DOSE CALCULATION FOR TISSUE INHOMOGENEITY IN LUNG CANCER BASED ON 6 MV PHOTON BEAMS

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Purpose **:** To evaluate the accuracy of dose calculation in lung cancer treatment planning using Two-dimensional radiotherapy (2D-RT) without inhomogeneity correction, with inhomogeneity correction by use of Power Law Tissue-Air Ratio Method (Power Law Method), and Three-dimensional conformal radiotherapy (3D-CRT) with inhomogeneity correction. The latter method takes into account in convolution algorithm.

Materials and Methods **:** Treatment was planned based on Alderson-Rando phantom held in an immobilization device. Doses were calculated on FOCUS release 2.0 planning system both for 2D-RT and 3D-CRT, and irradiation were performed on Varian C-Series 600C linear accelerator, 6MV x-ray. Thermoluminescent dosimeters (TLDs) were placed inside the target to compare the dose based on each method. The prescribed dose was180 cGy in isocenter.

Results **:** The delivered doses by using 3D-CRT planning and 2D with Power Law Method correction were closer to the prescribed dose (173 cGy, 172 cGy in a 5 x 5 cm^2 field and 175 cGy, 174 cGy in a 10 x 10 cm^2 field). The delivered dose by using 2D-RT planning without heterogeneity correction was significantly higher (212 cGy and 216 cGy).

Conclusion **:** Dose variation between measurement and calculation is due to tissue inhomogenity, especially in the lung. Power Law Method accounts with tissue inhomogeneity but not with the 3D shape of inhomogeneity tissue. 3-D treatment planning with inhomogeneity correction based on CT image, delivers more accurate dose. Use of 3-D planning in lung cancer should reduce the risk of radiation side effects while optimizing delivery to the tumor.

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Key words: Inhomogeneity, 2D-RT, 3D-CRT, Power Law Method, Prescribe dose, TLDs

INTRODUCTION

Radiotherapy for lung cancer can be given alone or in combination with surgery or chemotherapy, and a variety of protocols have been established (Table1). Small-cell lung cancer is mainly treated with chemotherapy. Depending on the stage, non-small-cell lung cancer may be treated surgically along with neoadjuvant or adjuvant chemotherapy. For

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Table 1. Major Groups of Patients with Lung Cancer Treated with Radiotherapy

Definitive
Operable patients
Postoperative radiotherapy
Involved lymph nodes (stages II and III)
Positive surgical margins
Chest wall invasion (T3)
Preoperative radiotherapy combined with chemotherapy
Marginally operable patients (stage IIIa or IIIb)
Inoperable patients
Conventional fractionated radiotherapy alone
Altered fractionated radiotherapy alone
Chemotherapy and radiotherapy
Sequential
Concurrent
For small-cell lung cancer
Palliative radiotherapy
External beam
Brachytherapy

inoperable disease, radiotherapy is used as definitive treatment, given at high doses with the intent to cure. A minimum of 60 Gy with conventional fractionation to the primary tumor and gross nodal disease is prescribed. Many institutions deliver more than 70 Gy and in Radiation Therapy Oncology Group (RTOG) protocol 93-11 is studying doses of up to 90.3 Gy to the lung [8], but the optimal dose has not been defined [9].

For traditional treatment planning, the tumor is visualized fluoroscopically and the amount of motion ascertained. 2-D treatment planning is usually done with imaging through the center of the primary tumor. Portals are drawn on the simulation films, both treatment planning and measurements are made at multiple levels of the chest for the purpose of evaluation of the dose to the tumor, spinal cord, and any other relevant areas. The AP-PA portal is treated up to spinal cord tolerance (40 to 50 Gy) followed by use of oblique fields that shield the spinal cord. This method of treatment planning, however, does not take into account tissue inhomogeneity. It can be better assessed using 3-D CRT, with CT simulator. A planning CT normally has 50 or more cuts for full 3-D volumetric planning. This provides a natural structural image of the tumor and critical organs, offering the potential advantage of improved dose delivery to a particular target volume by adjusting for tissue inhomogeneity [3,7,10,12]. We designed this study to compare the doses delivered based on 2-D and 3-D planning.

