Dose calculation with RadCalc in lateral electronic non-equilibrium

Jacob A Haider, PhD[1]; Trudy C Haider, CMD
[1] North Alabama Medical Center, Florence, AL and Magnolia Cancer Center, Corinth, MS

Abstract

IMRT plans can lead to small average leaf pair openings (ALPO). The range of the secondary electrons from photon interactions can be significantly larger than the ALPO. This condition leads to loss of lateral electronic equilibrium (LEQ). The loss of LEQ depends increases significantly as the size of beam-let openings and the density of the media gets smaller and the beam energy gets higher. Today's advanced dose calculation algorithms in treatment planning systems are equipped to handle small field dosimetry. However, conventional secondary point dose calculations do not account for loss of LEQ and result in large discrepancies in monitor units generated by the planning system and secondary dose calculation verification. We derived phantom scatter factors (*Sp*) experimentally in balsa wood under lateral non-equilibrium conditions. O'Connor's theorem is used to scale the measurements to small field sizes without making measurements in very small fields. Additionally, we also calculated *Sp* values using Acuros XB (Varian Medical System) which belongs to a class of Linear Boltzmann Transport Equation Solvers. The small field *Sp* values are entered in RadCalc (Lifeline Software Inc., member of LAP group) allowing dose computation in electronic non-equilibrium. We compared Radcalc monitor units to those in the Eclipse planning system (Varian Medical Systems) for hundreds of cases including many small lung lesion SBRT. The results are in excellent agreement (<2%) in almost all cases.

Introduction

Lateral electronic equilibrium (LEQ) exists when secondary electrons leaving a point of calculation laterally are compensated by electrons originating elsewhere. Loss of LEQ at a point results in reduction of dose. The degree of dose reduction depends on beam energy, media density and the leaf pair opening. The dose discrepancy between planning system and secondary dose calculations can be greater than 20%. If the LEQ is not accounted for in the lung or small lesions, then the second check is rendered meaningless. We provide a simple method to account for LEQ by extending phantom scatter factors in LEQ in Radcalc . The values are measured and or calculated for 6MV and 6 MV flattening free filter (FFF). The results of the dose calculated by Radcalc and those calculated by the treatment planning system yields excellent agreement in more than 50 randomly selected SBRT lung lesions and brain lesions. The treatment plans include 3D, fixed field IMRT, VMAT and hyperarc VMAT (Varian Medical Systems).

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Methods and Materials

The dose Inhomogeneity correction factor (ICF) in Region of Interest module (ROI) in RadCalc scales the field sizes for phantom scatter factor Sp and TMR as following

$$ICF = \frac{TMR\left(d_{CalcPt}^{effective}, r_{CalcPt}^{effective}\right) \times S_p(r_{CalcPt}^{effective})}{TMR\left(d_{CalcPt}^{Measured}, r_{CalcPt}\right) \times S_p(r_{CalcPt})}$$

where TMR is the tissue maximum ratio, *d* is the depth in medium and *r* is the radius of the field size. We extend the Sp values for very small field sizes by using density scaling theorem described by O'Connor. O'Connor's theorem states that the ratio of the fluence of secondary particles to that of primary particles, caused by an external source irradiating a medium in a collimated beam, is the same in two uniform media of the same composition but different density, provided geometrical distances are scaled inversely to density. From the density scaling theorem we get the following relationship between medium 1 and medium 2:

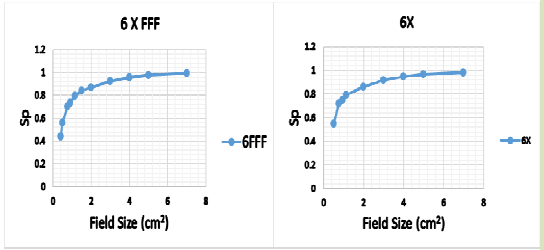
$$Sp(\rho 1, r1) = Sp(\rho 2, r2)$$

Where Sp is the phantom scatter factor, ρ is the relative electron density and r is the radius of field size. The above equation allows to measure phantom scatter factors for very small field sizes without having to measure collimator scatter factors for small field sizes.

Balsa wood is used to simulate the lung because it is comparable to tissue in composition and its effective atomic number is similar to tissue-equivalent polystyrene. The balsa wood has an electron density (ρ) = 0.16+/0.01. *Sp* for 1.6 cm (10x0.16 cm) may be calculated by measuring output factor at 10x10 cm in water and balsa wood at the depth of the maximum dose. All measurements were taken 100 cm SAD in order to remove the inverse square source dependence. All data are normalized to the nominal depth of maximum dose for each energy. We are aware of the uncertainty introduced by the presence of ionization chamber as it violates the Bragg-Gray cavity theory. The uncertainties in measurements get larger as the field size becomes smaller and it may be several percent for the smallest (~0.5 cm^2) scaled field sizes. The results includes some calculations performed in cork (ρ =0.19) using Acuros XB.

Results

The results of the measurements of phantom scatter factors in electronic equilibrium are shown in figure 1 and figure 2 for 6 MV and 6 MV FFF. The small field *Sp* values are entered in Radcalc for dose computation in electronic non-equilibrium. We compared Radcalc monitor units to those in the Eclipse planning system (Varian Medical Systems) for hundreds of cases including many lung and brain lesions. The results are in excellent agreement (<3%) in almost all cases with the exception of very small ALPO (<0.6 cm^2) where discrepancies may be several percent.



Site	Prostate W nodes	Lung	Lung	Lung	Lung	Lung	Brain	Brain
Planning Technique	VMAT	VMAT	IMRT	IMRT	3D	3D	VMAT/ HyperArc	VMAT/ Hyperarc
Average leaf pair opening (ALPO) cm^2	2.6	<1.4	<1.1	<1.1	2.4	0.95	0.6	0.95
% dose difference w S_p LEQ	2.5	<2.5	<1.2	<1.0	<1	<2.4	<2.0	<1.5
% dose difference w/o S_p LEQ	>4	>9	>14	>12	>6	>14	>15	>8

Discussion

Larger discrepancies are observed for very small volume lung lesions where PTV consists of significant low density. It is important to assign mean densities of each structure for a reasonable agreement and dose calculation points should be chosen at the center of unit density as much as possible. The authors are aware of uncertainties in dose measurements and the limits of O' Connors theorem as applied here. The method applied is a means to a reasonable secondary dose calculation check. The method is implemented and validated in RadCalc. However, the method discussed could be used in any point dose calculation software that employs similar algorithm. This method is implemented and validated in RadCalc. Further investigations should evaluate the new implementation of ray tracing for RadCalc's point dose calculation, as well as how these results compare to RadCalc's 3D Collapsed Cone, Monte Carlo and EPID Dosimetry modules

Conclusions

The accuracy of point dose calculations in small fields could be significantly improved by accounting for electronic non-equilibrium in phantom scatter factors ($\mathbf{S_p}$).

Contact

Jacob A Haider, PhD
Jacob.haider@gmail.com

References

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Radcalc, Version 7.1 Lifeline Software, Member of LAP Group
Acuros XB, Eclipse Version 16.1, Varian Medical Systems, Member of Siemens Healthineers