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A comparison of EDR2 radiographic and EBT radiochromic films for Helical Tomotherapy treatments dose verification

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PURPOSE

At our hospital we have two types of films for treatments dose verification: EDR2 radiographic (Kodak, Rochester, NY) and EBT radiochromic (ISP, Wayne, NJ) films.

Both dosimeters have high spatial resolution. EDR2 need development, have poor water equivalency and a not uniform energy response. EBT do not need development, are nearly water equivalent, have a constant response over a broad band of energies but when read with a flatbed scanner suffer from non homogeneous response[1]. Their response depend on film orientation during scanning. The overall procedure of film analysis is longer for EBT and they are significantly more expensive than radiographic films.

Our goal is to determine which dosimeter is more accurate for HI-ART Tomotherapy System (Tomotherapy Incorporated, Madison, WI) treatments dose verification. For this purpose, 2D distributions of absolute and relative dose of Tomotherapy treatments are measured with both films. Agreement of measured to calculated dose is evaluated using the gamma function[2]. Special attention is paid to films' behaviour in regions of the phantom corresponding to patient planning target volume (PTV) and organs at risk (OARs).

MATERIALS AND METHODS

Tomotherapy is an intensity modulated, image guided radiation therapy in which a photon source rotates continuously as in a computed tomography (Fig 1 - a). At the same time the couch moves towards the gantry so that irradiation is delivered trough helical pathways. The photon source is a 6 MV LINAC equipped with a binary multileaf collimator (64 leaves, 0.625cm at isocenter) that divides the radiation field into beamlets. The intensity of each beamlet is set by aperture time during the treatment. A proprietary inverse planning software (Tomotherapy Inc., Madison, WI) provides the optimal collimator openings time sequence for best coverage of target region and sparing of organs at risk. Integrated into the system is a megavoltage detector so that the LINAC, besides producing the therapeutical beam, serves also as a source for a megavolt CT scanning system. After initial patient positioning, a MV CT is acquired and registered with pre-planning kilovolt CT, and the eventual displacement of the patient is derived and corrected.

DQA: The Delivery Quality Assurance (DQA) consists in delivering a complete treatment session to a "cheese" phantom, that is a cilindrical solid water phantom, loaded with ion chambers and films (Fig 1 - b) and comparing measured dose with dose calculated by the TPS software. Prior to irradiation, the phantom is positioned on the couch using the red lasers. Red and green laser positions after initial phantom set up are marked on films.

Film calibration: Films are irradiated for calibration with Tomotherapy static fields in a solid water phantom at 1 cm depth, 85 cm source to surface distance (Fig 1 - c), to doses ranging from 0.21 Gy to 2-6 Gy depending on the maximum DQA dose. A thimble ion chamber is placed 1 cm below the film, and film dose is derived from chamber measurement and percent depth dose data. The calibration procedure is performed for every DQA.

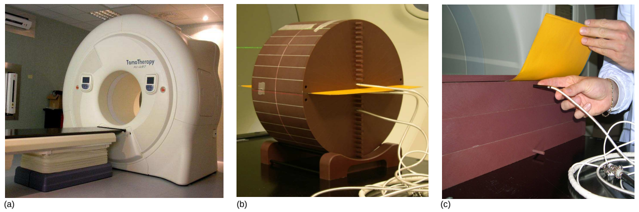

Fig 1. The Tomotherapy HI ART System (a), the cheese water phantom with EDR2 films prior to irradiation (b), and (c) film calibration

EDR2: EDR2 are developed at least 12 hours after irradiation, and scanned with a Vidar (Vidar Systems Corporation, Herndon, VA) scanner. Film analysis is performed with the Tomotherapy Film Analizer software. Calibration curve is plotted in terms of dose to pixel value (Fig 2 - a). Film images and calibration curves are exported in TIFF format for later analisys.

