Development of a New Radiotherapy Technique using the Quasi-Conformation Method

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The quasi-conformation therapy was performed to get a homogeneous dose distributions for irregeular shaped tumor lesion by using the arc moving beam and beam modifying filter which was made by cerrobend alloy (ρ=9.4 g/cc) metal.

In our dose calcuation programme, it was fundmentally based on Clarkson's method to calcuate the irregular multi-step block field in rotation therapy.

In this study, the expected relative depth doses under multipartial attenuator agree well with measured data at same plane.

The results of comparison the dose computation with that of TLD measurement are very closed within±5% uncertainties in the irradiation to phantom with quasi-comformation method.

And it has shown that irregular typed multi-step filter can be applied to quasi-conformation therapy in high energy radiation plannings.

Key Words: Irregular field, Multi-step filter, Quasi-conformation therapy

INTRODUCTION

Enough shielding of normal tissue in radiation therapy will increase the patients tolerance and the delivered dose to tumor.

Computed tomographic images offer the possibility of obtaining accurate dimensions and shape of tumor. The purpose of radiotherapy planning is getting the homogeneous dose at tumor site and minimum dose to normal tissue. But conventional radiotherapy has limitations to get a conformable dose distribution. This conformation therapy needs a full thickness of block (4-5 half value layers) or partial attenuation filter to modify the irradiating beam quantity.

This modification of the radiation beam is achieved by placing the attenuator of lead or cerrobend alloy metal into the beam.

The attenuation properties and narrow beam attenuation coefficients for lead are well documented[1~3]. Broad beam absorption of high energy photons in Lipowitz's has been studied for radiation protection purposes[4].

Recently, several articles has been reported the dose distribution, which was very different from symmetric arc rotation, of asymmetric field arc rotation with secondary blocks and field off-set facilities in high energy photon beams[5~7].

It is important to understand the principle of beam summation for the generation of isodose curves of arc rotation with irregular step attenuator field.

The dose distribution is very different according to shape of block, furthermore irregular multi-step attenuator as shown Fig. 1 also reveals different thickness by the different level of cross-sectional plane.

It is very difficult to determine the output accurately, especially in case that attenuator has been located in mid-line of radiation field[8].

Through this experimental and calculation model it will show the dose distribution for quasi-conformation obtained by arc rotation of asymmetric field with irregular multi-step atteunator and compare the dose calculation by computer simulation with actually measured dose at the region of interestings.

MATERIALS AND METHODS

1. Dose Calculation

The quasi-conformation therapy requires some irregular shaped and different thickness of block in radiation field for modification the dose distributions.

The shape and size of block were determined by tumor size and adjoining normal organs in fixed beam, but it is complex to determine the shape and thickness of block in arc or rotation therapy.

When the shape of the block is symmetric in fixed field, it is easy to image the dose distributions

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but difficult in asymmetric field arc therapy. To perfom the asymmetric arc rotation therapy or conformation therapy, at first, dose calcuations should be done at fixed beam with irregularly shaped, shielded field with different block thickness by vertical level of the field. (as shown in Fig. 1 and Fig. 2)

Khan et al[9] had calculated the dose with tissue-maximum ratio (TMR) and scatter-maximum ratio (SMR) in irregular field using 4-5 half value layers of shielding block.

In our study, calculation model is based on Clarkson's method but it will show the SMR depends on beam hardening through the different thickness of block.

A dose D_p (x, y, z) at point (x, y, z) in tissue will be apporoxamtely derived from primary and scattered beam as shown equation (1).

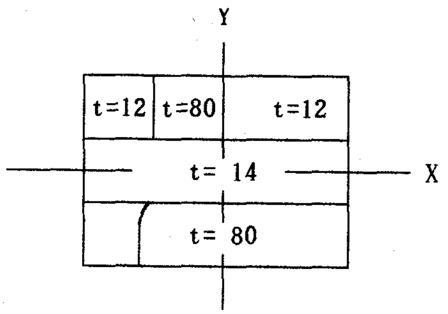

Fig. 1. Diagram of the irregular step filter. t represents the metal thickness (mm) of cerrobend alloy.

