Physica Medica xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Physica Medica

journal homepage: http://www.physicamedica.com

Original paper

About the non-consistency of PTV-based prescription in lung

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ARTICLE INFO

Article history:
Received 14 December 2016
Received in Revised form 16 March 2017
Accepted 18 March 2017
Available online xxxx

Keywords:
Monte Carlo
PTV
Lung
DVH
DMH

ABSTRACT

Purpose: The goal of this study is to show that the PTV concept is inconsistent for prescribing lung treatments when using type B algorithms, which take into account lateral electron transport. It is well known that type A dose calculation algorithms are not capable of calculating dose in lung correctly. Dose calculations should be based on type B algorithms. However, the combination of a type B algorithm with the PTV concept leads to prescription inconsistencies.

Methods: A spherical isocentric setup has been simulated, using multiple realistic values for lung density, tumor density and collimator size. Different prescription methods are investigated using Dose-Volume-Histograms (DVH), Dose-Mass-Histograms (DMH), generalized Equivalent Uniform Dose (gEUD) and surrounding isodose percentage.

Results: Isodose percentages on the PTV drop down to 50% for small tumors and low lung density. When applying the same PTV prescription to different patients with different lung characteristics, the effective mean dose to the GTV is very different, with factors up to 1.4. The most consistent prescription method seems to be the $D_{50\%}^{DMH}$ (PTV) DMH point, but is also limited to tumors with size over 1 cm.

Conclusions: Even when using the different prescription methods, the prescription to the PTV is not consistent for type B-algorithm based dose calculations if clinical studies should produce coherent data. This combination leads to patients' GTV with low lung density possibly receiving very high dose compared to patients with higher lung density. The only solution seems to remove the classical PTV concept for type B dose calculations in lung.

1. Introduction

Lung treatments are characterized by a high density tumor region surrounded with low density lung tissue. Type A algorithms, which do not take into account secondary electron transport in heterogeneities, lead to large errors in these low density regions [1–4]. Type B algorithms on the other hand take into account lateral electron transport in an approximate or exact manner. Details on the different dose calculation algorithms in the case of stereotactic treatments of lung lesions can be found in a recent review paper by Fogliata et al. [5]. Here we investigate in detail the consequences of using a PTV in combination with type B algorithms.

The PTV concept [6] is based on an uncertainty margin around the CTV in order to compensate for random and systematic uncertainties. The PTV is thus a fictitious volume including low lung density volume. In the case of type A algorithms, this poses no problem for prescribing to the PTV: the dose is (incorrectly) homogeneous, allowing conventional prescriptions. There is an issue however in the case of type B algorithms combined with the PTV concept: dose is correctly calculated, but the current prescription methods lead to inconsistencies and no consensus has been reached [7].

The conventional practice of prescribing to $D_{95\%}^{DVH}$ (PTV) is also commonly applied when type B algorithms are used for dose calculation (for example RTOG 0813 or LungTech EORTC). These type B algorithms calculate the dose correctly to both the tumor region and the surrounding lung [8]. A simple comparison with breast treatments can explain the issue at hand: when using a PTV in air for the flash region around breast in air (Fig. 1), the dose in air will be very low. This leads to a PTV DVH as shown in Fig. 1. In clinical practice, no one will prescribe or optimize on this type of volume for the breast. Neither will anyone use this kind of PTV volume to perform analysis of mean dose, median dose... In lung is the situation similar: less severe but more heterogeneous.

This could lead to dose escalation to the GTV, depending on tumor size and lung density. Furthermore, by optimizing the fluence to the PTV, an excessive fluence will be optimized in order to obtain high doses in low density regions. The comparison with

Abbreviations: MC, Monte Carlo; PTV, Planning Target Volume; DVH, Dose-Volume Histogram; DMH, Dose-Mass Histogram; gEUD, generalized Equivalent Uniform Dose; FFF, Flattening Filter Free.

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http://dx.doi.org/10.1016/j.ejmp.2017.03.009
1120-1797/

