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Research article

Method of predicting the mean lung dose based on a patient's anatomy and dose-volume histograms

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ABSTRACT

The aim of this study was to propose a method to predict the minimum achievable mean lung dose (MLD) and corresponding dosimetric parameters for organs-at-risk (OAR) based on individual patient anatomy. For each patient, the dose for 36 equidistant individual multileaf collimator shaped fields in the treatment planning system (TPS) was calculated. Based on these dose matrices, the MLD for each patient was predicted by the homemade DosePredictor software in which the solution of linear equations was implemented. The software prediction results were validated based on 3D conformal radiotherapy (3D-CRT) and volumetric modulated arc therapy (VMAT) plans previously prepared for 16 patients with stage III non–small-cell lung cancer (NSCLC). For each patient, dosimetric parameters derived from plans and the results calculated by DosePredictor were compared. The MLD, the maximum dose to the spinal cord ($D_{max\ cord}$) and the mean esophageal dose (MED) were analyzed. There was a strong correlation between the MLD calculated by the DosePredictor and those obtained in treatment plans regardless of the technique used. The correlation coefficient was 0.96 for both 3D-CRT and VMAT techniques. In a similar manner, MED correlations of 0.98 and 0.96 were obtained for 3D-CRT and VMAT plans, respectively. The maximum dose to the spinal cord was not predicted very well. The correlation coefficient was 0.30 and 0.61 for 3D-CRT and VMAT, respectively. The presented method allows us to predict the minimum MLD and corresponding dosimetric parameters to OARs without the necessity of plan preparation. The method can serve as a guide during the treatment planning process, for example, as initial constraints in VMAT optimization. It allows the probability of lung pneumonitis to be predicted.

Introduction

Presently, radiotherapy treatment planning is mostly based on clinical practice guidelines, such as guidelines from National Comprehensive Cancer Network,[1] which stratify patients according to risk groups. On the contrary, this allows the comparison of results with other institutions. In contrast, all patients are treated equally. Prescribed dose to the planning target volume (PTV) and constraints to the organs-at-risk (OAR) are the same for all patients with the same stage of the disease, regardless of the tumor size, localization, or the vicinity of the dose-limiting OAR. As a consequence, patients with large tumors or cancer located near a critical structure may not receive a sufficient dose, whereas others with more favorable anatomy are not treated at the highest total dose, even though it would be feasible. This group of patients could benefit from individualized radiotherapy. Moreover, when the dose escalation is considered, the main issue is to maintain the risk of complications at an acceptable level. This is often the case for patients with lung cancer, for whom the main limiting factor is the risk of radiation pneumonitis. The main commonly accepted dosimetric predictors for radiation pneumonitis for standard fractionation schemes are the MLD and the V_{20}.[2,3] Consequently, the main goal of the planning process, not only for patients with lung cancer but also for all patients with the cancer in the thorax, is to minimize the MLD or to keep it below a certain level.

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Unfortunately, information about the dose distribution in PTV and dose to OAR can be obtained only after the preparation of the treatment plan, which at present stage of modern 3D treatment planning, with a diversity of degrees of freedom, is a very time-consuming trial and error process. Additionally, despite the variety of tools that allow the evaluation of the plan, there is no unambiguous answer to the question, regardless of whether the optimal plan was obtained or the physician's expectations or both are feasible. Still, the quality of the prepared plan strongly depends on the planner's skills. Furthermore, when it is impossible to meet all objectives, it is difficult to assess which objective should be relaxed.

An approach that is currently used to deal with this problem is multicriteria (also called multiobjective) optimization. In this approach, the result is no longer a single plan but rather a set of Pareto-optimal plans, which cannot be improved in single dimension without worsening at least the one of the other dimensions.[4,5]

An alternative option is to correlate a patient-specific geometry with dosimetric parameters for OAR. Hunt et al.[6] found that the mean parotid gland dose can be predicted by a percentage of gland volume overlapping with PTV. In a similar manner, Moore et al.[7] described the correlation between the volume of OAR overlapping with PTV, and the OAR mean dose implemented in this model is a quality control tool for intensity-modulated radiotherapy (IMRT) treatment plans. There are also several articles presenting solutions based on training cohorts and institutional experience.[8,9] All the methods mentioned earlier are unable to propose a set of possible solutions as the multicriteria (also called multiobjective) optimization method can, but can still be used either as a support during IMRT treatment planning or as a quality control tool to enable treatment plan unification.

The aim of this study was to propose a method that may help unify the results regardless of the planner's skills, accelerate the process of achieving the best plan while preparing individualized radical radiotherapy or as a training tool for beginners in the planning field. We focused on the prediction of the achievable MLD and corresponding dosimetric parameters for other OAR without the necessity of time-consuming treatment plan preparation for patients with lung cancer.