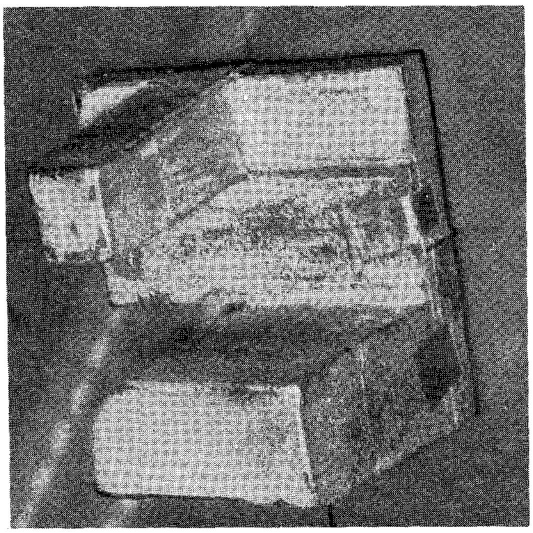

Fig. 2. Photograph for an irregular multi-step filter.

$$D_p\,(x, y, z, t)=D_o\left[\{K_p(x, y)\ TMR(0, z, t) + (1/N)\sum_{i=1}^{N} SMR\,(r_i, t)\} + \frac{Sp(0)}{Sp(r_z)}\right]\exp\,(-\mu t) \qquad (1)$$

Where D_o represents the output in fixed beam, K_p (x, y) is off-axis ratio of primary beam, r_z is field size at depth z at the central axis and μ and t are effective linear attenuation coefficient and block thickness (cm). And this formalization is based on the concept of the Clarkson's method, but each parameters are dependent upon the block thickness[10,11].

The authors used the TMR (O, t) and SMR (r, t) as variable when the block located in the beam path.

The dose distribution in the tissue at rotation therapy can be determined as following equation;

$$D'\,(x', y', z', t)=\int_{\theta_i}^{\theta_f} D(\theta)\,d\theta \qquad (2)$$

where θ_i and θ_f represent the initial and final degrees of rotation angle, respectively.

Basically, the point dose is function of depth, field size at given energy and source to axis distance.

In the point dose at rotation therapy, the point (x', y', z') of rotated axes is derived from rotation equations.

The dose calcuation for rotation therapy is performed through the rotation equation of the x axis in the fixed beam. And it has been included the three dimensional algorithm to calculate the point dose and scatter contribution through the the Clarkson's method in the irregular block.

2. Block Design

Determining the block thickness is dependent on the shape of normal organ surrounding the tumor and position of critical organs in the beam path at fixed or rotation therapy.

In rotation beam therapy, it should be taken into consideration to obtain adequate block thickness and shape in each plane as followings;

1) the shape of block depends on the normal and tumor tissues in each plane of CT scan.

2) CT films should be put on the coaxial level at the isocenter.

3) the specific dose such as normal tissue tolerance or tumor dose must be evaluated in each plane.

4) since the derived dose mainly dpends on depth in the tissue and block thickness, the dose under asymmetric block field may be differnt in a same plane as a function of rotation angles. And to

get a homogeneous dose plan, bicok thickness should be adjusted to fraction of dose differencies.

5) *one should calculate the dose profiles of* asymmetric block beam at the given depth.

6) *the toal tissue dose in rotation beams are* sum of the derived dose at given angle after converting the fixed beam profile with rotation equation.

To apply this concept and computation model to patient, this experimental study was performed with humanoid phantom. And actual application of above result to a patient with leiomyosarcoma of right hemidiaphragm was present here to illustrate the use of asymetric and multi-step irregular field with arc therapy. The tumor invaded superolateral aspect of right lobe of the liver superficially, and spreaded to adjacent pleura antero-posteriorly. Most of the gross lesion was removed surgically, but it was very difficult to remove residual lesion at the adjacent liver and pleura completerly. So irradiation field included right lateral pleura up to the 6th rib and upper half of right liver contacted with diaphragm.

