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Original research article

A depth dose study between AAA and AXB algorithm against Monte Carlo simulation using AIP CT of a 4D dataset from a moving phantom

Roger Cai Xiang Soh[a,b,*], *Guan Heng Tay*[c], *Wen Siang Lew*[b], *James Cheow Lei Lee*[b,c]

[a] *Department of Radiation Oncology, National University Cancer Institute, Singapore*
[b] *Division of Physics and Applied Physics, Nanyang Technological University, Singapore*
[c] *Division of Radiation Oncology, National Cancer Centre, Singapore*

ARTICLE INFO

Article history:
Received 20 September 2017
Received in revised form
15 May 2018
Accepted 9 August 2018

Keywords:
Dose calculation algorithm
AXB
AAA
Monte Carlo

ABSTRACT

Aim: To identifying depth dose differences between the two versions of the algorithms using AIP CT of a 4D dataset.

Background: Motion due to respiration may challenge dose prediction of dose calculation algorithms during treatment planning.

Materials and methods: The two versions of depth dose calculation algorithms, namely, Anisotropic Analytical Algorithm (AAA) version 10.0 (AAAv10.0), AAA version 13.6 (AAAv13.6) and Acuros XB dose calculation (AXB) algorithm version 10.0 (AXBv10.0), AXB version 13.6 (AXBv13.6), were compared against a full MC simulated 6X photon beam using QUASAR respiratory motion phantom with a moving chest wall. To simulate the moving chest wall, a 4 cm thick wax mould was attached to the lung insert of the phantom. Depth doses along the central axis were compared in the anterior and lateral beam direction for field sizes $2 \times 2\,cm^2$, $4 \times 4\,cm^2$ and $10 \times 10\,cm^2$.

Results: For the lateral beam direction, the moving chest wall highlighted differences of up to 105% for AAAv10.0 and 40% for AXBv10.0 from MC calculations in the surface and buildup doses. AAAv13.6 and AXBv13.6 agrees with MC predictions to within 10% at similar depth. For anterior beam doses, dose differences predicted for both versions of AAA and AXB algorithm were within 7% and results were consistent with static heterogeneous studies.

Conclusions: The presence of the moving chest wall was capable of identifying depth dose differences between the two versions of the algorithms. These differences could not be identified in the static chest wall as shown in the anterior beam depth dose calculations.

* *Corresponding author at*: Department of Radiation Oncology, National University Cancer Institute, Singapore.
E-mail address: rsoh002@e.ntu.edu.sg (R.C.X. Soh).
URL: http://www3.ntu.edu.sg/home/wensiang/index.html (W.S. Lew).

https://doi.org/10.1016/j.rpor.2018.08.003
1507-1367/

1. Background

The calculation of photon field dose distributions within low-density inhomogeneity in the presence of motion artefacts can be a challenge for algorithms in clinical treatment planning systems (TPS). Such clinical cases with low-density inhomogeneity and motion artefacts are common for lung stereotactic body radiation therapy (SBRT) treatments. During lung SBRT planning, dose calculations are performed on average intensity projected (AIP) images derived from four-dimensional computed tomography (4DCT) images.[1] This accounts for any tumour motion due to respiration during treatment. As high doses are being delivered in few fractions during lung SBRT, dosimetric precision for dose calculations are relevant and very important.

Most inhomogeneity studies compare calculated depth doses within static inhomogeneous phantoms.[2–10] Other respiratory motion studies done were only limited to the superior–inferior tumour motion.[11,12] A controlled depth dose study of external surface motion and anterior–posterior tumour motion will contribute to the understanding of calculated dose distributions under respiratory motion. Furthermore, small photon fields such as $2 \times 2\,cm^2$ can impose problems due to lack of lateral charge particle equilibrium and changes in energy spectrum. Under the presence of motion artefacts, small photon fields and low-density medium such as lung, the limitations of clinical dose calculation algorithms can be tested.