MATERIALS AND METHODS

Phantom simulation and immobilization

We used an Alpha cradle immobilization device to encompass an Alderson-Rando phantom ensuring the repositioning of a treatment (Fig. 1). The target was defined using fluoroscopy x-ray and laser marks were drawn on the sides of the phantom in preparation for the CT scan positioning [12] (Fig. 2).

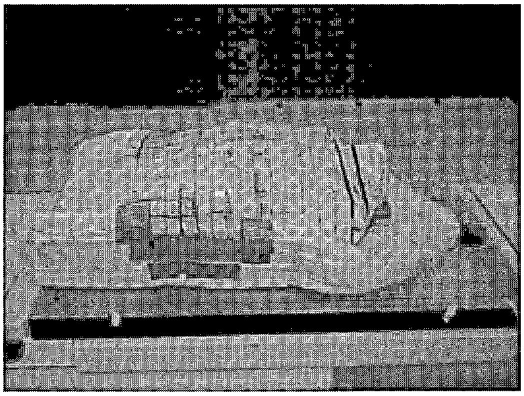


Fig 1. Immobilization device for phantom

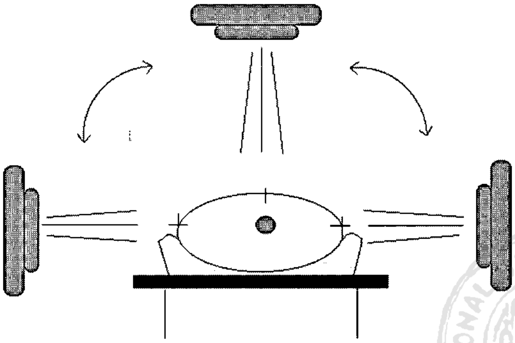


Fig 2. Phantom simulation

Phantom contouring and CT scanning

Plaster cast was used to contour curves in the body of phantom (Fig. 3) and should be done at the center of target. The body curve was loaded into the FOCUS planning system by using digitizer and then duplicating the same slice with at least five cuts. Dose calculation was done with 2-D and 3-D methods, and inhomogeneity of tissue was taken into account using Power Law Method in 2D and convolution method in 3-D dose calculation. CT scanning was done in the Radiology Department, and images data were transferred to the FOCUS planning system through DICOM 3 networking. Phantoms were repositioned according to the laser marks.

Dose calculations & Heterogeneity corrections

In 2-D RTP, doses are calculated in a 2-D grid established in the transverse plane in which

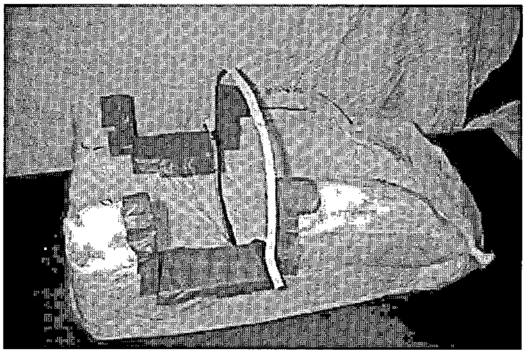


Fig 3. Phantom contouring

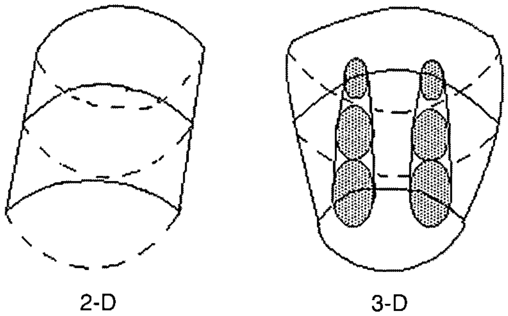
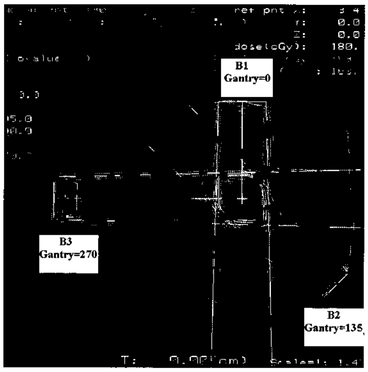
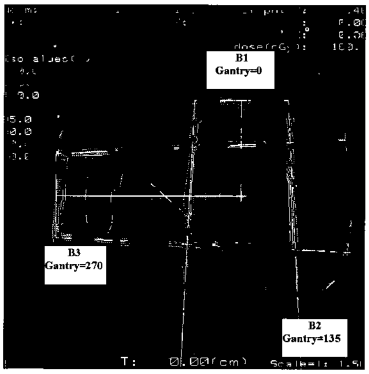


Fig 4: The differences between 2D and 3D heterogeneity corrections.