The main aim of the therapy planning was to deliver sufficint dose the tumor tissue and to preserve normal lung tissue and liver surrounded by target volume (as shown Fig. 3). The shielding block of different thickness by level was applied to

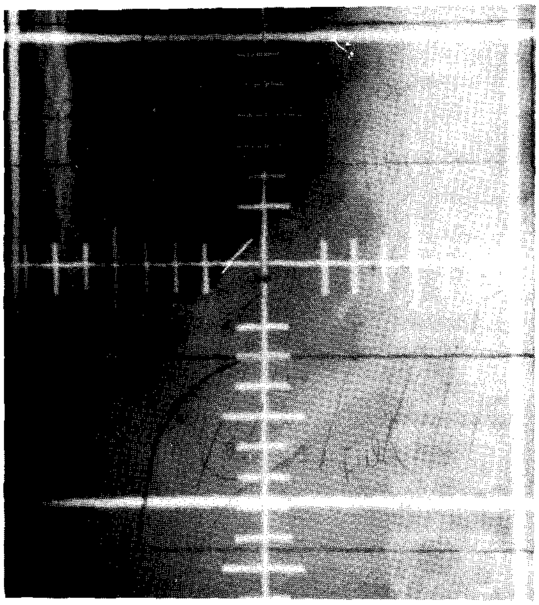

Fig. 3. Simulation film for irradiation of right hemidiaphragm with field size 16×16 cm².

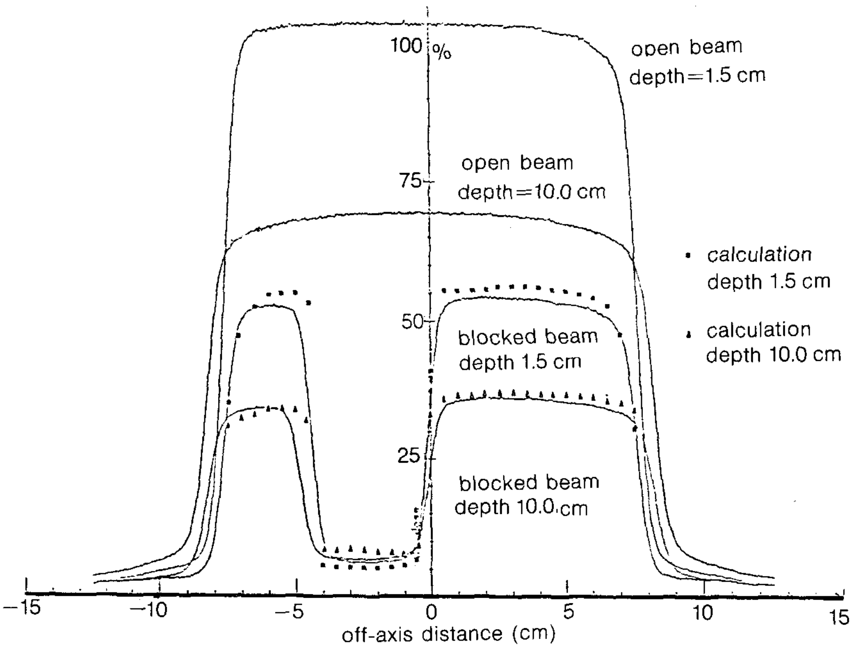

Fig. 4. Comparison the depth dose curve (line) for the irregular multi-step filter and that of the calculation (square for depth 1.5 cm and triangle for depth 10.0 cm) in 6 MV photon beam (SSD=100 cm, 16×16 cm² and inplane 5.0 cm).

obtain above purpose, that is, deliver homogenous dose to the whole diaphragm and pleura and protect adjacent normal tissue as possible as it can.

The full thickness of block (above the 4-5 HVL) at the medial core of upper field was used to give minimum dose to lung tissue and lateral part of partial attenuation filter to give maximum dose to pleura. With same idea, the lower one-third of field, leaving lateral one-fifth , was shielded with full thickness of block to treat entire diaphragm and superficial portion of right lateral liver.

