In vivo verification of radiation dose delivered to healthy tissue during radiotherapy for breast cancer

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Abstract. Different treatment planning system (TPS) algorithms calculate radiation dose in different ways. This work compares measurements made in vivo to the dose calculated at out-of-field locations using three different commercially available algorithms in the Eclipse treatment planning system. LiF: Mg, Cu, P thermoluminescent dosimeter (TLD) chips were placed with 1 cm build-up at six locations on the contralateral side of 5 patients undergoing radiotherapy for breast cancer. TLD readings were compared to calculations of Pencil Beam Convolution (PBC), Anisotropic Analytical Algorithm (AAA) and Acuros XB (XB). AAA predicted zero dose at points beyond 16 cm from the field edge. In the same region PBC returned an unrealistically constant result independent of distance and XB showed good agreement to measured data although consistently underestimated by ~0.1 % of the prescription dose. At points closer to the field edge XB was the superior algorithm, exhibiting agreement with TLD results to within 15 % of measured dose. Both AAA and PBC showed mixed agreement, with overall discrepancies considerably greater than XB. While XB is certainly the preferable algorithm, it should be noted that TPS algorithms in general are not designed to calculate dose at peripheral locations and calculation results in such regions should be treated with caution.

1. Introduction

The accuracy of treatment planning system (TPS) dose calculations is crucial to the overall integrity of radiotherapy treatment delivery. An established appreciation of the importance of dose calculation accuracy has motivated the continual development of calculation techniques which, when used in conjunction with improved computing power, has led to increasingly sophisticated dose calculation methods. Various algorithms are commercially available for dose calculation in radiotherapy. Each takes a different approach to the radiation transport problem and as such will return a different result to other algorithms under identical calculation conditions. The accuracy of these algorithms is usually verified at regions within and near the treatment beam however is less well documented at peripheral regions.

At present, convolution superposition and collapsed cone algorithms are commonly used in clinical practice for complex scenarios since their accuracy within heterogeneous media is generally regarded as superior to pencil beam convolution. These algorithms have begun to replace pencil beam convolution in many centres. More recently a deterministic grid-based Boltzmann solver, Acuros XB, has been released for the Varian Eclipse treatment planning system (Varian Medical Systems, Palo Alto, CA) which has shown promising results in complicated calculation scenarios. Agreement
Dose calculations from the TPS are often the only means of estimating the radiation dose reaching out-of-field locations in routine radiotherapy. However, very little data is available on the performance of these algorithms in such regions. Furthermore, TPS commissioning usually only requires data up to a few centimetres beyond the treatment field, so dose calculations at more distant regions are not supported by measured data. This work compares dose calculations from different TPS algorithms at the contralateral breast of 5 patients who underwent photon beam radiotherapy for breast cancer. Point doses from PBC, AAA and Acuros XB are compared at identical measurement points. In vivo TLD data is used as a benchmark for assessing the accuracy of each algorithm.

2. Methods

High-sensitivity thermoluminescent dosimeter (TLD) chips (Harshaw 100H, LiF:Mg,Cu,P material) were placed on the skin surface of 5 patients who underwent tangential beam radiotherapy for breast cancer at the Peter MacCallum Cancer Centre. TLDs were annealed in a TLD oven prior to use. Individual TLD sensitivity factors were used to correct the TL signal from each chip following a measurement. Sensitivity factors were assigned based on the relative signal of each individual chip to the batch average following 3 calibration cycles. Several ‘standard’ TLD chips from the same batch were irradiated to a known dose in a 6 MV 10 x 10 cm\(^2\) field at depth of maximum dose for each in vivo measurement. The TL signal from in vivo TLDs was compared with TLD standards allowing conversion to dose. Three TLD chips were used at each measurement point and placed in custom-made acrylic buildup domes (Figure 1). Six measurement points were used on each of the 5 patients: one in each cardinal direction to the contralateral breast, one at the mid axilla and one at the suprasternal notch.

![Figure 1](image_url) – Schematic depicting the buildup domes used for in vivo TLD measurements. Three TLD chips were housed in a single holder which was then taped to the patient’s skin. The Perspex (\(\rho=1.18\) g cm\(^{-3}\)) domes offer up to 1.0 cm thickness of buildup material.

All patients were prescribed 50 Gy in 25 fractions; TLD measurements were conducted for a single 2 Gy fraction and results extrapolated to a complete 50 Gy treatment. The point dose as predicted by the Eclipse treatment planning system was compared to in vivo dose measurements at identical locations for each patient. Dose at each point was re-calculated in Eclipse using Anisotropic Analytical Algorithm (AAA), Pencil Beam Convolution (PBC) and Acuros XB (XB).

3. Results

The results of in vivo dose measurements are shown in Figure 2a along with the corresponding TPS dose calculation at each point, expressed as a function of distance from the field edge (cm). TLD error
bars are indicative of a 10 % uncertainty associated with buildup dome positioning and patient setup errors (the uncertainties associated with relative dosimetry using TLDs are less, +/- 2 % on the 95 % confidence interval with careful calibration and handling). The ratio of calculated (TPS) / measured (TLD) dose at the same locations for each algorithm is shown in Figure 2b.