(a)



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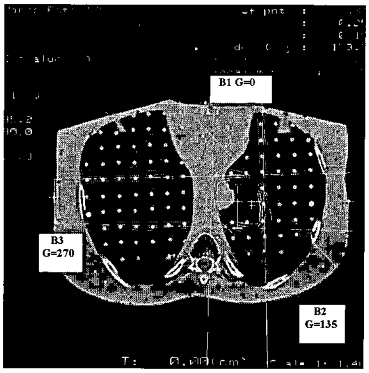

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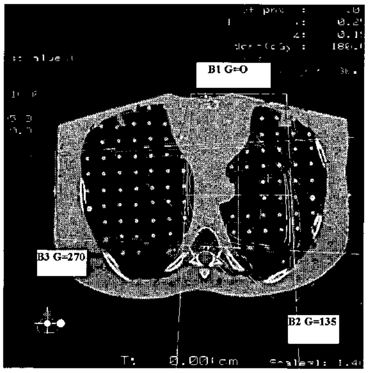

(d)

Fig. 5. 2D and 3D dose distributions in both fields. (a) 6 x 6 cm^2 field in 2D; (b) 10 x 10 cm^2 field in 2D; (c) 6 x 6 cm^2 field in 3D; (d) 10 x 10 cm^2 field in 3D.

the planning is done. The radiation source is assumed to be in the same plane; beam divergence is accounted for only in the planning plane. Heterogeneities are assumed to be infinite in the direction perpendicular to the planning plane. Power Law Method simply provides a way to correct tissue inhomogeneity with 2D-RT, does not account the whole shape of inhomogeneity tissue. An obvious difference between 3D-CRT and 2D-RT dose calculation is the use of a 3-D grid that accounts for the heterogeneity corrections in three dimensions (Fig. 4) [3]. We used FOCUS release 2.0 planning system in this study (convolution algorithm), and the dose distributions are shown (Fig. 5) and the energy was 6 MV x-ray.

TLD-100H dose response curve

We used a TLD-100 (LiF) chip in this study. TLD is one of the most widely used measurement tools in RT. Its advantages include various shapes, outstanding dose-response ability, and reusability. TLDs can be produced in powder, chip, and cube form. They are often used in measuring TBI, skin scattering, and non-iso-center field dose [5,14]. Before measurements, we first established a TLD-100 dose response curve by irradiating with doses of 60

Table 2. Beam data for 5 x 5 cm field

2D without heterogeneity correction	Beam 1	Beam 2	Beam 3
Gantry angle	0	135	270
Weighting (cGy)	60	60	60
Effective depth(cm)	9.7	11	17.4
MU	85	90	120
2D with Power Law Method			
Gantry angle	0	135	270
Weighting (cGy)	60	60	60
Effective depth(cm)	6.73	5.2	10.2
MU	75	71	87
3D with heterogeneity correction			
Gantry angle	0	135	270
Weighting (cGy)	60	60	60
Effective depth(cm)	6.8	5.5	10.1
MU	77	72	88

Table 3. Beam data for 10 x 10 cm field

2D without heterogeneity correction	Beam 1	Beam 2	Beam 3
Gantry angle	0	135	270
Weighting (cGy)	60	60	60
Effective depth(cm)	9.7	11	17.4
MU	76	80	104
2D with Power Law Method			
Gantry angle	0	135	270
Weighting (cGy)	60	60	60
Effective depth(cm)	6.73	5.2	10.2
MU	69	65	77
3D with heterogeneity correction			
Gantry angle	0	135	270
Weighting (cGy)	60	60	60
Effective depth(cm)	6.8	5.5	10.1
MU	68	65	77

cGy, 120 cGy, 180 cGy, 240 cGy, 300 cGy, and 360 cGy. The absorption values were read by a Harshaw 4000 TLD reader. The TLD-100 dose response curve is shown on Fig. 6.

