COMPARISON OF AN IMPROVED X-RAY SOURCE FOR USE IN ALL APPLICATIONS WITH THE EXISTING XOFT X-RAY SOURCE

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ABSTRACT

•Purpose: To compare the dose delivered to target tissue between the Xoft X-ray source with an improved X-ray source for use in Xoft applicators using existing TG-43 parameters for the X-ray sources.

•Method and Materials: Modifications were made to the existing Axxent HDR X-ray source to increase the dose rate and improve the source lifetime. Measurements were made comparing the dose through balloon applicators, vaginal cylinders, and the cervical applicator to the prescription surface/point. Isodose contours for the balloon and vaginal applicators were also compared. In all cases, the same treatment plan was used for both X-ray sources for a given applicator. Measurements were made is a shielded water tank using Gammex Solid Water® phantom. The test fixture held Gafchromic™ EBT3 film and an encapsulated PTW 34013 ionization chamber mounted at the prescription surface 90° from the applicator plane. Three of each type X-ray source were used in the averages.

•Results: For the Balloon applicator, the average measured dose difference at the 1 cm APBI prescription surface ranged from -3.0% for a 3.4 cm diameter balloon to -0.2% for a 5.4 cm diameter balloon. Balloon IORT treatment plans were evaluated for volumes of 20cc to 130cc. Dose differences ranged from -5.1% for the minimum fill to -0.3% for the largest fill. For vaginal applicators, the average difference in dose at the 0.5 cm prescription surface ranged from -4.4% for the 30 mm applicator to -1.8% for the 35 mm applicator. For the cervical applicator, the average dose difference at point A was -2.8%.

•Conclusions: The difference between dose delivered to the prescription surface for all applicators tested was less than 6% with no modification of the TG-43 parameters. It is expected that an update of these parameters for the new source will increase this agreement.

BACKGROUND

- The Axxent® Electronic Brachytherapy (eBx) System utilizes a miniaturized X-ray source to apply radiation directly to a tumor bed within the body. The Axxent X-ray Source delivers high-dose rate, low energy radiation treatment without the use of radioactive isotopes.
- The Axxent eBx System has been FDA-cleared for the general treatment of "lesions, tumors and conditions in or on the body where radiation is indicated".
- The miniaturized X-ray source has been used with a family of saline-filled Balloon Applicators, Vaginal Cylinders, and Cervical Applicators, as shown in figure 1, to treat breast, endometrial, cervical, and other cancers using the Xoft 50 kVp source TG-43 parameters.
- The Improved X-ray source has been used with the Surface Applicator to treat surface lesions since 2016 using TG-61 formalism.
- The original Xoft X-ray source has a limited use life due in part to the deterioration of the components around the source during radiation and cooling.

Figure 1 Balloon, Vaginal, and Cervical Applicators

Figure 2. The Axxent eBx Controller

METHODS

MOTIVATION

- The Axxent HDR X-ray source has a limited lifetime due in part to radiation damage to the source catheter and breakdown of the insulation around the source due to the conductive coolant required to dissipate heat generated at the X-ray target.
- Composition of the X-ray catheter was modified to produce greater radiation robustness, the need to remove coolant from the source catheter between uses was eliminated, and the efficiency of the X-ray target was increased decreasing overall treatment times (figures 3,4).
- It is desirable to use this improved source in all applications.

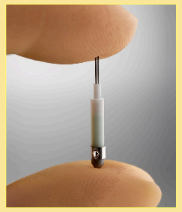

Figure 3. Xoft Axxent X-ray source.

