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Experimental evaluation of ALFARD treatment planning system for 6 MV photon irradiation: a lung case study

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Summary

Purpose: Simple inhomogeneity correction methods available in a number of currently applied treatment planning systems are not accurate enough for dose calculations in lung irradiations. The purpose of this study was to evaluate the accuracy of the ALFARD treatment planning system in dose calculations for lung irradiation.

Material and methods: An anatomic thorax phantom and a 6 MV photon beam were used for our irradiation. Our set-up consisted of an anterior single field for the left lung of a thorax phantom with field sizes of 5 x 5 cm^2 and 10 x 10 cm^2. The percentage depth doses for each point in the lung were measured by a Pinpoint ionization chamber and calculated by the ALFARD treatment planning system. The results of calculations and measurements were compared.

Results: The ALFARD calculations overestimated measurements at all points and field sizes. The magnitude of error increased with depth of the calculation point from 2.7% to 17.3% for the field size of 5 x 5 cm^2. The error for 5 x 5 cm^2 was approximately twice as high as that for 10 x 10 cm^2.

Conclusions: The ALFARD treatment planning system cannot calculate the dose in the lung accurately. This may be due to inherent deficiencies of the effective path length method, which is implemented in the ALFARD treatment planning system.

Key words: treatment planning systems, ALFARD, effective path length method, lung irradiation, accuracy.

Doświadczalna ocena systemu planowania leczenia na przykładzie naświetlania płuc fotonami o energii 6 MV

Streszczenie

Cel: Proste metody korekcji niejednorodności stosowane w wielu dostępnych obecnie systemach planowania leczenia nie są dostatecznie dokładne, jeżeli chodzi o obliczenie dawek w przypadku napromieniowania płuc. Celem niniejszej pracy była ocena dokładności systemu planowania leczenia ALFARD dla przeprowadzania obliczeń przy napromieniowaniu płuc.

Materiał i metody: W napromieniowaniach stosowano fantom anatomiczny klatki piersiowej oraz wiązkę fotonów o energii 6 MV. Układ pomiarowy składał się z pojedynczego przedniego koła przedstawiającego lewe płuco w fantomie klatki piersiowej o wymiarach pól 5 x 5 cm^2 oraz 10 x 10 cm^2. Procentowe dawki głębokie dla każdego punktu w płucu zmierzono za pomocą komory jonizacyjnej typu Pinpoint i obliczono używając systemu planowania leczenia ALFARD. Wyniki obliczeń i pomiarów zostały ze sobą porównane.

Wyniki: Obliczenia ALFARD dały wyniki wyższe od pomiarów dokonanych we wszystkich punktach i polach. Wielkość błędu wzrosła wraz z głębokością punktu obliczeniowego od wartości 2.7% do 17.3% dla pola o wymiarach 5 x 5 cm^2. Błąd ten był w przybliżeniu dwa razy większy niż błąd w przypadku pola o wymiarach 10 x 10 cm^2.

Wnioski: System planowania leczenia ALFARD nie jest w stanie dokładnie obliczyć dawkę na płuco. Może to być wynikiem nieodłącznych niedoskonałości związanych z metodą efektywnej długości toru zastosowanej w systemie ALFARD.

Słowa kluczowe: systemy planowania leczenia, ALFARD, metoda efektywnej długości toru, napromieniowanie płuc, dokładność.

Introduction

For optimum treatment of cancer, the radiation dose must be planned and delivered with a high degree of accuracy. The International Commission on Radiation Units and Measurements (ICRU) recommends that the dose be delivered with an error not greater than 5% [1]. However, accuracy of ±3% and ±3.5% in the overall process has been recommended [2,3], and it is desirable to calculate the absorbed dose distribution with an accuracy of at least 3% [3].

The ability to deliver a homogeneous dose distribution during the treatment of lung malignancies with megavoltage photon irradiation is complicated by differences that exist in the physical density (ρ) and electron density between the lungs and the surrounding soft tissues. The lung parenchyma has a significantly lower density than that of water and soft tissue ($\rho = 0.15$-0.30 relative to water) [4,5]. In low-density tissue such as the lung, transmission is increased relative to that in water-density tissues. The effect of an inhomogeneity on the primary absorbed dose is easy to calculate. However, its effect on scattered radiation and electron transport throughout the irradiated volume is complex. The correction for an absorbed dose will depend on the radiation beam energy and field area, lung density, and on lung and soft tissue depth and shape [4-11]. If the lower density of the lung is not taken into account and dose calculations are performed assuming unit density throughout, the error in the dose in the lung can be greater than 40% [10,11].

