Clinical Implementation of a Treatment Planning System used for INTRABEAM IORT

S. GROS[1], S. HOFFMAN[1], S. GUPTA[1], C. HENTZ[1], B. EMAMI[1], W. SMALL[1], A. SETHI[1], C. ILLANA[2]
1 Department of Radiation Oncology, Stritch School of Medicine, Loyola University Chicago, Maywood IL, USA
2 GMV, Isaac Newton 11 (PTM), 28760 Tres Cantos, Madrid, Spain

Introduction

3D dose distributions from an INTRABEAM X-ray source equipped with FLAT and SURFACE applicators were measured in both homogeneous and heterogeneous phantoms. The measured data were subsequently compared with a Monte Carlo (MC) based commercial treatment planning software (TPS) for IORT [1]. We are investigating the ability of the TPS to accurately predict measured doses in phantom and patient geometries.

Methods

Measurements

Depth-dose rates for a 50-kV INTRABEAM x-ray source equipped with FLAT (Ø 1- 6 cm) and SURFACE (Ø 1-4 cm) applicators were measured with a calibrated parallel plate ion chamber (PTW 34012) along the central axis (CAX) in a water phantom (figure 1).

EBT3 Gafchromic films (Ashland, NJ) were combined with solid water to measure 2D dose distributions for each FLAT and SURFACE applicators. The films were placed at 0 mm (SURFACE), 5 mm depth (FLAT) parallel to the applicators surface, and along the central axis of the applicators (figure 2). The x-ray source was set to deliver a CAX dose of 1 Gy at 0 mm (SURFACE) and 5 mm (FLAT) depths.

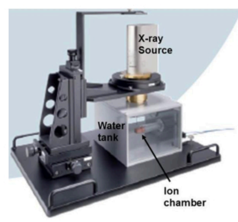


Figure 1: IC measurement set-up

Treatment planning software calculations

The RADIANCE TPS (GMV, Spain) provides a hybrid Monte Carlo algorithm that accounts for photoelectric and compton interactions. Dose distributions for a 50 kV INTRABEAM x-ray source were calculated for all FLAT and SURFACE applicators in water medium in order to model the experimental conditions for the EBT3 films measurements (figure 2).

The Monte Carlo calculation parameters were:

- Prescription: 1 Gy at 5 mm depth (FLAT)
  1 Gy at 0 mm depth (SURFACE)
- Dose computation algorithm: Monte Carlo in heterogenous medium
- Number of particles simulated: 5 x 10^6
- No noise filtering
- Dose grid resolution: 1 mm

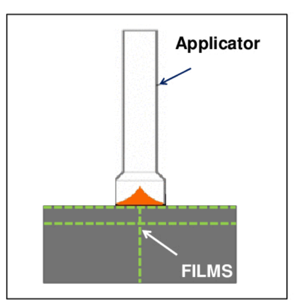


Figure 2: Set-up for film measurements

Comparison of dose distributions

The 3D doses from RADIANCE were exported as DICOM RT dose files. The radio-chromic films were calibrated with the red channel using RIT (Radiological Imaging Technology, CO). The Ion Chamber data, films measurements and RADIANCE calculations were analyzed with MATLAB (The Mathworks, MA). The comparison focused on depth dose variation and on x-ray beam characteristics relevant to clinical use: surface dose, homogeneity, field sizes and penumbra width. Example dose distributions from RADIANCE are shown in figure 3.

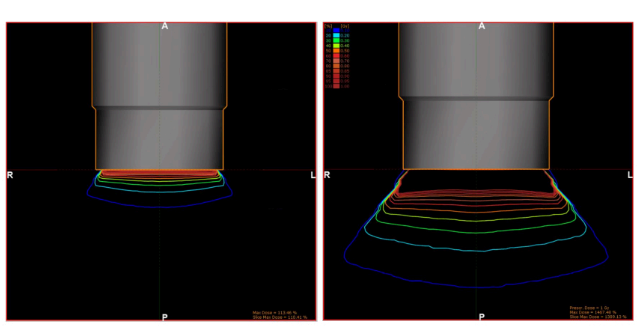


Figure 3: Example dose distributions calculated by RADIANCE in water medium for 3 cm SURFACE and FLAT applicators

Results

Central axis depth dose

Figure 4 presents an example depth dose comparison between ion chamber data, films measurements, and RADIANCE (MC) calculations for 4 cm FLAT and SURFACE applicators. The results show good agreement between the Monte Carlo calculations and both ion chamber and film doses measurements in water medium up to 15 mm depth. A difference of up to 5% can be seen at larger depths between MC and measured doses.