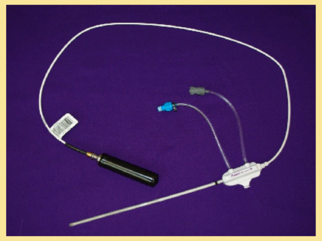

Figure 4. Improved Xoft Axxent X-ray Source with cooling catheter

EXPERIMENTAL SETUP AND METHOD

- All Balloon, Vaginal Cylinder, and Cervical Applicator measurements were made using a Gammex SolidWater™ test fixture designed for previous applicator validations with fixture modifications for each applicator type (Figure 5). The fixture is designed to hold radiochromic film in a plane parallel to the applicator source channel axis and to hold the encapsulated PTW model 34013 ionization chamber at the prescription surface. All measurements were made with this test fixture immersed in a shielded water tank (figure 6).
- Three of the improved X-ray sources (model S7600) and three of the original sources (model S7500) were tested for each applicator type and size.
- Accelerated Partial Breast Irradiation (APBI) Balloon Applicator treatment plans with inflation diameters representing the midpoint of each balloon size were used.
- IntraOperative Radiation Therapy (IORT) Balloon Applicator treatment plans with balloon fill volumes from 20 cc to 130 cc, representing the minimum and maximum volumes for these applicators were used.
- A treatment was administered to produce a specified dose to Point A for a straight tandem with 2 cm ovoids.
- Identical treatment plans, scaled by the measured Air Kerma Rate (AKR) of each individual source, were used for both source types, based on the S7500 TG-43 parameters previously established[1]. An Axxent eBx controller was used to administer all plans (figure 2).
- The SolidWater encapsulated ionization chamber was used to measure the absolute dose at the prescription surface (0.5 cm for the Vaginal Cylinders, 1.0 cm for the Balloon Applicators) at 90° aligned with the center of the applicator.
- GafChromic EBT3 film images were scanned using an Epson Expression 10000XL desktop scanner and converted to text images using ImageJ for further processing using LabView Software.
  - An Isodose mask was created using an image of the isodose contours calculated by Varian BrachyVision™, scaled to the film dimensions.
  - The calibrated film image was aligned with and multiplied by the isodose mask to produce isodose contours from the film. These contours were unwrapped and the average dose and deviation from the average can be determined.

1. "Calculated and Measured Brachytherapy Dosimetry Parameters in Water for the Xoft Axxent X-Ray Source: An Electronic Brachytherapy Source", Rivard, MJ, et. al. Medical physics 33 (11), 4020-4032.

Figure 5. Test fixture modified for the cervical applicator

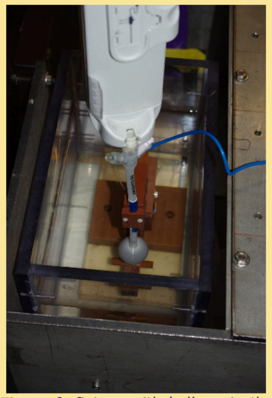

Figure 6. fixture with balloon in the water tank

RESULTS AND DISCUSSION

Balloon Applicators

- The dose at the 1 cm APBI 3.4 Gy prescription surface at 90° was measured using the ionization chamber with average results presented in table 1.
  - Measurements for balloon fill diameters of 3.4 cm, 4.6 cm, and 5.4 cm are reported for the 3-4 cm, 4-5 cm, and 5-6 cm balloons respectively. The 5x7 cm ellipsoidal balloon was filled to 110 cc, representative of the diameter midpoint of its designed volume.
  - The largest average deviation between the source types is -3.0% observed for the smallest diameter applicator tested.
  - In all cases, the average prescription point dose measured for the S7600 source is lower than that for the S7500 source.
- The dose reported for the IORT treatment plans was measured at the 0.5 cm prescription surface at 90° with average results presented in table 2.
  - Saline fill volumes of 20cc, 30cc, 60cc and 130cc represent minimum, maximum and intermediate fill volumes.
  - The largest deviation between the average of the source types is -5.1% observed for the smallest fill volume.