EBT: After waiting at least 12 hours for self development, EBT films are read with an Epson 1680 (Epson Seiko corporation, Nagano, Japan) flatbed document scanner. We use only the central 10x15cm^2 region of the scanner for better homogeneity of response. The remaining area of the scanner is covered by pieces of opaque radiographic films to reduce scattered light. Every scan is acquired 5 times in transmission mode, at 150 dpi with all corrections turned off. A set of dark images, with the scanner completely covered by stacks of opaque radiographic film is acquired to determine scanner background signal. Blank images are also acquired for identification of faulty pixels. Multiple images are averaged and red component is extracted. Net optical density (netOD) matrices are calculated, following Devic *et al*[3], as:

$$netOD(i,j) = \log_{10}\left(\frac{I_{unexp}(i,j) - I_{bckg}(i,j)}{I_{exp}(i,j) - I_{bckg}(i,j)}\right)$$

where $I_{exp}(i,j)$, $I_{unexp}(i,j)$, $I_{bckg}(i,j)$ are values of the (i,j) pixel in the red component of the exposed, unexposed film, dark images. Dose response curve is fitted by the function: $Dose = a \cdot netOD + b \cdot netOD^c$ (Fig 2 - b). Conversion to dose is performed with a home made MATLAB routine.
Dose matrices are saved in TIFF format.

Image registration: Film images and calculated dose distributions are imported in FilmQA (3cognition LCC) software. Film dose matrices are registered using film markers that correspond to green laser position and indicate the origin of the machine coordinate system.

Comparison of film readings: Measured dose distributions are compared with dose calculated by the treatment planning software using the gamma function (Fig 3). The percentage of points inside a ROI with gamma below 1 (tolerance of 3mm and 3% of the maximum calculated dose) is calculated.
The gamma test is repeated after normalizing measured dose distributions to dose at the same point in the PTV. We compared absolute dose readings in points inside regions in the phantom corresponding to patients' OARs and PTV. We performed ten Tomotherapy treatments (2 prostate, 3 head and neck, 2 lung, 1 brain, 1 spine cancer, 1 medulloblastoma treatment) on a "cheese" phantom loaded with EDR2 films, and repeated the procedure using EBT films.

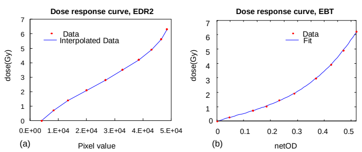

Fig 2. Dose response curves of EDR2 (a) and EBT films (b)

RESULTS

Gamma tests: Radiochromic films show better gamma test scores for absolute dose in 8 cases over 10. Average values of the gamma factor over the 10 patients confirm better results for EBT (See Table 1). After normalization of dose, DQAs with better gamma tests are equally shared between EBT and EDR2. Average gamma factor is higher when EBT films are used, but very close results are obtained with the two films.

Dose to PTV and OARs: Absolute doses to PTV measured with EBT (Table 2) have a better agreement to TPS calculations than EDR2 in 6/10 cases. Average difference between measured and calculated dose to PTV is lower for EBT. OARs absolute doses (Table 3) are more similar to calculated values when measured with EDR2 in 6/10 treatments. Average difference between measured and calculated dose to OARs is lower for EBT. After normalization to PTV dose, difference to TPS calculations is lower for EDR2 in 7/10 DQAs. Average dose difference is again better for EBT.

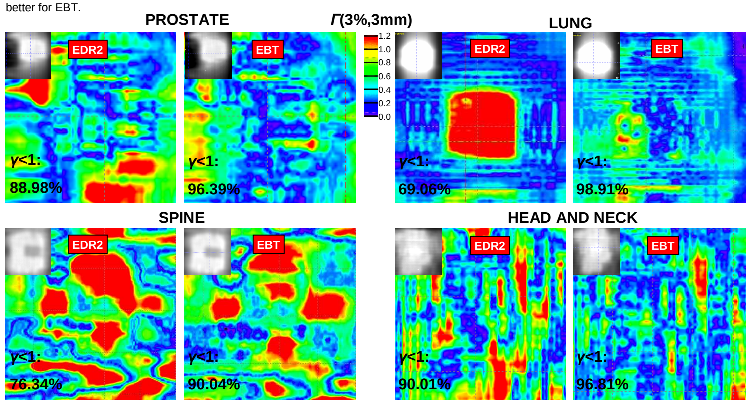

Fig 3. Results of DQA for EDR2 and EBT films for prostate, lung, spine and head and neck treatments

Treatment	γ<1 (%) absolute dose EDR2	absolute dose EBT	relative dose EDR2	relative dose EBT
Brain	100	98.9	99.66	98.6
Craniospinal	1.06	54.30	54.30	52.27
Head & neck	98.43	99.22	98.56	98.85
Head & neck 2	90.01	96.81	92.3	91.55
Head & Neck 3	74.03	87.95	64.76	82.27
Lung	93.76	96.2	87.56	89.56
Lung 2	69.06	98.61	99.95	99.71
Prostate	88.98	96.39	92.33	95.36
Prostate 2	91.77	90.87	91.64	90.63
Spine	76.34	81.14	76.48	82.3
AVERAGE:	78.34	90.04	85.75	88.11