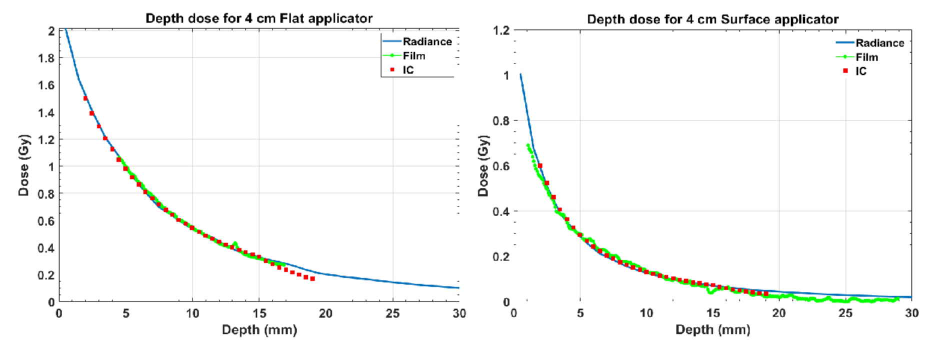


Figure 4: Comparison of depth doses along central axis for 4 cm FLAT and SURFACE applicators from ion chamber data (IC), Film measured CAX dose (Film) and TPS (RADIANCE) calculated dose

Surface dose

Table 1: Ratio of applicators surface doses to doses at 5 mm depth for TPS calculations

Applicator Ø (cm)	FLAT		SURFACE	
	D_{0mm}/D_{5mm}	D_{max}/D_{5mm}	D_{0mm}/D_{5mm}	D_{max}/D_{5mm}
1	4.7	9.5	6.8	6.9
2	3.4	38.1	5.1	5.7
3	2.3	14.5	4.0	4.5
4	2.0	31.7	3.5	4.5
5	1.8	46.5		
6	1.8	12.5		

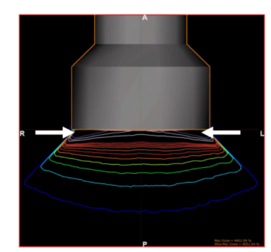


Figure 5: Location of surface dose hot spots for flat applicators

The ratios of surface dose to dose at 5 mm depth along the central axis (D_{0mm}/D_{5mm}), and ratios of maximum surface dose to reference dose (D_{max}/D_{5mm}) estimated by RADIANCE are shown in Table 1. The results indicate that:

1. The surface dose varies with applicator type and size
2. SURFACE applicators produce a surface dose 3.5 to 6.9 times the reference dose
3. FLAT applicators surface doses are greater, up to ~40 times the reference dose

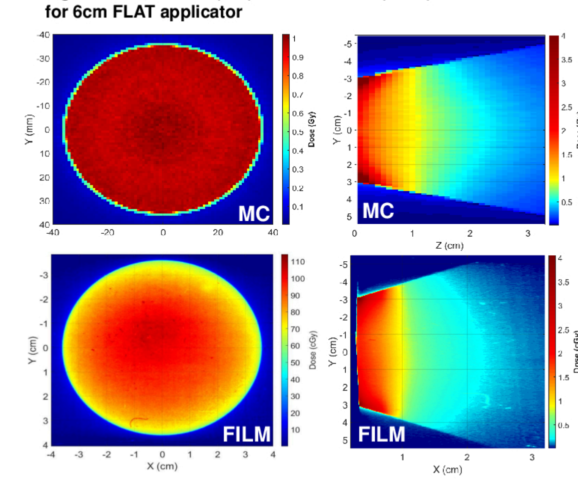
The surface dose hot spots are located at the periphery of the surface dose distribution, as indicated by the white arrows in figure 5. Adding shielding might protect superficial tissue from unnecessary exposure when using FLAT applicators clinically. Additional measurements will be needed to confirm these results.

