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Technical Communication

Visualization of an Intra-Operative X-Ray Source With Liquid Scintillation Imaging

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Abstract

Intraoperative radiotherapy (IORT) is an alternative to full course radiotherapy for select patients. The IntraBeam (Zeiss, Germany) delivery system uses a low energy (50kVp) x-ray source. In this communication, a method for rapidly characterizing emissions from an IORT x-ray source is shared. A leaded glass phantom was filled with liquid scintillation cocktail (LSC) (Ultima Gold; PerkinElmer, USA) and a 13 MP CMOS detector used to collect images and videos. Scintillation images were analyzed with relative intensity plotted as a function of distance from the bare probe tip. RGB channels were separated, blue selected, smoothed, and overlaid with isodose lines. Videos allowed time-resolved visualization of energy deposition. Elemental composition of LSC fluid was compared to water and soft tissue. LSC has a lower effective Z (5.9) than water (7.2) and tissue (7.1). Observed relative intensity compared to Monte Carlo depth dose in water revealed an under-response (max, 9.49% at 5mm). Optimization of LSC composition, parameters for image collection, and derivation of correction factors are areas of future study. This visualization method shows potential for rapid commissioning of an IORT x-ray source with scintillation imaging.

Introduction

Intraoperative radiotherapy (IORT) for breast cancer has been actively studied for over 20 years [1-3]. The largest trials have explored low energy x-rays (30-50 kV), targeted intraoperative radiotherapy (TARGIT-IORT) and high-energy electrons (3-12 MeV), electron intraoperative radiotherapy (ELIOT) [4,5]. Designed to investigate non-inferiority and equivalence, results have been controversial but indicate acceptability for select patients [6]. Long-term TARGIT-IORT data has demonstrated comparable local control and overall survival to external beam radiotherapy [7].

The current protocol for commissioning low energy x-ray sources uses a parallel-plate ionization chamber [8]. Several investigators have also used radiochromic film for dosimetric analysis [9-11]. Film measurements are valuable for their spatial resolution which allows visualization of dose distributions. However, care must be taken when collecting measurements with film [12]. Film from different manufacturers have varying sensitivities and dependencies, including non-linear energy response [13]. While the use of ionization chambers is well established and reliable, film remains a tedious art form, with both methods consuming valuable clinical time.

Scintillation imaging is an active area of study with potential for rapid readout [14-16]. Coupling liquid scintillation with optical imaging, scintillation imaging allows near real-time visualization of volumetric dose distributions by collecting light intensity proportional to energy deposition. The current work demonstrates proof-of-principle for rapid characterization of an IORT x-ray source using liquid scintillation imaging.

Methods and Materials

Experiments were performed with a 50kVp x-ray source, IntraBeam (Ziess, Germany); bremsstrahlung photons are produced by a dithered electron beam impinging upon an Au target on the inner probe tip. The manufacturer (Ziess, Germany) provided leaded glass phantom was filled with commercial liquid scintillation cocktail (LSC), Ultima Gold (PerkinElmer, USA). LSC emits blue light proportional to imparted energy. Chemical compositions of commercial LSCs are proprietary; however, a generalized formula consists of organic solvent, surfactant, primary scintillator (emitting UV light), and secondary scintillator (emitting blue light).

Visualizations were collected with a 13 MP CMOS detector, 1080p resolution, with 30 fps video. Image processing was performed with ImageJ (National Institute of Health, USA) [17]. RGB channels separated and blue, color of LSC emissions, analyzed quantitatively. For visualization, smoothing was applied and intensity contour lines overlaid. Intensity with distance from surface of probe tip was determined by collecting a line profile and normalizing to maximum intensity at the surface of the x-ray source probe tip.

Results

Visualization of X-Ray Source

Acquired videos yielded visualization of the swept, dithered, nature of beam generation. Images provided

visualization of emission intensity around the x-ray source probe tip and quantification of intensity fall-off with distance, See Figure 1.

