原 著

**AN ANALYSIS OF LUNG DENSITY AND THE DOSE
CORRECTION METHOD**

Toshio Ueda and *Kazuhiro Takahashi

Department of Radiation Therapy, Aichi Cancer Center Hospital,

*Kanematu Electronics Ltd.

(論文受理 1988年11月4日)

(最終論文受理 1989年1月20日)

(Code No. 700, 713, 732)

Key words: Lung density, Inhomogeneity correction, Treatment planning, Computed Tomography.

(Article received; Nov., 4, 1988)

抄 録

放射線治療計画の不確実な要素の一つに患者体内の組織の不均一性が挙げられる。照射容積内における肺のごとく内部臓器の組織の不均一は放射線治療において常に遭遇することである。ICRUの報告書や既版の資料によれば、肺の密度は 0.3 gm/cm^3 としてある。しかしながら、肺の密度はそれぞれの患者ごとに異なっている筈である。今までに報告されている体内組織の不均一に対する線量計算の処理方法の中で、合理的で正確とされている方法は複雑である。市販されている治療計画システムでは組織不均一の補正計算法は比較的簡単な方法が用いられている。本論文では、現有する治療計画用の組織不均一補正計算システムの能力範囲を利用して日常業務に使用するうえでの肺の密度をどのように考慮するかについて検討した。肺の密度範囲を包含できると考えられる低密度物質を試料としてそれらの密度とCT値の関係、およびこれらの物質のコバルト 60γ 線および6 MV X線に対する吸収を求め肺の代用ファントムとしての可能性を確認した。肺腫瘍患者4名についてX線写真上での腫瘍部および健常部の密度分布を求めた。CT像から照射領域内における平均の肺密度を基にした線量計算値と、画素ごとに密度を求めて計算した値の比較をした結果、最大の差は2.7%であった。

1. Introduction

One of the uncertainties in treatment planning for radiotherapy is tissue heterogeneity in patients. The tissue heterogeneity of the internal organs such as the lung, in the irradiated volume, is most commonly encountered in radiotherapy. The lung and other air cavities do have a major impact on the dose distribution. According to the ICRU report¹⁾ and some other published data^{2,3)}, often, the density of lung is taken as 0.3 gm/cm^3 .

However, the density of the lung varies among individual patients. The algorithms for the heterogeneity corrections have been improved with more accurate methods. But it seems unrealistic to apply the most

AN ANALYSIS OF LUNG DENSITY AND THE DOSE CORRECTION METHOD (植田・他)

sophisticated corrections to routine work at the present time because of increasing complexity and computer time.

The purpose of this paper is to analyze the lung density and to evaluate the performance of a commercially available system on the tissue heterogeneity corrections.

For treatment planning, the C.M.S. Modulex RTP computer system has been utilized at Aichi Cancer Center Hospital for seven years. The Tissue Air Ratio method has been applied with this system for the tissue inhomogeneity correction algorithm. For contour input to treatment planning, the system of data transfer to the computer has two forms; direct tracing of the cross sectional data provided by CT scanner or conventional axial transverse tomograms, and automatic data transfer from a CT scanner by a magnetic tape. An automatic conversion from quantitative CT data to the tissue density value is not available in the system installed at Aichi Cancer Center Hospital. Therefore, lung density of individual patients must be entered for the tissue inhomogeneity corrections after assigning the appropriate density values.

For a translation from CT number to lung density, phantom studies using low density materials were made. The absorption coefficients of low density materials were derived to confirm if low density materials are applicable as a substitute of low density tissue.

Lung density patterns of four patients were analyzed to investigate the magnitude of the density deviation in definite areas of the lung where the density was assumed to be constant.

After these studies, the conventional method which is provided on the Modulex RTP system was compared to the pixel by pixel correction method.