The Effective Path Length (EPL) methods calculate inhomogeneity correction factors using water-equivalence or radiological depth. These methods have been evaluated in many investigations, and their inaccuracy in lung dose calculations has frequently been reported [12-15]. It is not only the accuracy of the algorithm itself that introduces errors, but also the implementation of that algorithm into a treatment planning system (TPS) and it customization, i.e. the modelling of the beam parameters, can be a source of error. Hence, it is the responsibility of physicists to evaluate the accuracy of the treatment planning system used clinically and to be aware of the limitations and inaccuracies of the algorithms used.

There were some questions that encouraged us to undertake this study. (1) How accurate is the ALFARD system in dose calculations for lung irradiation? (2) Are the differences between measurements and conventional dose distributions clinically significant?

To answer these questions, we calculated point doses for a lung case using the ALFARD system, which corrects the tissue inhomogeneity by the EPL method. For calculations and measurements we used an anatomic inhomogeneous thorax phantom. The results of calculations were compared with measurements to show the accuracy of the treatment planning system, and the causes of errors and effective parameters in dose calculations were discussed.

Material and methods

Thorax phantom

In this research, we used an anatomic thorax phantom for dosimetry. This phantom is shown in *Figure 1*. The phantom was made in accordance with the ICRU report number 48 [12].

The thoracic spine was modelled by a Teflon (density $= 2$ g/cm^3) cylinder, of 20 cm in length and 3 cm in diameter. Cork of 0.2 g/cm^3 density was used as a lung tissue substitute. The phantom was built from polyethylene as a soft tissue substitute. For point dose measurements by an ionization chamber, several holes were made in polyethylene and cork. These holes were filled up with cylinders of the same size. Each cylinder was drilled according the external shape and size of the chamber. For dose measurements at a given point, the simple cylinder was replaced with the chamber fitted cylinder.

The mass density of polyethylene, Teflon and cork were determined by dividing the measured weight by the calculated volume. For polyethylene, cork and Teflon, the values for mass density were 0.94, 0.2 and 2 (g/cm^3), respectively.

The geometry of irradiation is shown in *Figure 1*. The left lung of the phantom was irradiated by anterior field of 6 MV photons. Field sizes of 5 x 5 cm^2 and 10 x 10 cm^2 were used for irradiation.

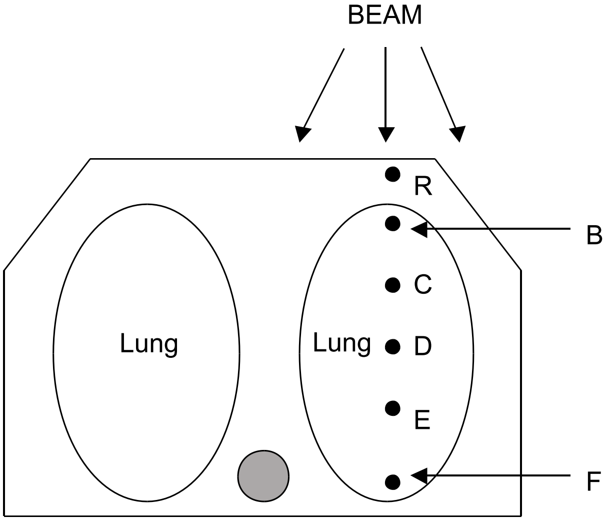

Figure 1. Schematic representation of the thorax phantom and the irradiation geometry.