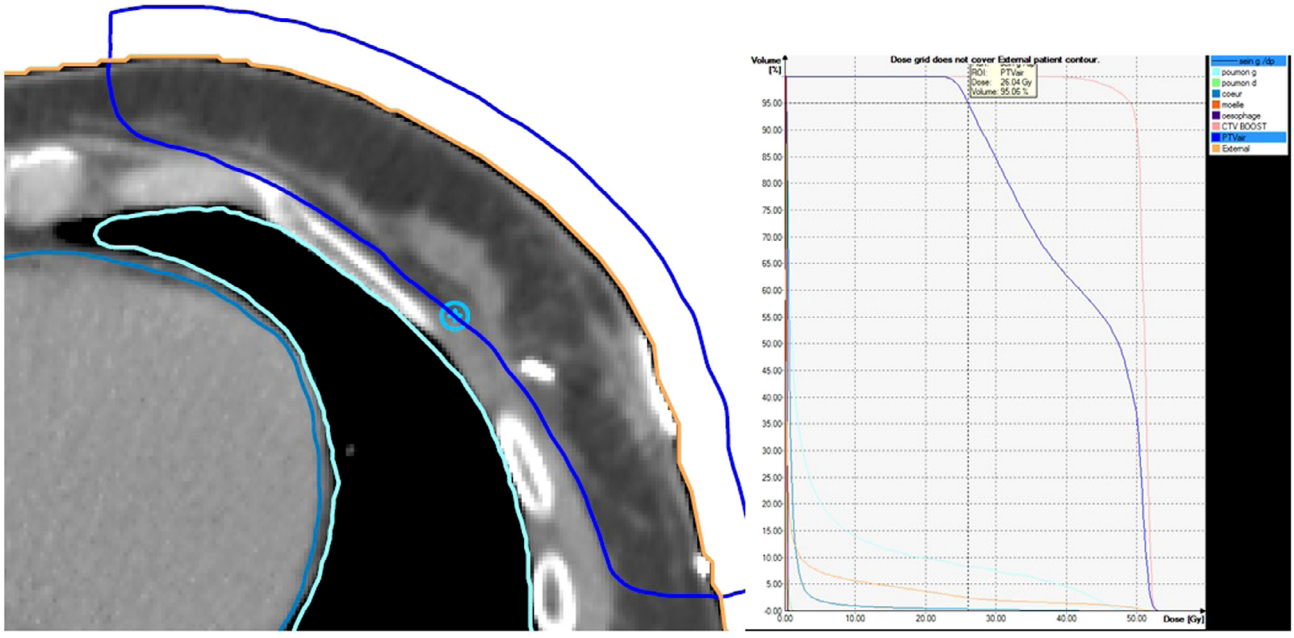

Fig. 1. Breast treatment with PTV in air, calculated with a Collapsed Cone algorithm. The DVH shows a skewed behavior.

breast treatments holds again: in water, this will play less of a role. In lungs, higher dose to the GTV is not really an issue, but inconsistencies in the results of clinical studies and evidence-based medicine are a real issue. Coherent dose prescriptions and dose reporting are required in order to apply correctly the dose prescriptions [7,9]. In lung, this issue is further complicated due to the large variety of lung and tumor densities and tumor sizes amongst patients: are these factors taken into account in "conventional" prescriptions?

Lacornerie et al. [10] demonstrated in a clinical setting (Novalis, Clinac and Cyberknife) that prescribing to the PTV using a type B algorithm leads to an under-estimation of the dose to the GTV, due to important differences between lung and target density. They demonstrated that prescribing directly to $D_{50\%}$ of the GTV reduces the dose variability. However, the PTV is used during optimization with a type A algorithm in order to obtain sufficient fluence around the GTV and to provide robustness against positioning uncertainties.

Van der Voort et al. [4] show that different dose levels according to the size of the lesion should be used when using MC based dose calculations (CyberKnife). They encountered the issue of the dose coverage of the PTV depending on several parameters. They optimized the MC volume to the PTV in order to respect the classical 95% PTV or isodose coverage and propose different dose prescription levels as the usage of PTV is very variable for MC calculated dose distributions.

In the current paper, we investigate in detail the issues related to combination of the PTV prescription with type B calculated dose distributions for lung treatments focusing on the impact of lung density, target density and target size. We also investigate whether these issues can be resolved by using the Dose-Mass Histogram (DMH) concept [11,12] or the generalized Equivalent Uniform Dose (gEUD) concept [13,14].

2. Methods

2.1. Monte Carlo calculations

Monte Carlo calculations simulate particle transport by taking into account secondary electron transport in heterogeneities. The EGS++ [15] and BEAMnrc packages [16–18] were used for Monte Carlo dose calculations. A custom user code was programmed in order to speed up calculations by taking into account the correlations between the particle histories for different setups. Electron and photon cut-off energies were defined as 0.521 MeV and 0.01 MeV respectively. The number of histories was chosen in order to obtain an uncertainty level below 0.7%. The BEAMnrc model of the 6 MV Cyberknife from Wagner et al. was used [19]. The theoretical setup consists of a spherical isocentric irradiation of a central GTV inside a 10 cm radius low density lung sphere (Fig. 2), corresponding to a central lung tumor. This is comparable to the setup of [3], but here we investigate the consequences of prescribing to a PTV with type B algorithms. The CyberKnife uses a 6 MV Flattening Filter-Free (FFF) accelerator, thus results should be comparable to any other 6 MV-FFF based linac attaining a 5 mm PTV margin.

2.2. Influencing factors

Using the theoretical setup as defined in Fig. 2, there are several influencing factors for lung treatments. The factors investigated are: a) lung density, b) tumor density and c) tumor size. Realistic lung and tumor density values were taken from measurements of 30 patients: lung density was between 0.1 g/cm^3 and 0.5 g/cm^3, tumor density was found between 0.8 g/cm^3 and 1.1 g/cm^3. Even though 0.1 g/cm^3 lung density might seem very low, this is actually a common value encountered in our patient population.

Tumor size varied between 5 mm and 5 cm diameter. A PTV margin of 5 mm was applied. For each tumor size, the collimator size was chosen to correspond to the PTV size in water for a single field. The difference between the isodose percentage for a single beam and an isocentric irradiation is shown in Fig. 3: an isocentric setup leads naturally to a broader penumbra. This figure also shows the underlying reason for the use of 80% isodose line surrounding the tumor in the past (type A algorithms). A single beam has its sharpest penumbra at the 50–60% isodose line. The combination of multiple beams then leads to the 80% isodose line surrounding the tumor at the specific collimator size: this is not the point of the sharpest gradient for the combination of beams. This % isodose line varies slightly in water around the 80% value

Please cite this article in press as: Lebredonchel S et al. About the non-consistency of PTV-based prescription in lung. Phys. Med. (2017), http://dx.doi.org/10.1016/j.ejmp.2017.03.009