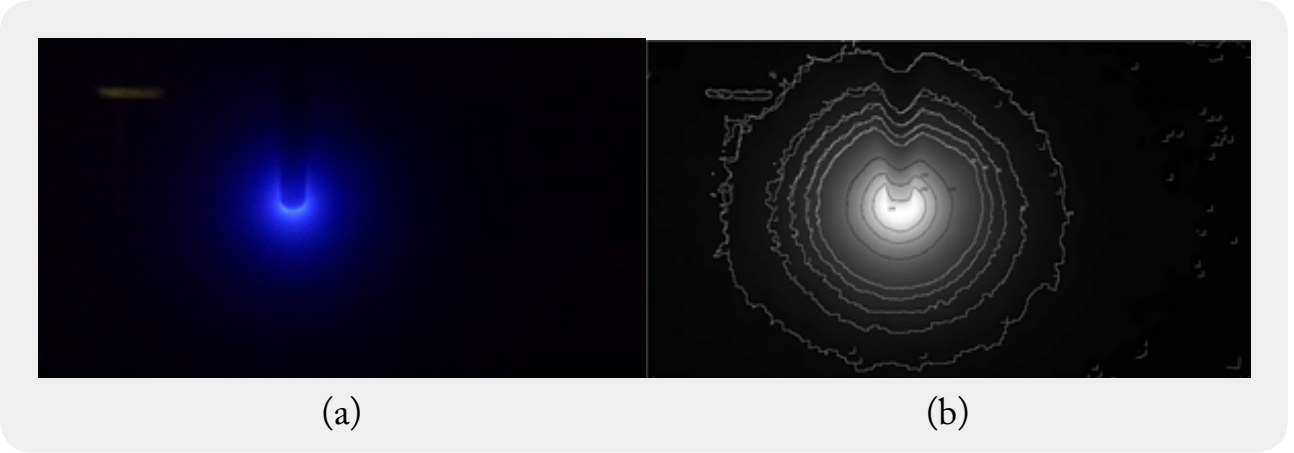

Figure 1: *Still images of scintillation produced by x-ray source in LSC (a) raw RGB image, streak in upper left due to reflection from phantom surface; (b) blue channel, smoothed with pixel intensity contours overlaid.*

Intensity Variation With Distance, Comparison With Published Values

Intensity variation with distance for RGB and blue channel, were plotted with Monte Carlo derived depth dose values in water. Scintillation images were observed to under-respond; nearly 10% at 5mm with blue channel, See Figure 2, Table 1.

Water Equivalence of Medium

The elemental composition of LSC fluid, provided by the manufacturer (Perkins-Elmer, USA), was compared to water and soft tissue, as defined by ICRU 44 [16]. LSC fluid was determined to have a lower effective Z (5.9) than water (7.2), See Table 2.