Treatment planning system

We used the ALFARD TPS, version 4.06, as a conventional dose calculation system. This takes medium density into account using the Effective Path Length method. This method only accounts for changes in the primary photon transport by assuming electron equilibrium. To determine the effective depth in this system, the section between the surface and a given point is divided into *N* sub-sections. The density in each of the points determined is computed using a method of linear interpolation between the closest points. In practice, interpolation is made in two dimensions, which means that the four nearest points are taken into consideration. The effective depth for a given point is calculated by multiplying the average density by the geometrical depth. The basic beam data, including percentage depth doses (PDDs) and beam profiles for different filed sizes and depths, were obtained using the RFA300 automatic (Scanditronix) water phantom and entered into the treatment planning system. By comparing the results of the ALFARD calculations with the water phantom measurements, we checked the accuracy of TPS calculations for the homogenous phantom. The difference between the calculated and measured PDD was less than 0.8% for field sizes of 10 x 10 cm^2 and of 5 x 5 cm^2.

Dose measurements

A 6 MV photon beam of a Philips SL75/5 linear accelerator was used in this study. For point dose measurements in the phantom we used a Pinpoint chamber type 31006 with 0.015 cm^3 sensitive volume, and a Unidose E-electrometer produced by PTW-Freiburgh. According to the manufacturer's recommendations, in order to get reliable results the chamber was connected to the electrometer for 10 minutes and preirradiated with 2 Gy. For each point three readings were obtained and averaged. The readings were corrected for temperature and pressure changes during measurements.

The reference point for the normalization of readings was point R at a depth of 1.5 cm (depth of maximum dose) on the central axis of the beam. All irradiations were made at the source to surface distance (SSD) of 100 cm. According to the results of Rice et al. [16] the measurements of the dose in the lung made with different detector-phantom combinations should differ by less than 1% from the measurements made in water-like material as long as there are no additional fluence perturbation effects due to the introduction of a detector. Also, their results showed that the material and thickness are not critical in the determination of lung dose correction factors under conditions of electron equilibrium. This study shows that, when using an ionization chamber for lung dose measurement by selecting an appropriate chamber and considering the measurement points, we can make measurements with desirable and reliable accuracy (error $< 1\%$). However, for the relative dose measurements in a thorax phantom, the uncertainty of measurements was $\pm 1\%$.

Relative readings of the chamber at each point to the reference point readings were multiplied by 100 and considered as PDD for each point. Point R was considered to be reference point in our set-up. For each point, the error of the calculation method was calculated according to the following formula:

$$\text{Error}\,\% = [(\text{Calculation} - \text{Measurement}) / \text{Measurement}] \times 100$$

For the purposes of comparison between calculations and measurements, we used the measured PDD data of 6 MV photons in a homogenous water phantom. This data has been obtained using a RFA 300 (Scanditronix) automatic water phantom and has been entered into the treatment planning system as basic beam data.

Results and discussion

The results of calculations and measurements for both field sizes are shown in *Figures 2 and 3*. To better illustrate the photon depth dose changes in a low-density material we included the measured PDD curve of 6 MV photons for the homogenous water phantom in our graphs. As the photon beam enters the low-density material, the attenuation of primary photons decreases and the absorbed dose for points in the lung increases. But there is another effect which plays an important role in the absorbed dose. In low-density material, i.e. the lung, the scattered radiation decreases and results in a lower absorbed dose. In our case the lower attenuation effect of primary photons is dominant and the absorbed doses in the lung are higher than the absorbed doses in the homogenous water phantom for all points.

It can be seen that the ALFARD overestimates the PDD for points in lung for both field sizes, and the magnitude of the overestimation increases with the depth of points. The maximum error for the field size of 10 x 10 and 5 x 5 cm^2 amounts to10.7% and 17.3%, at point F respectively.

The errors of the ALFARD calculations for all points are shown in *Table 1*. The magnitude of error for the field size of 5x5 cm^2 is approximately twice as high as that for the field size of 10x10 cm^2. This is due to the loss of lateral electron equilibrium at smaller field sizes, coupled with the reduction in photon scatter in a low-density medium. This effect becomes more prominent at points B and C for a smaller field