But middle one-third of field was shield with about one half vaue layer to obtain the homogeneous dose in entire target volume (details of block was shown in Fig. 1).

MEASUREMENT

The dose under the partial attenuation filter was measured by using WP-600 three dimensional scanner (Wellhöfer, Germany) with 0.14 ml ion chambers, one of them is for scan probe and the other is for reference chamber.

The dose profile was performed at the upper and lower one-third of the radiation field respectively.

The source to surface distance is 100 cm and the other setup parameters are shown as Table. 1.

The humanoid phantom was used for evaluation of the dose distribution with teflon-embedded TLD rod (1 mm diameter and 6 mm length) and TL reader Victoreen 2800.

The humanoid phantom (slice no. 16, 18 and 20) was irradiated to field size 16×16 cm^2 with multi-step irregular shaped filter and arc moving in 6 MV photon beams. The angle of arc rotation was total 210 degrees from 215 to 65 degrees to counter-clockwise and weighted beam from 65 to 90 degrees to clockwise to increase dose at the anterior portion. And linear accelerator needed some special devices to weight at the some given direction with small arc moving beam.

Dose distributions of computer simulation were also monitored with teflon-embedded TLD in humanoid phantom.

Table 1. Geometrical Parameters of the Experimental Setup

Nominal energy	Source-to-surface distance (mm)	Source-to-tray distance (mm)
6 MV Photon	1000	565

RESULTS

In conformation therapy, rotation therapy is general mode of treatment with uniform thickness of block.

In this study, we suggest that the dose distribution of asymmetric and multi-step blocked beam

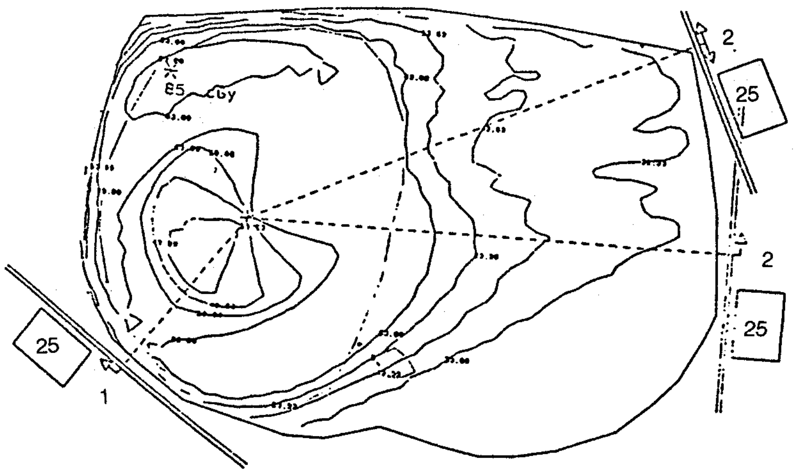

Fig. 5. Dose distributions of phantom slice #16 for pleura irradiation with 16×16 cm^2 and weight beam of B1:B2 is 100 to 20 in 6 MV photon beam. The arc beam of B1 is from 215 to 65 degrees and B2 is from 65 to 90 degrees in clockwisely. The 50% of isodose curve is to select.

can be obtained with the Clarkson's method for calcuation of scatter contribution at an interesting point.

Computer simulation of arc beam therapy is generally based on the superposition of multi-beam coming from the samll arc field spaced same angular intervals around the axis of rotation.

The block design was determined from several level of CT slice to obtain prescribed dose at the target and to keep tolerance dose at the normal organs. The gross appearance of shielding block for lung is width 40×length 40×height 80(mm), and for liver is round-corner block with 80 mm height of cerrobond alloy (as shown Fig. 2).

The profile curves measured in open and multi-step block field, field size 16×16(cm), depth 1.5 and 10(cm), are presented with continuous line in Fig. 4, and results of computation by equation (1) with multi-step block field at the same depth and field presented with dark dotted lines.

The results of dose profiles are compared with caluation data in the multi-step block field irradiated by 6 MV photon beam. It showed that calculation data are agree well with measurement within±3% uncertatinties except near the boundary of different block thickness.