2. Method and Results

2.1 Relationship between CT number and physical density.

The relationship between the CT number and the density of materials ranging from 0.1 to 0.8 gm/cm³ was analyzed. The materials used for the CT number calibration are shown in Table 1. Their physical densities were

Table 1 Materials used for the analysis of the relationship between CT number and physical density (g/cm³)

Timbers	(density)	Plastics	(density)
Fir	(0.354)	Polystyrene	(0.184)
Cypress	(0.400)	"	(0.271)
J. Cedar	(0.449)	Urethane	(0.097)
Magnolia	(0.509)	"	(0.179)
Chestnut	(0.531)	"	(0.261)
Pine	(0.557)	"	(0.288)
Cherry	(0.701)	"	(0.301)
Oak	(0.931)	"	(0.420)
		"	(0.642)

Fig. 1 Relationship between CT number and physical density.

determined volumetrically and they were selected to include the range of lung densities. Materials were formed into cylindrical shapes of 3 cm diameter. The samples were immersed in a water phantom of 30 cm diameter. Six samples were scanned at one time, and repeated scans were performed when the samples were interchanged in order to check for possible errors due to beam hardening. Scanning was performed with a GE CT/T 9800 general purpose scanner, using an image reconstruction diameter of 345 mm and the scan time of 2 seconds.

The results obtained are illustrated in **Figure 1**. The average CT numbers are indicated by open and closed circles, and a cross, for urethane, styrene and timber, respectively. The bars in the figure are standard deviation of CT numbers obtained from 700 pixels which represent the entire area of each sample. Within the examined range of density, a linear relationship between physical density and CT number was observed, and the regression line did not significantly differ from the observed values. The standard deviation for timbers was large, due to the annual rings.

The empirical relationship between the physical density and the CT numbers, derived from the data of **Figure 1**, is:

$$C_n = 973.44P - 993.16$$

where; P is physical density of the sample and C_n is a CT number of scanned sample which has the density P .

2.2 Measurement of absorption coefficients

The mass absorption coefficient for each sample was derived from experiments with a narrow beam of cobalt 60 gamma rays and 6 MV X-rays. The transmitted dose and sample thickness expressed in gm/cm^2 were plotted on semi-logarithmic graph paper and are shown in **Figure 2**. Both curves for cobalt 60 gamma rays and 6 MV X-rays agree well with the percentage depth dose data for zero field of infinite SSD published by Brit. J. Radiol, Supplement No. 11, and with our experimental data obtained in a water phantom. The results show that these materials are appropriate as low density substitutes for dose measurements and for density analysis of low density tissue by CT scanning.

Fig. 2 Attenuation curves obtained with various physical density materials for cobalt 60 gamma rays and 6 MV X-rays.

Fig. 3 The region of interest selected for analysis lung density in the CT image.

2.3 Estimation of the actual lung tissue density

Four patients having malignant disease in the lung were scanned by the CT scanner under the normal shallow breathing conditions. The radiologically normal and abnormal areas were chosen for density analysis. The section chosen for density measurements was at the center of the field length. **Figure 3** shows a typical region of interest selected for the density analysis. The CT numbers of 324 pixels contained in an 18 mm square

AN ANALYSIS OF LUNG DENSITY AND THE DOSE CORRECTION METHOD (植田・他)

were analyzed and distributions were obtained. The density distribution of normal and abnormal area in the lungs for four patients are shown in Figure 4.

A group of the distribution on left side in the figure represents densities of normal lungs, and another group of right side is of tumor. In the normal lungs, density is between 0.05 and 0.25, although the value of 0.3 has been generally taken as a standard value. The abnormal area of lungs showed a higher density, ranging from 0.95 to 1.05 gm/cm³.

The density of highest frequency, and the minimum and maximum value for each patient are summarized in Table 2. As for the tumor region, a narrow distribution was observed as shown in Figure 4. The tumor density in the lung was almost the same as water.

2.4 Comparison between the two correction methods.

Patient data from the CT scan were transferred to the Modulex RTP computer through the magnetic tape. One treatment field was chosen for the comparison between the regional method and the pixel by pixel method. Doses along the central axis of the beam were calculated for the treatment of the lung tumor using the average lung density within a contour area, as shown in Figure 5. The average CT number of this area was converted to density by equation (1). A data manipulation program was developed for sampling the quantitative CT data along the axis of the beam. Figure 6 demonstrates a CT number profile of pixel by pixel values along the central

Fig. 4 Density distribution of the lung for four patients.

