Lung cancer IMRT

An analysis of 6-MV versus 18-MV photon energy plans for intensity-modulated radiation therapy (IMRT) of lung cancer

Elisabeth Weiss\textsuperscript{a,b},* Jeffrey V. Siebers\textsuperscript{a}, Paul J. Keall\textsuperscript{a}

\textsuperscript{a}Department of Radiation Oncology, Virginia Commonwealth University, Richmond, VA, USA, \textsuperscript{b}Department of Radiotherapy, University of Göttingen, Göttingen, Germany

Abstract

**Purpose:** To analyse the supposed benefits of low over high photon energies for the radiotherapy of lung cancer.

**Materials and methods:** For 13 patients, 6- and 18-MV IMRT planning was performed using identical planning objectives and dose constraints. Plans were compared according to dose–volume histogram (DVH) analysis including conformity and homogeneity indices (CI and HI) and overall plan quality (composite score CS), considering also magnitude and location of planning target volumes (PTVs).

**Results:** With 6-MV plans, CSs were better in 11/13, HIs in 10/13 and CIs in 6/13 patients compared with 18-MV plans. Six-MV plans resulted in a better normal tissue sparing except for specified dose levels to the thorax and spinal cord. On average differences between 6 and 18 MV both for the PTV and normal tissues were not statistically significant ($p > 0.05$). Considering size and location of the PTVs as well as their relative position to normal tissue, overall no significant differences between 6 and 18 MV were observed.

**Conclusions:** On average no clinically or statistically significant differences between 6- and 18-MV plans were observed. High photon energies should therefore not be excluded \textit{a priori} when a dose-calculation algorithm is utilized that accurately accounts for heterogeneities.

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Keywords: Non small-cell lung cancer; Intensity-modulated radiotherapy; Normal tissue toxicity; Dose conformity; Dose homogeneity

Photon energies between 6 and 10 MV are typically used for the radiation treatment of lung cancer. Presently, low photon energies $\leq 10$ MV are required in several lung cancer treatment protocols, such as RTOG 0412/SWOG S0332 and other active RTOG protocols. The use of low photon energies is also recommended in national and international guidelines [1,33].

The reason for preferring low to high energy photons when irradiating lung tumors lies primarily in an increased lateral electron transfer in low density tissue, such as lung, when using photon energies $\geq 10$ MV. The resulting electron disequilibrium leads to a wider penumbra for high photon energies and a consequent decrease in central axis dose [26,40]. To compensate for the degraded dose to the tumor, field widths need to be enlarged. This phenomenon is well known and has repeatedly been described, particularly in experiments using single or opposing photon fields [5,10,12,43].

The choice of the optimal energy is a trade-off between better depth penetration and higher lateral spread as energy increases. At higher beam energies, inaccuracies in dose algorithms that utilize only photon path-length corrections are aggravated, further dictating the choice for low beam energies.

Superposition/convolution (SC) algorithms are increasingly used for treatment planning in clinical routine. Compared to pencil beam algorithms, kernel-based models such as SC algorithms account for photon transport and, on a macroscopic scale, the increased electron range in low density tissue such as lung [2,17,29]. Calculations of the dose to the lung PTV, the $V_{20}$ and the mean lung dose showed an overestimation of more than 10% with correction-based algorithms such as pencil beam compared to SC algorithms [9,32]. Limitations of SC algorithms have been demonstrated in extreme situations for small-field, high energy, single beam phantom geometries, however, the effects are reduced for multibeam clinical cases [19,20,27,44,46]. In a recent publication, Monte Carlo algorithms have been used to benchmark the accuracy of SC calculations for lung IMRT, using the Pinnacle SC algorithm that was also used in this study. The mean relative difference for PTV dose parameters was below 2% for both 6 and 18 MV photons, indicating that the Pinnacle algorithm is capable of calculating the dose also for high energies with...
an excellent accuracy. The comparison of mean lung doses showed a difference below 4% between MC and SC algorithms again both for 6 and 18 MV photons [38]. Our own comparison between MC and SC was in the same range [22].