As the configuration of shielding block already discribed previously, when one try to deliver sufficient dose at the upper and lower one-third of fields, it should be considered overdose at the middle one. So it needs to reduce overdose at the middle one with partial attenuation filter.

In this study, the 12 and 14 mm thickness of cerrobend alloy was place on centre and other part of beam, respectively, except fully shielding area as shown Fig. 1.

Fig. 5 to Fig. 7 show the computer simulation of asymmeric field arc therapy and 50% of isodose curve is optimized for 200 cGy of tumor dose.

By the computer simulation, the dose level at the adjacent normal lung is apparently lower than central region, about 80% of tumor dose. And it also shows about 24% less dose in the liver than central region.

The accuracy of the treatment planning for asymmetric field rotation was checked with Teflon-embedded TLD rod, which is 1 mm diameter and 6 mm lenght. The TLD rods were individually calibrated using 6 MV photon beam. The TLD rods were placed in isocenter level of phantom for right middle lung, slice #16, central mid-plane of phantom for right diaphragm slic #18 and lower field of phantom for the liver, slice #20, respectively.

Fig. 8 shows the comparison the dose distribution of computer simulation with that of the Teflon-embedded TLD measurement with humanoid phantom. The measured data agree well with the computer predictions within±5% of uncertainties.

These all compuer calculations show very close to that of measurement except for upper slice #16.

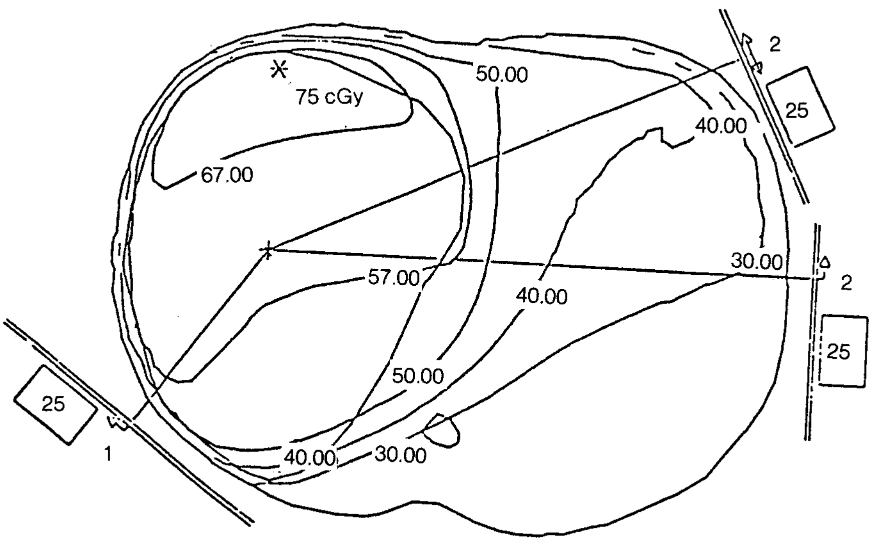

Fig. 6. Dose distributions of phantom slice #18 (middle part of field) for right hemi-diaphragm irradiation with same arc rotation with irregular multi-step filter and beam weight of figure 5.