Previous inhomogeneous phantom studies compared the performance of Anisotropic Analytical Algorithm (AAA) and Acuros XB dose calculation (AXB) algorithm (both from Varian Medical Systems, Inc., Palo Alto, CA), version 10.0.28, against Monte Carlo (MC) simulation. It was found that the accuracy of the algorithms depends on the photon beam energy, field size and density of the medium.[2–8] The recent release of an improved version for both AAA and AXB algorithms, version 13.6.23, highlighted key changes in the dose prediction performance, especially in how each algorithm account for inhomogeneities.

2. Aim

To our knowledge thus far, no was study done for the depth dose differences between a full MC simulation and two versions of AAA and AXB algorithm under the presence of a moving tumour and chest wall.

This study will systematically investigate the comparison of MC calculated depth doses from an independently modelled treatment head against independently simulated 6X depth doses calculated using AAA and AXB algorithm, versions 10.0.28 and 13.6.23. Dose calculations were done on the QUASAR respiratory motion phantom (Modus Medical Devices Inc., London, ON). Electron Gamma Shower Monte Carlo simulation package developed by the National Research Council of Canada (EGSnrc)[13] was used for the full Monte Carlo simulation. MC simulated data were validated against measurement under homogenous condition in water, as well as inhomogeneous condition in a static lung phantom. MC was used as a benchmark for depth dose comparison in the respiratory phantom for this study. Anterior and lateral beam depth doses were compared to investigate depth dose differences for both superior–inferior and anterior–posterior motion of the tumour.

3. Materials and methods

3.1. *Full Monte Carlo simulation model*

Monte Carlo calculations were done using EGSnrc V4-r2.4.0, consisting of BEAMnrc and DOSXYZnrc user codes developed by the National Research Council of Canada. A Linux-based computer cluster which comprised of 12 Intel Xeon central processing units (CPUs) with processing speeds of 2.67 or 3.4 GHz and a total of 40 GB of RAM was used for the calculations.

Phase space files for a Varian Clinac iX linear accelerator treatment head (Varian Medical Systems Inc., Palo Alto, CA) of 6 MV photon beam for field sizes $2 \times 2\,cm^2$, $4 \times 4\,cm^2$ and $10 \times 10\,cm^2$ (100 cm SSD) were generated using BEAMnrc. The initial electron beam was 6.1 MeV with focal spot width of 0.3 cm at full width at half maximum. The energy spectrum of the bremsstrahlung beam was matched with the phase space file released by International Atomic Energy Agency (IAEA) phase space database.[14] Computational efficiency was increased using variance reduction technique such as directional bremsstrahlung splitting (DBS). The global photon and electron cut-off energies were 0.01 MeV and 0.7 MeV respectively. The splitting number was set to 1000 and the electron splitting was performed in the lower layers of the flattening filter as recommended.[15] Range rejection was turned on with varying ECUTRR and was considered for electrons with energy less than 2 MeV (ESAVE_GLOBAL = 2).[16] EXACT was chosen for the boundary crossing and electron step algorithms. Both BEAMnrc and DOSXYZnrc usercodes used similar settings. All DOSXYZnrc dose calculations were performed using 1×10^{10} histories with statistical uncertainties below 1%. EGSnrc calculation voxel size was set similar to Eclipse treatment planning system (TPS) (Varian Medical Systems, Palo Alto, CA) calculation grid size of 0.25 cm. The uniform calculation grid size across considered algorithms was an improvement from the previous inhomogeneity dose modelling done by Zvolanek et al.[17]

3.2. *AAA and AXB algorithm*

AAA and AXB algorithm were configured for Varian Clinac iX using Eclipse TPS. Calculations were done across AAA version 10.0.28 (AAAv10.0), AAA version 13.6.23 (AAAv13.6), AXB algorithm version 10.0.28 (AXBv10.0) and AXB algorithm version 13.6.23 (AXBv13.6) against MC simulation. Dose to medium (D_m) reporting mode was chosen for AXBv10.0 and AXBv13.6, similar to previous studies.[6,7,18–20] From here on forth, the terms "AAA" and "AXB algorithm" will be used to describe both versions of their algorithms (i.e. AAAv10.0, AAAv13.6 and AXBv10.0, AXBv13.6 respectively). Depth dose profiles for field sizes $2 \times 2\,cm^2$, $4 \times 4\,cm^2$ and $10 \times 10\,cm^2$ were calculated with calculation grid size of 0.25 cm.