Irradiation

In our study, we used the two oblique fields and an anterior beam technique. Dose was calculated using 5 × 5 and 10 × 10 cm^2 fields with and without heterogeneity corrections. Heterogeneity correction shows less effective depth in both fields. And the beam datas are shown in Table 2 and Table 3. TLDs were placed inside the target and irradiated with 6 MV x-ray (Fig. 7).

RESULTS

Table 4 and Table 5 show the measured doses at the target, which were irradiated with different monitor unit calculated by 2-D, Power Law Method, and 3-D treatment planning. 2D-RT without heterogeneity correction shows higher dose error approximate 20% than prescribe dose (212 cGy, 216 cGy in a 5 × 5 and 10 × 10 cm^2 field). With Power Law Method correction, the measured doses show a dose error approximately 5% (172 cGy, 174 cGy in a 5 × 5 and 10 × 10 cm^2 field), and 3D-CRT measured doses show the dose error less than 4% (173 cGy, 175 cGy in a 5 x 5 and 10 × 10 cm field).

DISCUSSIONS

Using TLDs to measure the irradiated dose would have its shortcoming because of 2~4% error average even in a good condition. It is still being used in routine dose measurement due to the outstanding shape ability and reusable bene-

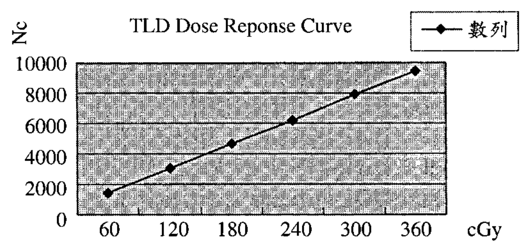

Fig. 6. TLD dose response curve (R^2= 0.998)

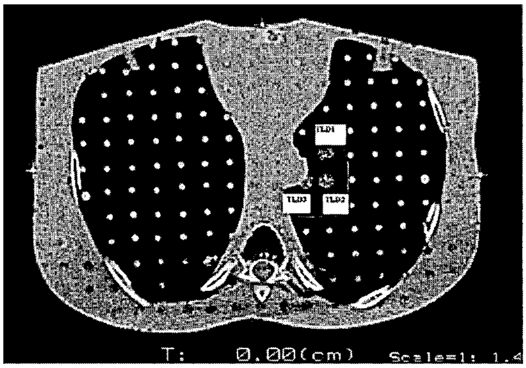

Fig.7. TLDs placement in central cut

Table 4. Phantom measuring result in 5 x 5 cm field.

Energy 6 MV	TLD1	TLD2	TLD3	Average (cGy)
2D without heterogeneity correction				
Planning dose	180.6	179.5	181	180.3
Measured dose	214	212	211	212.3
Error	+18.50%	+18.10%	+16.50%	+18%
2D with Power Law Method				
Planning dose	180.6	179.5	181	180.3
Measured dose	171	173	172	172
Error	-5.30%	-3.60%	-4.90%	-4.60%
3D with heterogeneity correction				
Planning dose	181.1	180.5	177.4	180
Measured dose	173	176	170	173
Error	-4.40%	-2.40%	-4.10%	-3.80%

* P<0.001 in comparison with and without heterogeneity correction.

Table 5. Phantom measuring result in 10 x 10 cm field.

Energy 6 MV	TLD1	TLD2	TLD3	Average (cGy)
2D without heterogeneity correction				
Planning dose	181.2	179.7	180.9	180.6
Measured dose	217	216	215	216
Error	+19.70%	+20.20%	+18.80%	+19.60%
2D with Power Law Method				
Planning dose	181.2	179.7	180.9	180.6
Measured dose	176	174	172	174
Error	-2.80%	-3.10%	-4.90%	-3.60%
3D with heterogeneity correction				
Planning dose	181.5	181	177.6	180
Measured dose	178	173	173	174.6
Error	-1.90%	-4.40%	-2.50%	-2.96%

* P < 0.001 in comparison with and without heterogeneity correction.

fits plus less expensive. This experiment results simply show 2D-RT without heterogeneity correction in lung area would produce dose error approximately to 20% higher than prescribe dose. And the accuracy dose of lung correction concerns with the thickness of lung tissue, beam energy and irradiated field size.