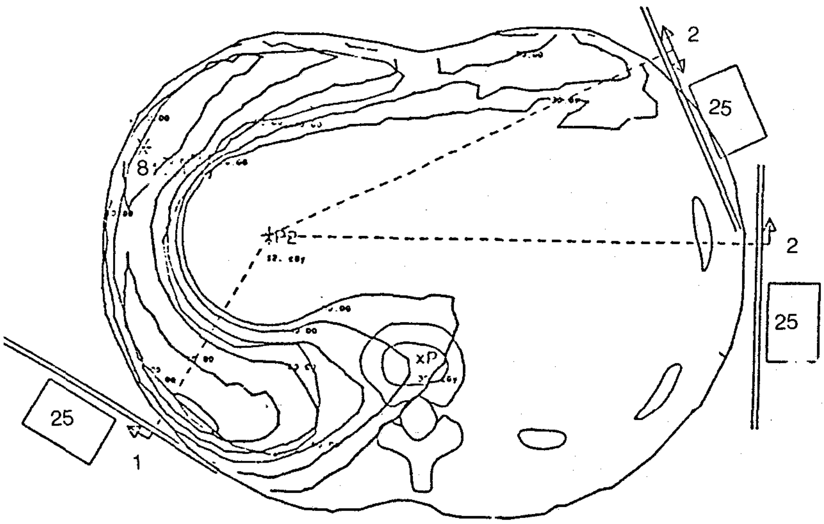

Fig. 7. Dose distributions of phantom slice #20 (lower part of field) for right hemidiaphragm irradiation with same arc rotation with irregular multi-step filter and beam weight of figure 5.

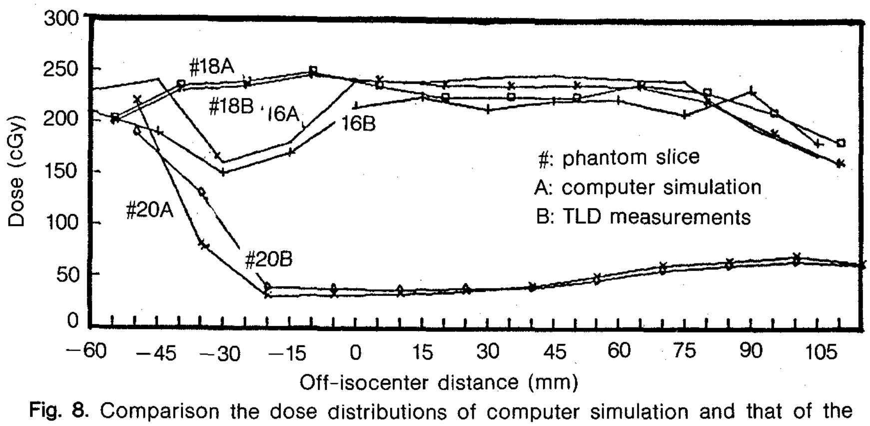

Fig. 8. Comparison the dose distributions of computer simulation and that of the Teflon-embedded TLD measurements with the humanoid phantom.

The 4-5 half value layers of block should be extended to shield the critical organ in rotation therapy. In the rotation therapy, the shielding area reveals a round shape and its diameter of rotation axis is almost same to shielding region of the off-axis in fixed beam.

And asymmetric dose simulation is based on the same concept except that a part of the fixed beam is blocked.

DISCUSSION

The conformation therapy is a technique to deliver enough doses to the target volume and to protect critical organs and normal tissues from the irradiation coincidently, as possible as it can, through the arc or rotation therapy.

Since the field shaping and selective protection techniques for the radiotherapy with megavolt radiation beam were started by K. A. Wright et al (1959)[12], but the conformation therapy technique was developed by S. Takahashi (1965)[7] who used a multi-leaf filters for shaping the irradiation fields in rotation therapy. By his contribution, this conformation therapy could be applicable in clinical practice. But dose computation model to expect dose distribution had not been fully developed yet, so it very difficult to modify a beam for giving homogenous dose to the tumor lesion, which contatined ofter normal organ or tissues at the pariphery or inside of it.

Radiation therapy beams are often modified to fit variations in patient contours, densities of tissues interposed between the surface and target volume, and tolerant dose of critical organ near the tumor. The modifications of photon beams are achieved by placing attenuating materials, such as lead or Lipowitz's metal, into the beam between the source and the patient.

Recently, Pelta et al[3] reported successful treatment of chordoma of the third lumbar vertebra surrounding spinal cord using moving beam therapy with fields with asymmetric with respect ot rotational axis of the collimator head. In this report, they checked the accuracy of the treatment-planning software for asymmetric rotation using TLD. The measured data agree well with the computer prediction except for the cenral cold area where computer calculation over estimated the scattered dose under block.

In general, when a beam modifying filter is inserted into the photon beam, usually the characteristics of the beam could be changed slightly because of the scattered photons produced in the filter.