Intensity-modulated radiotherapy has found increasing use also for the treatment for lung cancer patients. Considering typical characteristics of high energy photon beams, such as lower entry doses and higher depth dose penetration compared with lower energies, an analysis of the choice of photon energy for multiple beam arrangements appears to be meaningful [5,42].

Many lung tumors treated with radiotherapy have a central rather than a peripheral location. In addition, all lymph nodes potentially requiring radiation treatment are situated in the mediastinum or peribronchial regions. Therefore, in general, treatment techniques in which beams pass through the mediastinum, giving only low weight to lateral or oblique beams that transverse the lung, are preferred. Since lateral electron transfer is much lower in the mediastinum, tumor location is expected to influence the choice of beam energy during treatment planning.

It is the aim of this study to compare 6- and 18-MV photon energies for IMRT of lung cancer patients and to investigate whether recommendations to use photons ≤10 MV for the treatment of lung cancer are also applicable to IMRT, when an accurate algorithm such as superposition/convolution is used during plan optimization.

Materials and methods

To compare 6- to 18-MV isodose plans, treatment planning was performed retrospectively on 13 selected CT scans from lung cancer patients. Locoregional tumor stages ranged from T1N0 to T4N3 with both peripheral (4 pat.) and central tumor localizations (9 pat.). The tumor was situated in the upper or middle lobes in 10/13 patients. The mean macroscopic tumor volume was 45.2 cm³ (range 0.9–299.8 cm³). Affected mediastinal lymph nodes were diagnosed in seven patients.

Expiration is the most stable respiratory position with the longest duration in the breathing cycle [35]. It was therefore assumed to be the most representative phase, despite the potentially beneficial effect of larger lung volumes during inspiration with regard to lung toxicity [4]. Moreover, since planning was performed for gated IMRT delivery, lung tumor motion, usually claimed to be a limiting parameter for lung IMRT, was minimized during expiration [11,39]. The computed tomography (CT) scans selected for this study were therefore acquired in expiration with continuous 2.5 mm slices using a multislice CT scanner (GE Healthcare Technologies, Waukesha, WI). CT scans were part of respiratory-correlated 4D CT data sets provided by MD Anderson Cancer Center, Houston, TX.

Contouring was performed manually using a commercially available planning system (Pinnacle, Version 6.2, Philips Medical Systems, Milpitas, CA). The gross tumor volume (GTV) was defined as all macroscopically identifiable tumor including lymph nodes with a diameter of at least 1 cm in the short axis on CT. The clinical tumor volume (CTV) enclosed the GTV with an 8 mm margin towards lung tissue [13] and a 5 mm margin around affected lymph nodes. The CTV was edited to not cross lobe boundaries and to not include the chest wall or organs situated in the mediastinum unless infiltrated by the tumor. For the planning target volume (PTV), an 8 mm margin was added isotropically to the CTV. The mean volume of the CTVs was 110.9 cm³ (range 6–552.2 cm³), while the mean volume of the PTVs was 264.9 cm³ (range 37.3–1009.2 cm³).

IMRT appeared to be the most appropriate planning method for the purposes of a parametric plan comparison study, since a set of well-defined constraints and the use of a single metric, i.e. a composite score (CS) as an indicator for plan quality, allow objective plan comparison. The CS takes into account the actually achieved dose distribution for PTV and organs at risk after plan optimization, relative to the initially given constraints. The CS is the weighted sum of the plan subscores for individual anatomic structures. A plan subscore is a measure for the deviation from the specified dose, dose—volume, or dose—response objective for that structure. The greater the deviation, the greater the plan subscore for that structure.

A further advantage of using IMRT is avoidance of the complex and subjective determination of an appropriate PTV-to-beam block margin required for conformal therapy. This computation is included in the optimization process itself.