2D dose distributions

Figure 6 shows examples of 2D dose distributions from RADIANCE calculations (MC) and from film measurements (FILM) obtained for the 6 cm FLAT applicator at 5 mm depth, and along the Central axis.

Noticeable qualitative differences can be observed between Monte Carlo and measured profiles in terms of field divergence and 2D profiles uniformity.

Figure 6: Calculated (MC) and measured (FILM) dose distributions for 6cm FLAT applicator



Dose Homogeneity

The dose homogeneity was calculated as the ratio Dmax/Dmin from TPS calculations and film measurements. The max homogeneity $\mathbf{H_{max}}$ agrees within 2%, while the depth of max homogeneity ($\mathbf{d_{Hmax}}$) agrees within 1 mm. Differences in $\mathbf{d_{Hmax}}$ are larger for FLAT Ø > 3 cm.

The film measurement set-up could not reach the applicators surface. However, the RADIANCE calculations agree with results from reference [2].

Table 2a,b: Maximum homogeneity of dose distribution for (a) FLAT applicators and (b) SURFACE applicators

(a)

Applicator Ø (cm)	RADIANCE		FILM	
	H_{max}	d_{Hmax}(mm)	H_{max}	d_{Hmax}(mm)
1	1.02	7.95	1.03	7.25
2	1.07	8.16	1.07	7.5
3	1.05	1.14	1.03	1.2
4	1.09	0.57	1.10	6.5
5	1.08	0.55	1.08	6.5
6	1.07	0.59	1.13	5.5

(b)

Applicator Ø (cm)	RADIANCE	FILM [2]
	H_{max}	H_{max}
1	1.01	1.06
2	1.13	1.13
3	1.11	1.08
4	1.27	1.07

Penumbra

The depth dependence of the 80%-20% penumbra widths from RADIANCE calculations and film measurements is shown in figure 7. The data were fitted with parametric functions to model the depth variation for FLAT and SURFACE applicators.

The penumbra for FLAT applicators is < 1 mm until past $\mathbf{d_{Hmax}}$. It then increases due to scattering of the primary x-ray beam.

The penumbra for SURFACE applicators follows a similar increase as seen for FLAT applicators past $\mathbf{d_{Hmax}}$.

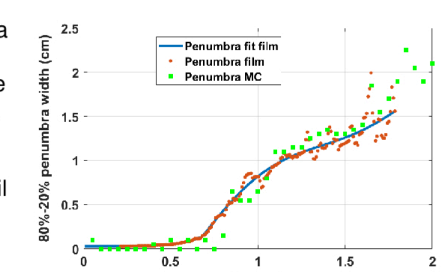


Figure 7: Example penumbra widths for 5 cm FLAT applicator

Conclusion

RADIANCE calculations in water medium fairly agree with ion chamber and film measurements for depth doses along the CAX. We were able to determine that the hybrid Monte Carlo algorithm can calculate several important beam characteristics relevant for clinical situations and verify the results with our and other published work [2]. However, discrepancies seen for beam divergence *versus* depth and 2D dose distributions uniformity need further investigation.

On-going / future work

Our TPS is being updated to the latest version. On-going work consists of evaluating the Monte Carlo dose calculation in heterogeneous media. In parallel, we are testing the TPS in real clinical conditions including for the simulation of superficial skin treatments. Finally the surface dose for FLAT applicators will be measured in solid water in order to verify the potentially high surface doses calculated by the TPS.

[1] RADIANCE – a planning software for intra-operative radiation therapy, Transl. Cancer Res. (2015); 4(2):196-209
[2] Dosimetric characterization of INTRABEAM miniature accelerator flat and surface applicators for dermatologic applications, Physics Medica 31 (2015) 224-232