Fig. 5 Average CT number determined over an area using automatic tracing in the CT scanner viewing console.

Table 2 Lung densities (cm/cm³) for four patients estimated from CT information.

Patient	Normal			Abnormal		
	Highest freq.	Min.	Max.	Highest freq.	Min.	Max.
K.	0.107	0.024	0.457	1.050	0.673	1.277
H.	0.189	0.106	0.616	0.909	0.570	1.133
A.	0.169	0.009	0.768	1.050	1.010	1.076
K.N.	0.128	0.018	0.498	1.011	0.963	1.045

Fig. 6 CT number and the corresponding density value in each pixel sampled along the beam central line.

CT number scaled on the horizontal axis (top), the corresponding density value (bottom).

axis of the beam. The CT number of each pixel was converted to density, and the equivalent tissue distances for each pixel were calculated. **Figure 7** shows the dose calculated by the two correction methods for the lung tumor treatment.

The solid curves were for cobalt gamma rays and for 6 MV X-rays, using a uniform lung density of 0.25 gm/cm³. The doses calculated by the pixel by pixel correction method are plotted with dotted curves. The solid curve and the dotted curve agree within reasonably permissible limits in the anterior lung region. Doses in the tumor area estimated by the pixel by pixel method were less than those obtained by the regional method. However, the difference between the two methods was 2.7 percent, maximum.

Fig. 7 Calculated dose for the field 8×10 cm cobalt 60 gamma beam and 6 MV X-rays.
Solid curves — regional method.
Plots — pixel by pixel correction.

Fig. 8 Calculated dose profile for the field 8×10 cm of cobalt 60 beam for different lung densities.

Discussion

The analysis of the lung density of four patients revealed that the normal lungs have regions of high and low densities, and that the average lung density differs from patient to patient.

Doses along the central axis on the same case mentioned above were calculated for the different lung densities by the regional method and are shown in **Figure 8** for cobalt 60 gamma rays. If the lung density changes from 0.1 to 0.5 gm/cm³, dose differences of 10 percent or more will occur in the tumor region. **Figure 8** indicates clearly that dosage error depends more on the lung density than the correction method.

The density data reported here are based on measurements in single transverse sections. The difference between relative electron densities and physical densities is three percent at the most for the material used in this study.

Among the various methods of tissue inhomogeneity corrections, the most sophisticated and accurate algorithm for practical clinical treatment planning is the equivalent tissue air ratio method⁹. The Monte Carlo calculation method must be the most powerful method of making the inhomogeneous corrections but it is not possible for routine clinical application with present computer facilities. The possibility of direct access to a CT scanner for treatment planning depends on the individual hospitals where the CT scanner has been installed, and most radiotherapy centers do not have direct access to the CT scanner for treatment planning. Generally, the treatment planning computer in a radiotherapy department is separate from the CT scanner in a diagnostic radiology department and the CT scanner usually is busy with diagnostic oriented studies.

AN ANALYSIS OF LUNG DENSITY AND THE DOSE CORRECTION METHOD (植田・他)

One of the uncertainties associated with the patient, introduced during treatment planning is heterogeneity in the body and relevant landmarks⁵⁾.

Uncertainties also will be introduced with the dynamics of the thorax caused by respiration during radiation treatment⁶⁾. In general, the treatment planning is performed with a static image that ignores patient motion. With these uncertainties, it becomes obvious that errors cannot be avoided even though the most sophisticated correction method is applied.

According to the papers by Brooks⁷⁾, Geise⁸⁾ and Sontag⁹⁾, the traditional methods for making inhomogeneity corrections are probably sufficient on the precise lung density measurements. Several reports have appeared for tissue inhomogeneity corrections with increasing accuracy and complexity. These algorithms require a great deal of expense and computer time. Each system has its own limitations and advantages, so it may be necessary to consider the relative convenience of the system and its capabilities.