IMRT planning was performed using the Pinnacle treatment planning system (version 6.2) with the collapsed cone convolution implementation of the superposition algorithm [2,26]. The SC algorithm was chosen for this work as it accounts for the electron disequilibrium in lung and, compared to Monte Carlo algorithms, is increasingly available on commercially available planning systems. During optimization, shortcomings of the pencil-beam scatter estimation are accounted for using the delta-pixel-method, where pencil beam is used during optimization and then corrected for with a SC algorithm after five iterations. Full scatter is therefore considered during optimization. Furthermore, following convergence, individual segment weights for the MLC leaf segments are re-computed using the SC algorithm, and segment-weight re-optimization is used to further refine the plan. Convergence errors should therefore be minimal. During our TPS commissioning, differences between doses calculated with the SC algorithm and film measurements at 5 cm depth in a water-equivalent phantom were <2% or <2 mm for IMRT fields for both 6 and 18 MV photon energies.

The prescribed dose was 74 Gy (5×2 Gy/week) to follow the maximum tolerated dose of the currently active RTOG protocol 0117. The objective of inverse planning was to deliver the prescribed dose to at least 95% of the PTV with a dose range not exceeding −10% and +20% of the prescribed dose [25,30]. In general, six coplanar non-opposed predominantly anterior—posterior beams were chosen with angles depending on the tumor location. Beam arrangements did not vary between the 6- and 18-MV plans.

For plan optimization a Quasi-Newton gradient-based method was employed, using a sequential quadratic programming method to minimize a quadratic objective function which is constructed from a set of dose- or dose—volume based objectives for individual regions of interest.
(Pinnacle® P®IMRT User Guide). Plan optimization for 6 and 18 MV was performed using identical constraints. Constraints were defined as maximum doses or dose–volume histogram (DVH) limitations with weight factors depending on the respective normal tissue. The total lung volume was defined as the combined volume of the right and left lungs after subtraction of the GTV. Treatment planning was designed to limit the total lung volume receiving 20 Gy ($V_{20}$) or higher to 30% of the lung volume [16]. Esophagus and spinal cord were expanded isotropically by 5 mm to get the respective planning organ-at-risk volumes (PRVs). Plan optimization was performed with the aim to keep the esophagus PRV dose of 55 Gy ($V_{55}$) to 30% of the organ volume and to limit the maximum spinal cord PRV dose to 45 Gy [3,36,37]. The heart was not to receive more than 40 Gy ($V_{40}$) in 50% of the heart volume [14]. To reduce high dose volumes outside the PTV, a constraint was defined that limited the dose to the thorax (except the PTV) to 80 Gy as a maximum [22].

After conversion to segmental multileaf collimator (MLC) (step-and-shoot) leaf sequences, all plans were deliverable on the linear accelerators of the department (Varian 2100EX, Varian, Palo Alto, CA). Although it became evident during the inverse planning process that in individual patients, modifications of objectives, constraints and the respective weights may have resulted in clinically more acceptable plans, we adhered to the initially chosen parameters in order to allow optimum plan comparability. Due to the retrospective nature of this study, none of the IMRT plans were actually delivered.

Based on the developed 6- and 18-MV IMRT plans, DVHs were calculated for the PTV and for all above-mentioned normal tissue structures. The following questions were analysed:

1. Concerning the PTV, do 6-MV plans result in improved dose distributions compared with 18-MV plans? For general plan comparison, composite scores were calculated. Further, plans were analysed comparing mean, minimum and maximum doses to the PTV as well as dose homogeneity and dose conformity. The homogeneity index (HI) was defined as $D_{5\%}/D_{95\%}$ (minimum dose in 5% of the PTV/ minimum dose in 95% of the PTV). The lower (closer to 1) the HI is, the better the dose homogeneity. Since not all parts of the PTV were covered by the prescribed dose, the conformity index (CI) was calculated as follows: $CI = CF \times SF$ (spill factor), where the CF was defined as the percentage of the PTV volume receiving at least 74 Gy and the SF as the volume of the PTV receiving at least 74 Gy relative to the total 74-Gy volume (see also RTOG protocol 98–03). The closer the CI value is to 1, the better the dose conformity.