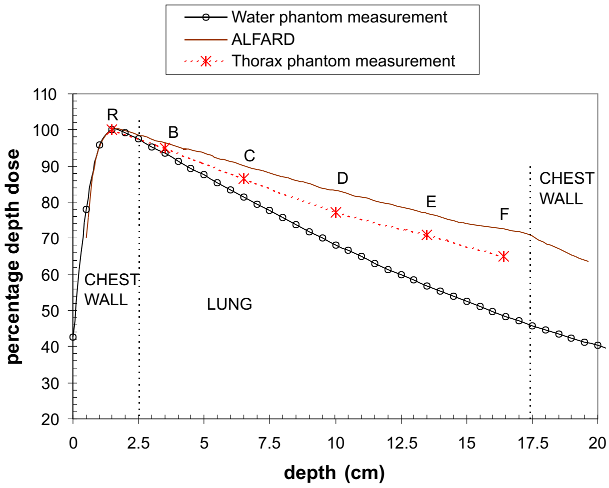

Figure 2. Percentage depth dose for a 6 MV photon beam calculated by the ALFARD TPS and measured by a Pinpoint ionization chamber in an inhomogeneous thorax phantom (SSD = 100, field size = 10 x 10 mm^2). The percentage depth dose curve measured in a water phantom is included for purposes of comparison.

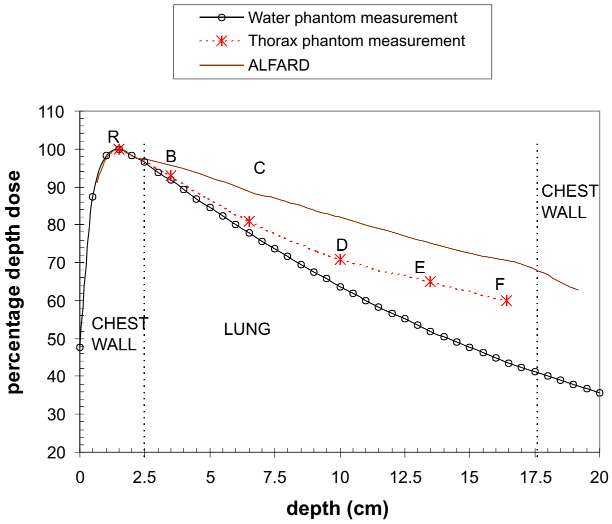

Figure 3. Percentage depth dose for a 6 MV photon beam calculated by the ALFARD TPS and measured by a Pinpoint ionization chamber, in an inhomogeneous thorax phantom (SSD = 100, field size = 5 x 5 mm^2). The percentage depth dose curve measured in a water phantom is included for purposes of comparison.

size, because these points are close to the chest wall/lung interface where electronic equilibrium does not exist for high energy photons and small fields. Our findings are in agreement with the results of other investigations [9,13,14], which showed that the EPL method works better for large field irradiation of the lung and should not be used for small field irradiations.

Table 1. The error of ALFARD calculations compared with measurements for both field sizes.

points	field size 10 x 10 cm^2	field size 5 x 5 cm^2
B	0.7%	2.7%
C	4.0%	9.6%
D	7.0%	15.5%
E	7.7%	16.0%
F	10.7%	17.3%

When calculating the dose at a greater distance from an inhomogeneity, the EPL methods give results with acceptable errors; within 2-3% [7-10]. For a complex inhomogeneity medium and for dose calculations within or in the near vicinity of an inhomogeneity, the EPL methods are burdened with errors as high as 10% [11]. The overestimation of the EPL methods leads to an incorrect choice of the margin between the target volume and the beam edge, resulting in an under-dosage of the PTV. Also, the dose in the lung will be wrongly predicted, especially in small fields and at greater depths, thus hampering dose optimisation based on dose levels in organs at risk [11,16].

Conclusions

Our goal in this study was to evaluate the accuracy of the ALFARD treatment planning system for photon dose calculations in lung irradiation. In order to accurately measure the point dose in the lung, and avoid the perturbation effect of the ionization chamber, we used a Pinpoint chamber for our measurements. Our results were in agreement with previous investigations [8,9,11,13,14]. The results showed that the EPL methods satisfactorily model primary dose variation. However, the amount of scattered radiation reaching the calculation point mainly depends on its position in the medium with respect to the inhomogeneity as well as on the size of the inhomogeneity. Therefore, these methods fail to account for any changes in the dose resulting from scattered photons. Our results showed that if we consider 3% as an acceptable error for dose calculations in an inhomogeneous thorax phantom [3], the errors of the ALFARD TPS were higher than 3% for all points in both field sizes except for point B *(Table 1).*

Inaccuracy of the ALFARD TPS in lung dose calculations was predictable because the algorithm used in the TPS only accounts for changes in photon primary transport on assuming electron equilibrium.

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