Material and methods

Method description

The method is designed for patients with non–small-cell lung cancer (NSCLC), but may be extended to the dose calculations in esophageal cancer treatment plans. It is based on the assumption that in the thorax region, the geometry of 2 opposing or almost opposing beams, close to anterior-posterior geometry, delivers the minimal MLD.[10] When the prescribed dose exceeds the cord tolerance dose, the introduction of the third beam, avoiding this organ, is necessary. Therefore, we assumed that the optimal plan consists of 3 beams and the minimal separation angle between each pair of beams is 60°. The latter assumption was made based on the estimation of the optimal wedge angle described by Podgorsak[11] and the largest wedge angle available in our clinic is 60°.

Based on the aforementioned assumption, the method searches for 3 optimal beam angles and their contribution to the total dose. To achieve this, for each patient 36 input plans were generated in treatment planning system (TPS). For all calculations, TPS with the analytical anisotropic algorithm and 2.5 cm grid size were used (v.10, Varian Medical Systems Palo Alto, CA). Each input plan contained a beam and which differed from others in the beam angle. The angular separation of the beam in each subsequent input plan was 10°, for example, in input plan number 1, the beam angle was 0°, in input plan number 2, the beam angle was 10°, and in input plan number 3, the beam angle was 20°. In the last input plan, number 36, the beam angle was 350°. For all 36 input plans, the beam isocentre was placed in the same place in the centre of the PTV mass, and the multiple leaf collimator aperture was defined according to the beam's-eye view of the PTV with an 8-mm margin. The 6 MV energy was used. The prescribed dose for each input plan equaled the total dose prescribed to the patient and normalized to the isocentre point. In this study, the same dose of 2.8 Gy to a total dose of 58.8 Gy was used for input plans, 3D-CRT plans, and VMAT technique. Next, the dose distribution for all 36 input plans were calculated, and the sum of the 36 input plans was generated. The necessary digital imaging and communications in medicine files (36 RTdose files, 36 RTplan files, and 1 RT structure file) were exported from Eclipse TPS and subsequently imported into the DosePredictor software. Through the possibility of treatment plan template creations in Eclipse TPS, the entire earlier described process, with beam creation, dose calculations, and data export, took approximately 10 minutes for each patient. An additional 5 minutes was necessary to obtain the predicted results from DosePredictor. Digital Imaging and Communications in Medicine files exported from TPS allowed for reading and processing all values of dosimetric parameters in selected organs listed in Table 1 in a quick and efficient way.

DosePredictor calculated the following set of linear equations for the aforementioned assumptions and for values of dosimetric parameters retrieved from Eclipse TPS, for the combination without repetition of all input plans and their various weights

$$P^{alg} = w_1 P_i + w_2 P_j + w_3 P_k$$

where $i \neq j$, $i \neq k$, $j \neq k$ and $i, j, k \in \langle 1, \ldots, 36 \rangle$.

$\sum_{l=1}^{3} w_l = 1$ where P^{alg} is the predicted dose for the selected organ calculated by DosePredictor for all 3 beams. P_i, P_j, and P_k denote the values of the dosimetric parameter in the selected organ obtained for 1 of the 36 input plans. The following dosimetric parameters were considered: $D_{max\ cord}$ in the spinal cord, MLD and mean esophageal dose (MED). Parameter w_l is the weight of the beam, which was changed from 0.1 to 0.5 with step 0.1. Combinations with weights greater than 0.5 were not considered. The range of the w_l parameter was chosen to avoid situations in which most dose is deposited from single direction.

For each set of w_l, w_2, and w_3 values and i, j, and k numbers of input plans, a vector consisting of $D_{max\ cord}$, MLD for lung and MED was created. The result was a set of vectors. Before the calculations were started, the user had to specify the constraints for each organ to be included in the calculations. Table 1 presents a list of constraints used in this study. All vectors containing values that were above *a priori* specified constraints were excluded from the analysis. The remaining (acceptable) results were sorted from the lowest to the largest value of the MLD. The first one, corresponding to the lowest value of MLD, was presented as the best one. Apart from this, the user could still use sliders to interactively search the space for other acceptable results.

As we do not use noncoplanar geometries for patients with NSCLC in our clinic, all the calculations were restricted to coplanar

Table 1
Constraints taken as the input data to the DosePredictor for method validation purpose (without the last row—PTV) and used during all plans evaluation

Organ	Constraint 1	Constraint 2	Constraint 3
Spinal cord	$D_{max} < 45$ Gy		
Lung	MLD < 20 Gy	$V_{20\ Gy} < 35\%$	$V_{5\ Gy} < 60\%$
Esophagus	MED < 34 Gy		
PTV	D_{mean} = prescribed dose (dose normalization method)	$D_{98\%} > 95\%^*$	$D_{2\%} < 107\%$

* If the constraint not possible to fulfill, the $D_{min} > 90\%$ accepted.