2. Concerning normal tissue, do 6-MV plans result in better sparing of organs at risk? Plan comparison for normal tissue was performed for clinically relevant dose and volume levels. For lung and thorax, volumes receiving low doses such as 5 and 10 Gy were calculated to evaluate the potentially higher volumes irradiated with IMRT compared with conventional conformal radiotherapy and to analyse the effect of photon energy on those low-dose volumes. The irradiated partial volumes of the total lung volume were compared for different dose levels ($V_{5/10/ 20/30/50}$) as well as the mean lung dose [16,45]. Similarly, the partial volumes of the thorax were calculated for different dose levels from $V_{5}$ to $V_{50}$ and the mean thorax dose. The effects of different photon energies on dose to heart and esophagus were compared for the respective mean doses and specified dose levels ($V_{35/55}$ esophagus, $V_{50/40}$ heart) [3,6,14,23,31,36,37]. For the spinal cord, $D_{0\%}$ doses were compared.

3. Are there tumor-related characteristics that predict when higher photon energies are beneficial? Although the main aim was to investigate whether the dogma to use only low energy photons for lung cancer is true, despite the limited patient numbers, we also tried to determine if subgroups of patients could be identified who would potentially benefit from higher photon energies before planning in order to avoid unnecessary planning efforts. For this purpose, CSs, HIs and Cs of the two photon energies were related to size and location of the PTVs. In addition, the position of organs at risk, relative to the tumor, were analysed – taking into account the dose deposition in the respective organs depending on photon energy.

A two-tailed t-test was applied to analyse statistical significance of the two photon energies (Microsoft Excel analysis functions). A significant difference was assumed for $p < 0.05$.

**Results**

**Ad 1. Comparison of 6- versus 18-MV plans for the PTV**

For all patients together, the mean CS was lower (better) with 6 MV (0.1437 versus 0.1595, $p = 0.86$), implying that on average 6-MV plans met the given planning objectives and constraints better than the 18-MV plans. The difference was, however, not statistically significant. For 2/13 patients, the composite score was lower with 18 MV than 6 MV.

On average, 6-MV plans, compared with 18-MV plans, resulted in lower $D_{5\%}$ (78.91 versus 79.16 Gy) and higher $D_{95\%}$ doses (70.88 versus 70.61 Gy). Consequently, mean HIs improved with lower photon energies. With the mean $V_{74}$ being larger for 6 MV both inside and outside the PTV ($V_{74}$: 347.49 cm$^3$ for 6 MV versus 336.34 cm$^3$ for 18 MV), 6-MV plans had better Cs compared with 18 MV. Fig. 1 compares a 6-MV plan and an 18-MV plan for a left-sided central tumor and shows only marginal differences between the two photon energies both for the PTV and normal tissue. For all evaluated patients, differences were in general small and not significant between the two photon energies (Table 1). Eighteen-MV showed superior results in individual patients with CI being better in seven and HI in three patients.

**Ad 2. Comparison of 6- versus 18-MV plans for normal tissue**

**Lungs:** The mean dose to the total lungs was reduced with 6-MV compared to 18-MV plans (Table 2). Lungs...
volumes receiving 5, 10, 20, 30 or 50 Gy were smaller with 6 than 18 MV.

Thorax: Although the mean dose to the thorax was lower for 6 MV, the volumes covered by the 20-, 30- and 50-Gy isodose were on average smaller for 18 MV compared with 6 MV (Table 2). As a measure for dose concentration to the PTV and for sparing of normal tissue, the ratio between the mean PTV and the mean thorax dose was calculated. This ratio was on average 7.43 for 6-MV and 7.33 for 18-MV plans ($p = 0.92$), showing a slightly better sparing of overall normal tissue with 6 MV.

Esophagus: 6 MV plans resulted in smaller volumes receiving at least 35 and 55 Gy as well as lower mean organ doses (Table 3).