Mohan and Chui (1986, 1987) and Starkshall (1988) have also identified similar inaccuracies by the traditional scatter intergration approach near the boundaries defined by blocks or collimations. They proposed the differential pencil beam dose computated with Monte Carlo method and the convolution techniques to improve accuracy of calcuations near the boundaries[13,14,15].

In our experimental study, the different thickness of attenuating filter made by cerrobend alloy (i.e. Lipowitz's metal) is placed into the beam for modification of beam quantities and for obtaining nearly homogeneous dose distributions at tumor target (that is quasi-conformation therapy).

The authors suggested the dose calcuation model with multi-step and irregular shaped field which is based on Clarkson's method for correction the traditional scattering in the tissues.

The dose measurement under the partial attenuated beam was performed with water phantom and ionization chamber. And Fig. 4 has shown the comparison of calculation dose to measured dose in the water phantom. The results of computation in the most part of the field were agreed well with measurement within±3% uncertainites except at the boundaries with 10% higher than measurement dose of mult-step blocks.

But it seems that this discrepancy is caused by the limitation of ion chamber size to measure the dose at boundary of blocks.

The dose distributions in the field showed that the relative homogeneous dose in the whole tumor region could be obtained with arc rotation beam with multi-step attenuated beam in 6 MV photons.

The calculated dose of normal lung and liver are less than that of tumor, except small hot area of 30 ~50% higher in treatment region, respectively.

If the attenuated filter is devieded into more sectors, it could be applied to asymmetric arc rotation therapy for conformation.

The results of the TLD measurements have shown that they are very close to dose profiles of computer simulation except the phantome slice # 16 as shown Fig. 8. It seems to be a set-up or dosimetric error, but they are in the range of acceptance as within±5% uncertainties in whole target volume.

CONCLUSION

Asymmetric field with multi-step attenuation filter is available for fixed beam and/or rotation therapy in high energy photon beam.

The block thickness and shape are dependent on the tumor size, shape and surrounding normal tissues.

Our dose calculation model is fundamentally based on Clarkson's method and the homogeneous dose in tumor could be obtained accurately within±3% discrepancy for multi-step partial attenuated 6 MV photon beams.

And this multi-step irregular shaped filter could be applicable for the conformal radiotherapy through the computer simulations.

Furthermore, the procedures of dose monitor is very important to confirm the plan of conformation therapy, because the error in dose calculation would result in severe problems in radiotherapy.

In our experimental study, the results of comparison the dose distribution of computer simulation to that of TLD measurements are very closed within±5% of uncertatinties.

We believe that this technique of quasi-conformation therapy will be done with relatively economical material and increased response of radiotherapy.

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= 국문초록 =

Quasi-Conformation 치료를 위한 새로운 방사선치료기술의 개발

계명대학교 의과대학 치료방사선과학교실

최 태 진 · 김 진 희 · 김 옥 배

종양모양에 거의 일치하는 선량분포를 얻기위해 다층부정형필터를 이용하는 방법을 보였으며, 필터의 재질은 Lipowitz (일명 cerrobend alloy) 금속체를 이용하였다.

선속내 필터의 놓임은 일차선의 감쇄와 함께 조직내 산란선 기여율의 변화가 예상되므로 필터의 두께에 따른 SMR의 변화가 계산에 이용되어야 된다. 이에 본 연구의 계산선량은 실측치의 3% 이내에서 잘 일치됨을 알 수 있었다.

다층부정형필터를 이용한 펜톰의 원호조사의 선량평가는 동일 필터에 의한 고정조사의 선량분포가 적용되었으며, 가상 종양에 거의 일치하는 선량분포를 얻을 수 있었다.

한편, 컴퓨터모의계산된 선량과 열발광산량계(teflon-embedded TLD)의 실측선량은 비교적 ±5% 범위내에서 잘 일치됨을 알 수 있었으며, 이 치료방법은 현재 차폐체로 많이 이용되고 있는 Lipowitz 금속체를 사용함으로써 보다 쉽게 응용되어질 것으로 생각된다.