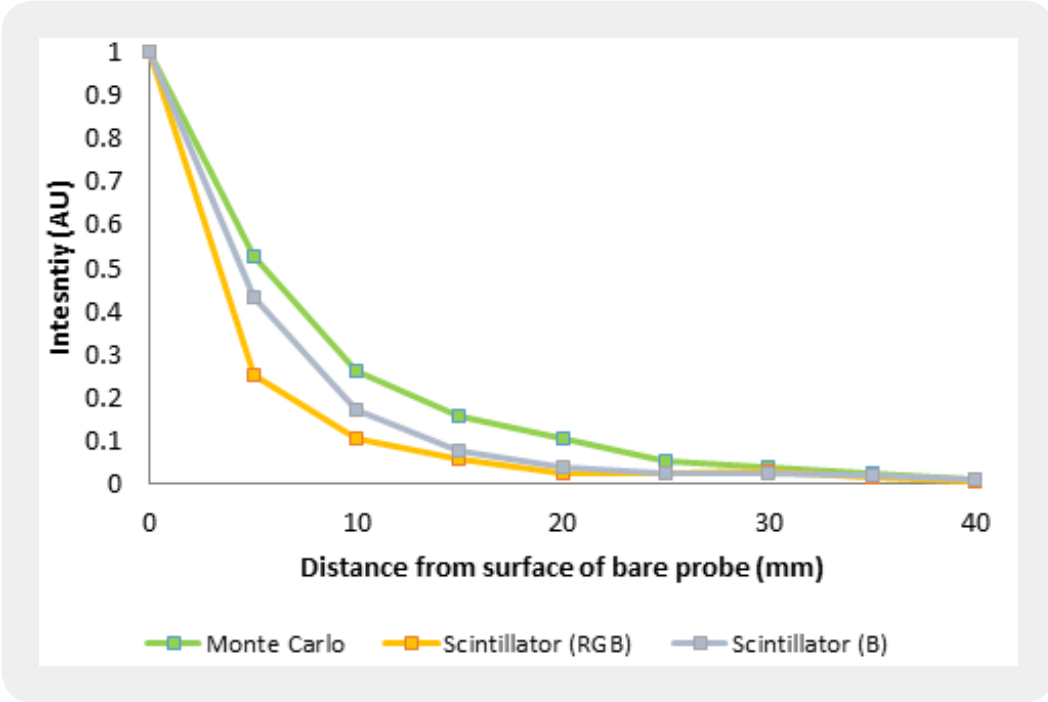

Figure 2: *Normalized intensity plotted with distance from x-ray source probe tip surface; Monte Carlo depth dose in water [18], RGB and blue channel values. Probe tip used for scale; 55 pixels per mm*

Table 1: *Normalized intensity and percent difference as a function of distance from probe tip surface between scintillation (RGB & blue channel) and Monte Carlo derived depth dose in water [18].*

X (mm)	Monte Carlo [15]	Scintillator (RGB)	%Diff (RGB)	Scintillator (B)	%Diff (B)
0	1.000	1.000	0.00%	1.000	0.00%
5	0.526	0.255	27.16%	0.431	9.49%
10	0.263	0.107	15.60%	0.173	9.06%
15	0.158	0.057	10.08%	0.078	7.95%
20	0.105	0.026	7.91%	0.039	6.60%
25	0.053	0.024	2.88%	0.027	2.52%
30	0.039	0.031	0.85%	0.024	1.59%
35	0.026	0.014	1.20%	0.020	0.67%
40	0.013	0.007	0.60%	0.012	0.14%

Table 2: *Elemental composition and effective Z for Water, Soft Tissue [16], and LSC.*

Element	Z	A	Water	Soft Tissue	LSC
Hydrogen	1	1	0.111	0.102	0.096
Carbon	6	12	-	0.143	0.789
Nitrogen	7	14	-	0.034	0.002
Oxygen	8	16	0.889	0.708	0.095
Sodium	11	23	-	0.002	0.002
Phosphorus	15	31	-	0.003	0.014
Sulfur	16	32	-	0.003	0.002
Chlorine	17	35	-	0.002	-
Potassium	19	39	-	0.003	-
Effective Z			7.2	7.1	5.9

Discussion

Difference between LSC emission intensity and published depth dose data are believed to be due to the volumetric nature of dose deposition coupled with integrated collection of light emissions. Integration of light incident the detector leads to a higher intensity near the center of sphere (probe tip). Normalizing by this value results in points further from the tip appearing to under-respond, as observed.

Low energy ionizing radiation interactions are predominately photo-electric and highly dependent on atomic number, Z. Kirov, *et al.* studied a silicon doped LSC, others continue to explore this method to obtain a water equivalent LSC [19,20]. LSC fluid composition, optimization of image exposure, and derivation of a correction factor for integration along the ray path are areas for further study [21].

Conclusion

The results of this study confirm the feasibility of visualizing emissions of an IORT x-ray source with liquid scintillation imaging. This work demonstrates a low-cost method of real-time visualization of ionizing radiation. Further study of this dosimetry technique may yield a method for rapid commissioning and clinical deployment of IORT technology.

Author Contributions

Sole author performed experiments, analyzed data, and wrote communication.

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Conflicts of Interest

The author declares no conflict of interest.

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