Heart: The mean heart dose, $V_{30/40}$ was lower with 6 MV than with 18 MV (Table 3).

Spinal cord: Mean $D_{0.1\%}$ doses of the spinal cord were higher with the 6-MV than the 18-MV plans (Table 3).

For the studied normal tissue none of the observed differences were found significant (Tables 2 and 3).

Ad 3. Comparison of 6- and 18-MV plans with respect to tumor-related characteristics

Influence of PTV magnitude and location on CS, CI and HI

Patients were divided into groups with large PTVs (median 589.75 cm$^3$), small PTVs (median 86.30 cm$^3$), and patients with central and peripheral tumor location.

Differences in CS between large and small PTVs were marginally significant both for 6 and 18 MV ($p = 0.055$ both
for 6 and 18 MV), implying that objectives and constraints could be met more easily for small PTVs as opposed to large PTVs. Differences in HI were marginally significant between large and small tumors for both photon energies ($p = 0.06$ for 6 and 18 MV). No significant differences were found between the 6- and 18-MV plans for CSs, Cls and HIs comparing large PTVs, small PTVs, and peripheral and central PTVs (Table 4).

The composite score was found to be better with 18 MV for two patients compared with 6 MV. These patients either had small or intermediate sized central tumors. Although several patients had better Cl (7) and HI (3) values with 18-MV plans, no correlation to tumor position and tumor size was observed in these patients. Fig. 2 shows the better sparing of esophagus and heart with the 6-MV plan in a patient with a small peripheral tumor, but a better conformity of the 74-Gy isodose to the PTV for the 18-MV plan.

**Influence of the relative position of organs at risk and PTV on the ability to meet overall planning constraints for different energies**

**Lungs:** Irradiated lungs volumes were smaller with 18 MV in three patients for $V_{20}$ and four patients for $V_{5}$, $V_{10}$, $V_{30}$, and $V_{50}$. All of those patients had central tumor locations. In patients with peripheral tumors, no significant difference between 6 and 18 MV was observed.

**Thorax:** The thorax volumes covered by a specified dose level were smaller with 18 MV for $V_{5}$ in seven, $V_{10}$ in five, $V_{20}$ in eight, $V_{30}$ in ten and $V_{50}$ in seven patients. In four of 13 patients, the ratio between mean PTV dose and mean thorax dose was higher for 18 MV, indicating a relatively better sparing of the thorax compared to 6-MV plans. All four patients had central tumor positions.

**Esophagus:** $V_{35}$, $V_{55}$ and mean esophagus dose were lower with 18 MV in six, four and three patients, respectively. In two of these patients, the PTV was located close to the esophagus.

**Heart:** Four (mean heart dose) and three patients ($V_{30/40}$) had improved heart sparing with 18-MV plans. These were patients with small central tumors away from the heart. For the two patients with PTVs directly adjacent to or covering parts of the heart, 6 MV resulted in better heart sparing.

**Spinal cord:** $D_{0.1\%}$ doses were higher with 6 MV than 18 MV in 6/13 patients. None of the patients had a PTV close to the spinal cord.

Overall, there was no statistically significant relation between any of the evaluated dose parameters, photon energy and the relative position of the respective normal tissue structure to the tumor ($p = 0.77–0.99$).

**Discussion**

The present planning study showed no significant differences between 6- and 18-MV photon energies for any of the evaluated parameters. This is in accordance with the findings by Liu et al., who in their comparison between conventional 3D conformal radiotherapy and IMRT planning also included 18-MV IMRT plans and found no noticeable difference between 6- and 18-MV IMRT plans. Results of a detailed analysis were, however, not shown [25].