Balloon Applicator	Inflation Size	S7500 Dose (Gy)	S7600 Dose (Gy)	% Difference
3-4 cm	3.4 cm	3.46	3.35	-3.0%
4-5 cm	4.6 cm	3.61	3.52	-2.5%
5-6 cm	5.4 cm	3.34	3.34	-0.2%
5x7 cm	110 cc	3.32	3.31	-0.4%

Table 1. APBI measured dose

Balloon Vol (cc)	Expected Dose (Gy)	S7500 Dose (Gy)	S7600 Dose (Gy)	% Difference
20	10.4	10.10	9.59	-5.1%
30	11.8	11.35	11.12	-2.0%
60	11.5	11.56	11.40	-1.4%
130	13.3	13.33	13.29	-0.3%

Table 2. IORT measured dose

Vaginal Cylinders

- The dose measured at the 0.5 cm prescription surface for each Vaginal Cylinder is presented in table 3.
  - The prescription dose for the 20, 25, 30 and 35 mm cylinders is 7.0 Gy.
  - The largest deviation between the average of the source types is -4.4% for the 30 mm cylinder.

Cylinder Size (mm)	Expected Dose (Gy)	S7500 Dose (Gy)	S7600 Dose (Gy)	% Difference
20	7.09	7.15	6.86	-4.1%
25	7.09	7.16	6.87	-4.1%
30	7.06	7.20	6.88	-4.4%
35	6.86	7.02	6.90	-1.8%

Table 3. Vaginal Applicator measured dose

Expected Dose Pt A (Gy)	S7500 Dose (Gy)	S7600 Dose (Gy)	% Difference
3.0	3.10	3.01	-2.9%

Table 4. Cervical Applicator measured dose

Cervical Applicator

- The expected dose at Point A was 3.0 Gy for the straight tandem with 2.0 cm ovoids. The measured dose at Point A is presented in table 4.

Isodose Contours

- Dose contour averages for each balloon and cylinder were calculated, with representative results presented in figure 7 and table 5.
  - The difference between the source types, out to ±150° from the distal tip of the applicator, is less than 10%, with larger systematic differences at larger polar angles.

Expected Dose (Gy)	S7500 Dose (Gy)	S7600 Dose (Gy)	% Difference
1.9	1.87	1.84	-1.6%
2.6	2.43	2.40	-1.4%
3.4	3.45	3.40	-1.5%
4.5	4.74	4.63	-2.3%
6.4	6.53	6.30	-4.0%

Table 5: Dose contour averages for the 4.6cm balloon

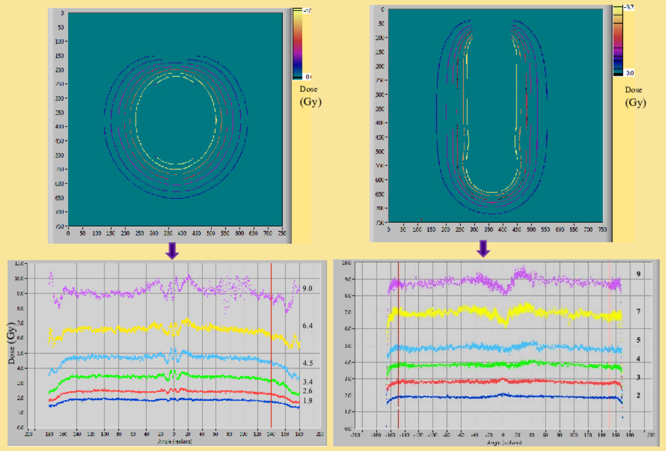

Figure 7. Sample isodose contours for the 4.6cm balloon and 25 mm cylinder for the S7600 source

▪The 100 source average output (AKR) of the S7600 X-ray source is 12% higher than that of the S7500 source, decreasing overall treatment times.

SUMMARY & CONCLUSION

- The dose distribution of the improved S7600 X-ray source was evaluated through Balloon, Vaginal Cylinder, and the Cervical Applicator using the TG-43 parameters for the S7500 source.
- Agreement of the dose at the prescription surface at 90° was shown to be within 5% for APBI, Cylinder, and cervical plans, with the S7600 dose reduced compared to the S7500 dose.
- Isodose contour shape was in agreement within 10% for contour averages, with reduced dose in the proximal direction for the S7600 source.

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