Table 1. Results of gamma tests

Treatment	PTV dose (Gy) D_{EDR2}	D_{EBT}	D_{cal}	$\left\lvert\frac{D_{EDR2}-D_{cal}}{D_{cal}}\right\rvert$	$\left\lvert\frac{D_{EBT}-D_{cal}}{D_{cal}}\right\rvert$
Brain	1.421	1.382	1.346	5.57%	2.67%
Craniospinal	1.5	1.43	1.430	4.90%	0.00%
Head & neck	1.895	1.9	1.888	0.37%	0.64%
Head & neck 2	1.647	1.68	1.626	1.29%	3.32%
Head & Neck 3	1.714	1.787	1.744	1.72%	2.47%
Lung	4.64	4.46	4.45	4.39%	0.36%
Lung 2	5.398	5.204	5.12	5.43%	1.64%
Prostate	2.793	2.797	2.761	1.16%	1.30%
Prostate 2	2.423	2.42	2.38	1.81%	1.68%
Spine	1.414	1.393	1.386	2.02%	0.51%
			AVERAGE:	2.52%	1.46%

Table 2. Absolute dose to PTV measured with (D_{EBT}) and EDR2 (D_{EDR2}) films, Calculated by TPS (D_{cal}), differences beween calculation and measurements.

Treatment	OAR	Absolute OAR dose (Gy) D_{EDR2}	D_{EBT}	D_{cal}	$\left\lvert\frac{D_{EDR2}-D_{cal}}{D_{cal}}\right\rvert$	$\left\lvert\frac{D_{EBT}-D_{cal}}{D_{cal}}\right\rvert$	Relative OAR dose (%) D_{EDR2}	D_{EBT}	D_{cal}	$\left\lvert\frac{D_{EDR2}-D_{cal}}{D_{cal}}\right\rvert$	$\left\lvert\frac{D_{EBT}-D_{cal}}{D_{cal}}\right\rvert$
Brain	Optical nerve	0.543	0.507	0.523	3.82%	3.06%	38.21%	36.69%	38.86%	1.66%	5.58%
Craniospinal	Lens	0.462	0.472	0.299	54.52%	57.86%	30.80%	33.01%	20.91%	47.30%	57.86%
Head & neck	Optical nerve	1.047	1.121	1.033	1.36%	8.52%	55.25%	59.00%	54.71%	0.98%	7.83%
Head & neck 2	Pituitary Gland	0.449	0.44	0.306	46.73%	43.79%	27.26%	26.19%	18.82%	44.86%	39.17%
Head & Neck 3	Eye	0.229	0.123	0.115	99.13%	6.96%	13.36%	6.88%	6.59%	102.62%	4.38%
Lung	Lung	0.66	0.51	0.55	21.60%	7.51%	14.31%	11.32%	12.28%	16.49%	7.84%
Lung 2	Lung	1.221	1.27	1.175	3.91%	8.09%	21.77%	24.40%	22.95%	5.15%	6.34%
Prostate	Bladder	0.486	0.522	0.4	21.50%	30.50%	17.40%	18.66%	14.49%	20.11%	28.82%
Prostate 2	Bladder	1.713	1.614	1.675	2.27%	3.64%	70.70%	66.69%	70.38%	0.45%	5.23%
Spine	Spinal cord	1.028	1.036	0.973	5.65%	6.47%	72.70%	74.37%	70.20%	3.56%	5.94%
				AVERAGE:	26.05%	17.64%			AVERAGE:	24.32%	16.90%

Table 3. Doses in phantom regions corresponding to patient OARs measured with EBT (D_{EBT}) and EDR2 (D_{EDR2}), values calculated by TPS (D_{cal}), and absolute differences between measured and calculated values.

CONCLUSIONS

Radiochromic films show a better agreement in terms of absolute measured dose to treatment planning software calculation, particularly in high dose regions. After normalization, the difference in accuracy between the two film types becomes less relevant.
In conclusion, when we need to check 2D absolute dose distribution and spatial resolution of the dosimeter is critical, we prefer EBT over EDR2. This can be the case of treatments of very small tumours, or treatments where a strongly inhomogeneous dose distribution is delivered.
In other cases, EDR2 can be used for relative dosimetry and absolute dose distribution can be obtained by normalization to ion chambers measurements.

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