Six-MV plans resulted in a slightly better average plan quality expressed by the composite score, and improved dose conformity and homogeneity. Similar to the PTV, the

**Table 1**

<table>
<thead>
<tr>
<th>Plan comparison for the PTV</th>
<th>6 MV</th>
<th>18 MV</th>
<th>$p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D_{\text{mean}}$ (Gy)</td>
<td>74.73</td>
<td>74.76</td>
<td>0.90</td>
</tr>
<tr>
<td>$D_{\text{50%}}$ (Gy)</td>
<td>70.88</td>
<td>70.61</td>
<td>0.82</td>
</tr>
<tr>
<td>$D_{\text{cc}}$ (Gy)</td>
<td>78.91</td>
<td>79.16</td>
<td>0.80</td>
</tr>
<tr>
<td>Cl</td>
<td>0.566</td>
<td>0.563</td>
<td>0.94</td>
</tr>
<tr>
<td>HI</td>
<td>1.116</td>
<td>1.125</td>
<td>0.80</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Volumes of total lung (minus GTV) and thorax (minus PTV) covered by selected dose levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy (MV)</td>
<td>$V_{5}$ (%)</td>
</tr>
<tr>
<td>Lungs 6</td>
<td>49.44 (18.31)</td>
</tr>
<tr>
<td>18</td>
<td>50.00 (18.30)</td>
</tr>
<tr>
<td>Thorax 6</td>
<td>36.81 (14.88)</td>
</tr>
<tr>
<td>18</td>
<td>36.82 (14.71)</td>
</tr>
</tbody>
</table>

The table gives mean values (SDs) for all patients.

Differences between 6 and 18 MV were not significant at any dose level ($p = 0.72–0.93$).
The application of 6- and 18-MV plans had no significant impact on normal tissue sparing, although on average 6 MV appeared to spare most of the analysed organs minimally better. Eighteen MV were found superior in subsets of patients, but patient numbers were not sufficient to determine statistically significant indicators of when it is superior. Neither PTV location nor PTV size played a significant role for the photon energy leading to the superior plan quality. In clinical routine, usually the frequency of patients with peripheral and lower lobe tumors is higher than in the analysed cohort of patients. This will, however, not interfere with

Table 4
Comparison of the mean composite score, the mean conformity and homogeneity index for size and location of the PTV

<table>
<thead>
<tr>
<th>Energy (MV)</th>
<th>Large PTVs Mean (SD)</th>
<th>Small PTVs Mean (SD)</th>
<th>Peripheral PTVs Mean (SD)</th>
<th>Central PTVs Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CS</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>0.2854 (0.2524)</td>
<td>0.0252 (0.0423)</td>
<td>0.2947 (0.3305)</td>
<td>0.0765 (0.1044)</td>
</tr>
<tr>
<td>18</td>
<td>0.3085 (0.2739)</td>
<td>0.0359 (0.0649)</td>
<td>0.3272 (0.3329)</td>
<td>0.0849 (0.1082)</td>
</tr>
<tr>
<td>CI</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>0.507 (0.092)</td>
<td>0.605 (0.072)</td>
<td>0.569 (0.04)</td>
<td>0.549 (0.114)</td>
</tr>
<tr>
<td>18</td>
<td>0.492 (0.084)</td>
<td>0.625 (0.074)</td>
<td>0.578 (0.106)</td>
<td>0.549 (0.107)</td>
</tr>
<tr>
<td>HI</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>1.176 (0.066)</td>
<td>1.068 (0.045)</td>
<td>1.167 (0.092)</td>
<td>1.101 (0.067)</td>
</tr>
<tr>
<td>18</td>
<td>1.193 (0.075)</td>
<td>1.070 (0.045)</td>
<td>1.178 (0.104)</td>
<td>1.107 (0.072)</td>
</tr>
</tbody>
</table>

All differences between 6 and 18 MV were not significant for any of the analysed parameters (p = 0.64–0.99).

Fig. 2. Energy comparison for a small peripheral lung lesion. (a) Six- and (b) 18-MV isodose distributions. The 74-Gy (dark blue), 40-Gy (purple) and 20-Gy (light blue) isodose curves are shown. The PTV is shaded red. (c) DVH comparison between six MV (solid lines) and eighteen MV (dashed lines).

application of 6- and 18-MV plans had no significant impact on normal tissue sparing, although on average 6 MV appeared to spare most of the analysed organs minimally better.