The density analysis of the lung of individual patients and the utilization of regional method for treatment planning is reasonable to achieve accurate treatment with the mode of use in daily practice because there is a scatter of lung densities among the patients.

Acknowledgements

We wish to express our gratitude to Dr. Yutaka Okumura and Mr. John Brentnall for their helpful discussions and suggestions in the preparation of the manuscript. We wish to thank Mr. Eimaro Fujii and Dr. Motohiro Suganuma in Industrial Research Institute, Aichi Prefectural Government, for preparing the test materials.

Presented at the 5th Asian Seminar for Radiographer/Radiological Technologists, Singapore, Sep. 28-Oct. 1, 1984.

References

- 1) ICRU : Determination of absorbed dose in a patient irradiated by beams of X or gamma rays in radiotherapy procedures. ICRU report 24., (1976).
- 2) Hendee W R : Radiation Therapy Physics, p 121, Year Book Medical Publishers Inc., Chicago, (1981).
- 3) Mould R F : Radiotherapy Treatment Planning, Medical Physics Handbooks 14, p. 43, Adam Hilger Ltd., Bristol, (1981).
- 4) Sontag M R and Cunningham J R : The equivalent tissue-air-ratio method for making absorbed dose calculations in a heterogeneous medium. *Radiology*, **129**, 787-794, (1978).
- 5) Van Dyk J, Keane T J and Rider W D : Lung density as measured by computerized tomography ; Implications for radiotherapy. *Int. J. Rad. Oncol. Biol. Phys.*, **8**, 1363-1372, (1982).
- 6) Henkelman R M and Mah K : How important is breathing in radiation therapy of the thorax. *Int. J. Rad. Oncol. Biol. Phys.*, **8**, 2005-2010, (1982).
- 7) Brooks R A, Michell L G, O'Conner C M, Dichiro G : On the relationship between computed tomography numbers and specific gravity. *Phys. Med. Biol.*, **26**, 141-147, (1981).
- 8) Geise R A and McCullough E C : The use of CT scanners in megavoltage photon beam therapy planning. *Radiology*, **124**, 133-141, (1977).
- 9) Sontag M R, Battista J J, Bronskill M J and Cunningham J R : Implications of computed tomography for inhomogeneity corrections in photon beam calculations. *Radiology*, **124**, 143-149, (1977).
- 10) Fullerton G D, Sewchand W, Payne J T and Levitt S H : CT determination of parameters for inhomogeneity corrections in radiation therapy of the esophagus. *Radiology*, **126**, 167-171, (1978).
- 11) Parker R P, Hobday P A and Cassell K J : The direct use of CT numbers in radiotherapy dosage calculations for inhomogeneous media. *Phys. Med. Biol.*, **24**, 802-809, (1979).

- 12) Van Dyk, J.: Lung dose calculations using computerized tomography; Is there a need for pixel based procedures? Int. J. Rad. Oncol. Biol. Phys., 9, 1035-1041, (1983).

社団法人 日本放射線技術学会賛助会員

消化管X線造影剤・造影補助剤

薬価収載

バリトップ・バルギン・バムスター

バリトップP (パウダー)
バリトップ120 (120%)
バリトップ110 (110%)
バリトップ100 (100%)

ネオバルギン共成 (パウダー)
バルギンS2号 (140号)
バルギンSゾル3号 (100%)
バムスター S130 (130%)
バルギン発泡顆粒 (造影補助剤)

※用法・用量、効能・効果、使用上の注意等については、添付文書をご参照ください。

〔資料請求先〕

Kaigen 株式会社 カイゲン

大阪市中央区道修町2丁目14号
TEL 06-202-8971 (FAX) 06-202-0872

大阪営業所 ☎ 0726-53-4071代

名古屋営業所 ☎ 052-834-1011代

札幌営業所 ☎ 011-631-3249代

広島営業所 ☎ 082-273-8801代

横浜出張所 ☎ 045-241-8668代

東京営業所 ☎ 03-438-2511代

福岡営業所 ☎ 092-441-0832代

仙台営業所 ☎ 022-288-6771代

金沢営業所 ☎ 0762-68-4125代