Power Law Method correction shows the dose error approximately to 5%, and 3D-CRT planning shows the best result (dose error < 4%). In general condition, use of Power Law Method would consider inhomogeneity factor within planning; however, this method does not account the whole shape of imhomogeneity tissue, and the later scattering from different interface. Even though our study shows the dose error around 5% in a phantom measuring, but with variety human body density, this error could increase high.

The loss of electronic equilibrium within and adjacent to low density materials can result in a dose reduction along the central axis and near the beam edge for photon beams [13]. Use of high photon energy (> 12 MV) in a small size would cause the loss of equilibrium and the dose reduction nearby interface boundary. RTOG protocol 91-05 recommends the use of photon beams for non-small cell lung cancer should be 12 MV or less [9]. In our study, we used 6 MV photon beams for lung cancer and with small field sizes of 5×5 cm^2 and 10×10 cm^2 could technically reduce the loss of electronic equilibrium. The loss of electronic equilibrium in a low density tissue like lung tissue depends on the beam energy and field size.

As the noted by Purdy [8], the current treatment planning algorithm has had limits in predicting dose distributions under the circumstances of losing electronic equilibrium in lung interface. Monte Carlo methods provided significant improved over existing methods in lung area and shown in many studies. This method provides the best result of calculating dose distribution but hasn't yet been wildly used due to the requirement of amount computer hardware and finance consideration.

In the existing methods, the general dose calculation with heterogeneity corrections for lung tumor remains essential because the various density of lung. In our study, we used convolution algorithms with heterogeneity correction. The advantage of this algorithm is that the model reflects a large amount of the physics that actually occurs as a radiation beam passes from the head of treatment machine through the patient. It accounts the effect of beam shaping and beam modification. [7].

CONCLUTIONS

The optimal dose for lung cancer has not been determined, but for non-small-cell cancer treated with radiotherapy alone or combined with chemotherapy, doses of 66 to 70 Gy are necessary for positive surgical margins. The traditional irradiation technique (AP/PA) is necessary in the first course of treatment which encompasses the primary tumor and risky regional lymph nodes up to spinal cord tolerance. However, a lung cancer treatment planning without heterogeneity correction would deliver higher dose to lung and increase complications during this period. It would affect the boosting course or interrupting the treatment. Our results show that 3-D CRT provides more suitable CT-based dose calculations than 2-D planning without heterogeneity correction or with Power Law Method correction. 3-D dose calculations using heterogeneity correction factors are proved more accurate. Dose-volume histograms (DVHs) also have emerged as a critical tool in 3-D planning. An accurate dose is more likely to provide better tumor control while simultaneously minimizing the risk of complications. According to our results, we suggest that 3D-CRT treatment planning should be the essential planning tool for lung cancer treatment.

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肺組織不均度於 6 MV 光子的劑量校正

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目的：藉由二度及三度空間放射治療計畫中組織不均勻度的考量與否，來評估肺部放射治療劑量的精確度。

材料與方法：本實驗以治療專用人體假體為人體肺組織參考，全程使用固定模具包覆假體，使其維持一致姿勢再現性，將熱發光劑量計置於腫瘤所在位置作劑量測讀並利用 Varian C-Series 600C 6 MV 加速器照射，所照射的劑量分別來自於二度、組織空氣比法修正後、及三度空間放射治療計畫，腫瘤的給予劑量為 180 cGy 。

結果：實驗結果顯示，經三度空間放射治療計畫及組織空氣比法修正後所測出的劑量較接近腫瘤的給予劑量（173 cGy 與 172 cGy 於 5 × 5 cm^2 照野， 175 cGy 與 174 cGy 於 10 × 10 cm^2 照野），而二度空間放射治療計畫由於未考量組織不均勻度，因此所測出的劑量很明顯的超出腫瘤的給予劑量）212 cGy 與 216 cGy 分別於 6 × 6 及 10 × 10 cm^2 的照野）。

結論：由於肺部組織密度的多元化，不同的計算考量方式將產生不同的照射劑量，雖然一般情況下利用組織空氣比法修正組織不均勻度有一定效果，但此方法並未考量不均勻度組織的形狀及側散射線，而三度空間放射治療計畫較二度空間放射治療計畫更能考量肺部組織密度的不均勻度及整體結構，提供較精確的劑量並減少治療中的負作用。

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關鍵詞：不均勻度、二度空間放射治療計畫、三度空間放射治療計畫、組織空氣比法、給予劑量、熱發光劑量計