Eighteen MV were found superior in subsets of patients, but patient numbers were not sufficient to determine statistically significant indicators of when it is superior. Neither PTV location nor PTV size played a significant role for the photon energy leading to the superior plan quality. In clinical routine, usually the frequency of patients with peripheral and lower lobe tumors is higher than in the analysed cohort of patients. This will, however, not interfere with
the general finding that 6-MV photons are not always superior to higher energies.

We also performed planning with mixed energy beams for a small peripheral tumor, a large peripheral and a central tumor. Eighteen-MV beams were used primarily for those fields where the tumor was situated distant to the beam entry to use the advantages of higher depth dose penetration with higher photon energies. For all three patients, no systematic improvement in plan quality was discernible when combining 6- and 18-MV beams in one plan.

All observed differences between 6- and 18-MV plans were small. A comparison of monitor units (MUs) per fraction showed no significant difference between 6- and 18-MV plans (707 versus 663 MU, \( p = 0.67 \)), indicating only clinically irrelevant elongations of treatment time with 6 MV compared to the total IMRT treatment time. From the clinical point of view, it therefore needs to be added that the observed variations in dose delivered to the PTV and normal tissue are certainly of a much lower scale compared with other more fundamental issues in the treatment of lung cancer patients, e.g. total dose, definition of the clinical target volume, tumor motion [15,34,35,39,41].

For IMRT it is most important to use an accurate algorithm, such as a SC algorithm, to, e.g. avoid convergence errors during optimization, so that dose deficiencies in the delivery of one beam can be compensated for by adjusting the intensity from the other beams [18]. Of further importance when comparing low to high energy photons is the generation of nuclear particles, in particular neutrons, induced by high energy photons [8]. However, in clinical routine the contribution of nuclear particles to total dose is presently not considered. From phantom measurements of penumbra width and PTV dose, low energy beams were recommended for tumors surrounded by lung parenchyma [24,28]. We are aware that phantom measurements might show deviations from even advanced dose-computation algorithms, such as the superposition/convolution algorithm, to a significant amount [7]. The awareness of the limitations of the used planning algorithm is, however, only one factor that influences the radiooncologist’s decision on an isodose plan. Also important is the quantitative assessment of dose delivered to normal tissue, which is usually not considered in phantom studies.

Selection of the optimum plan is particularly important in all patients with a high risk for treatment-related sequelae, such as combined modality treatment, compromised lung function and dose escalation protocols. High photon energies should particularly be considered for central tumor locations. This observation also supports the recommendations of the National Comprehensive Cancer Network NCCN, where higher photon energies are suggested for large tumors surrounded by consolidated or atelectatic lung and bulky lymphadenopathy (http://www.nccn.org).

**Conclusion**

For the treatment of patients with lung carcinomas, on average no significant differences between the 6- and 18-MV plans were observed when a superposition/convolution algorithm was used during plan optimization. In several patients, 18-MV plans were superior to 6-MV plans for the analysed indices. Sufficiently accurate planning algorithms are a prerequisite for decisions on high energy beams in the thorax region involving lung tissue [1,21]. Further studies on larger patient data sets are needed to identify subgroups where low/high photon energies are more applicable.

**Acknowledgments**

The authors acknowledge Drs. L. Dong and R. Mohan from the UT MD Anderson Cancer Center for supplying the CT data used for this study. The authors wish to thank Dr. C.F. Hess, University of Göttingen, and Dr. N. Dogan for their critical comments. Thank you to Devon Murphy for improving the clarity of the manuscript. This work was partially supported by NCI R01 CA 93626 and R01 CA 98524.

*Corresponding author. Elisabeth Weiss, Department of Radiation Oncology, Virginia Commonwealth University, PO Box 980058, Richmond, VA 23298, USA. E-mail address: eweiss@mcvh-vcu.edu*

Received 19 October 2006; accepted 25 October 2006; Available online 5 December 2006

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