From Figure 2, measurements were conducted at several distances that can be grouped into 3 distinct regions having different levels of agreement with TPS calculations: ‘near’ (<5 cm from field edge), ‘medium’ (11 to 15 cm) and ‘far’ (>19 cm). The performance of each algorithm is assessed using the average ratio of calculated to measured dose along with its relative standard deviation, expressed as a percentage (%RSD). Each algorithm can be compared within each region. In the near region the average ratios (TPS/TLD) for each algorithm were 1.36 (%RSD = 58), 1.56 (%RSD = 48) and 0.85 (%RSD = 44) for AAA, PBC and XB, respectively. In the medium region average ratios were 1.5 (%RSD = 60), 1.7 (%RSD = 37) and 0.94 (%RSD = 27). In the far region AAA returned no dose result (for any point beyond ~ 15 cm). The average ratio in this region for PBC was 1.17 (%RSD = 67) and 0.4 (%RSD = 35) for XB. The PBC dose calculations within this region were a constant value irrespective of distance beyond 20 cm (either 0.1 % or 0.05% of the prescription dose).

4. Discussion

An exponential dose falloff with increasing distance from the radiation field is shown in Figure 2a. It can be seen that TPS calculations underestimate dose at more distant regions (beyond ~ 20 cm from the field edge), where in the same region TLD measurements hint at a dose ‘bath’ of ~0.1% of the prescription dose, although with some degree of variability.

Figure 2b shows the ratios of calculated (TPS) to measured (TLD) dose as a function of distance from the treatment field edge. These results demonstrate considerable variation between algorithms. Convolution superposition algorithms (i.e., AAA and PBC) locally scale pre-defined (Monte Carlo-derived) dose kernels to calculate radiation dose distributions. In the case of PBC, this expansion is conducted along 2 dimensions while AAA utilises additional degrees of freedom within heterogeneous regions. Acuros XB employs a fundamentally dissimilar approach in that it explicitly
models particle interactions within different media to yield a numerical solution to the linear Boltzmann transport equation.

It was noted that although XB underestimated dose at larger distances from the field edge (> 20 cm) it was able to correctly predict the behaviour of the dose distribution, unlike AAA or PBC. The magnitude of this shortfall was on average 0.1 % of the prescription dose, presumably attributable to leakage radiation from the linac. Retrospectively correcting XB data for a 0.1 % leakage dose contribution at peripheral regions improves the XB to TLD ratio to 1.16 (%RSD = 23). This suggests that the use of Acuros XB in conjunction with a leakage dose correction may lend the ability to calculate peripheral dose to within +/- 15 % up to 24 cm beyond the field edge. For assessment of stochastic risks, such an uncertainty may be acceptable. More work is required to validate this correction-based approach.

5. Conclusions

Treatment planning system dose calculation algorithms are not designed to accurately predict peripheral dose, nor are data within these regions verified upon commissioning. This work has demonstrated that dose calculations should be used with caution as large errors have been shown in peripheral regions. Using the most sophisticated algorithms available in conjunction with an applied correction for leakage dose from the linac may improve dose calculations to achieve accuracy within +/- 15 %. Further validation work is required to accurately quantify leakage dose from different linac models.

6. References

[1] Papanikolaou N, Battista J J, Boyer A L, Kappas C, Klein E, Mackie T R, Sharpe M and Van Dyk J 2004 ‘Report of the Task Group No. 65 of the Radiation Therapy Committee of the American Association of Physicists in Medicine: Tissue inhomogeneity corrections for megavoltage photon beams’ Medical Physics Publishing, Madison, WI

[2] Van Esch A, Tillikainen L, Pyykkonen J, Tenhunen M, Helminen H, Siljamäki S, J. Alakuijala J, Paiusco M, Iori M and Huyskens D 2006 ‘Testing of the analytical anisotropic algorithm for photon dose calculation,’ Med Phys 33 11

[3] Fogliata A, Nicolini G, Vanetti E, Clivio A and Cozzi L 2006 ‘Dosimetric validation of the anisotropic analytical algorithm for photon dose calculation: fundamental characterization in water,’ Phys Med Biol. 51 1421-1438

[4] Ahnesjö A 1989 ‘Collapsed cone convolution of radiant energy for photon dose calculation in heterogeneous media,’ Med Phys 16 4130 577-592

[5] Ahnesjö A and Aspradakis M 1999 ‘Dose calculations for external photon beams in radiotherapy,’ Phys Med Biol 44

[6] Knöös T, Wieslander E, Cozzi L, Brink C, Fogliata A, Alberts D, Nyström H and Lassen S 2006 ‘Comparison of dose calculation algorithms for treatment planning in external photon beam therapy for clinical situations,’ Phys Med Biol. 51 5785-5807

[7] Han T, Mikell J K, Salehpour M and Mourtada F 2011 ‘Dosimetric comparison of Acuros XB deterministic radiation transport method with Monte Carlo and model-based convolution methods in heterogeneous media,’ Med Phys 38:5 2651-2663

[8] Vassilev O N, Wareing T A, McGhee J, Failla G, Salehpour M R and Mourtada F 2010 ‘Validation of a new grid-based Boltzmann equation solver for dose calculation in
radiotherapy with photon beams,’ Phys Med Biol. 55 581-598 doi:10.1088/0031-9155/55/3/002.

[9] Bush K, Gagne I M, Zavgorodni S, Ansbacher W and Beckham W 2011 ‘Dosimetric validation of Acuros XB with Monte Carlo methods for photon dose calculations,’ Med Phys 38:4 2208-2220

[10] Kron T 1994 ‘Thermoluminescence dosimetry and its applications in medicine – Part 1: physics, materials and equipment’, Australasian Physical and Engineering Sciences in Medicine 17 4 175 – 199