6 mm gap at the edge of a 35 mm applicator. Note that the initial symmetry of the perpendicular applicator began with an asymmetry of 3.1%, and the tipping had the effect of moving this asymmetry to the other side. Also note that the profiles are all normalized at the central axis, which has the effect of hiding the reduced dose expected for tipped applicators. The dose reduction of the 6 degree tilt would be about 13%, based on inverse squares reduction alone.

**Source Rotation Effects:**

Rotation of the source inside the applicator produced a minimal change in flatness and asymmetry, with less than 2% change in flatness or asymmetry as noted in figure 10.

**Surface Collimation:**

The films for four different surface collimation cutouts are shown in figure 10. Note that the ringing effect of the stepped filter is retained for each cutout. Also note that imperfections in the cutouts are reflected in the dose at the surface. The measured profiles for cutouts from 10 mm diameter to 30 mm diameter in figure 11, show little change in flatness and asymmetry, and the sharp edges of the PTW were either retained or enhanced.

## Discussion

**Discussion**: The design of the Xoft Axxent surface applicators must include a flattening filter to reduce the dose at the central axis. This filter will have a beneficial effect of increasing the depth dose due to beam hardening, but will also reduce the dose rate. A simple inverse-squares and attenuation model predicts that the distance between the filter and the source will introduce variation in the beam profiles. This result implies that care must be taken to place the source inside the applicator, but also implies that small variations in the source location due to manufacturing tolerances will also affect the dose profile. These variations in SFFD will also affect SSD, and hence affect dose rate. This result leads to a recommendation that the dose rate and surface profile be measured when replacing the source.

These results are not limited to Electronic Brachytherapy. Surface therapy using Ir-192 HDR brachytherapy sources, such as the Leipzig or Valenica applicators are in use. The source location of the Ir-192 pellet of an HDR afterloader is typically adjusted at each source change to a tolerance of +/- 1 mm (although +/- ½ mm is certainly achievable). The model described here only looks at the effect of inverse squares and flattening filter design. It can be expected that similar variations would be observed for Ir-192 applicators.

An important note is that the stepped filter and chamfered filter used in this study were initial prototypes, and have since been improved to both reduce the overall ringing effect, and the sensitivity to SFFD. However, the need to individually measure each new source and then to correctly orient the source, applicator and treatment area is key to delivering a safe, well-characterized, efficacious dose.

## Conclusion

**Conclusion:** The Xoft Axxent surface applicator shows some sensitivity to the source-applicator-treatment area arrangement as demonstrated here with model and measurement. Errors in SFFD should be minimized during use. The stepped disk filter design tested here is superior to a chamfered disk, but can be improved. The source-filter is sufficiently concentric to prevent profile shifts, but the dose is very sensitive to the filter-source distance, as predicted by the geometric model. Small tilts of up to 2 degrees, or a 1.2 mm gap on one side of the 35 mm cone, can be tolerated. Larger gaps should be avoided or mitigated. Skin collimation preserves both profile and penumbra. Lastly, dose rate output measurements and surface profiles must be obtained for each new brachytherapy source-surface applicator combination, whether electronic or radio-isotopic.


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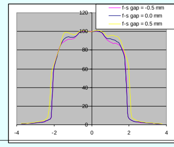


Fig 7. As predicted by the Matlab model (figure 6), when moving the source away from the filter, the horns increase. A 7% increase in the beam flatness at the surface is introduced.

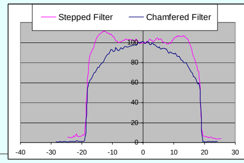


Fig 8. Dose profiles at the surface for the Chamfered filter compared to a stepped filter.. Although the stepped filter introduces a ringing effect , the overall flatness inside the 80% field width is reduced from 20% to 7%.

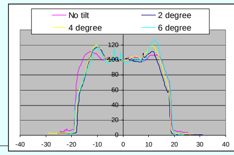


Fig 9. Tipping the cone raises the surface dose on one side. The right side of the plot is the side with the introduced gap. As the original untilted beam had an inherent asymmetry, the titled beam actually removed this. Tilts of 2, 4 and 6 degrees correspond to 1.2, 2.4 and 3.6 mm gaps at one edge of the cone.

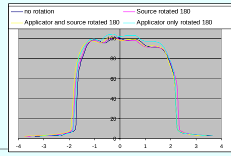


Fig 10. A minimal effect is noticed when rotating the source relative to the applicator assembly.

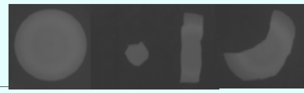

Fig 11. Surface dose films of an open 355 mm collimator, 10 mm cutout, 10x30 mm rectangular cutout, and 20 x 35 mm crescent. Note the Light ringing effect caused by the stepped flattening filter, as well as the sharp penumbral boundary created by the 3 TVL equivalent cutout.

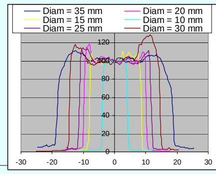


Fig 12. Dose profiles at the surface under Tungsten cutouts ranging from 10 mm to 35 mm. Some increase in dose is noticeable at the edges of the larger cutouts. Also notice the sharp penumbral transition, even for the smallest cutouts (< 2 mm from 20% to 80%).