Computerized Radiotherapy : A Proposal for a System Using Three Dimensional Computed Tomography*

Fumiaki Ogawa**, Hiroshi Itoh**, Noriko Minami** and Yuji Saeki***

**First Department of Radiology, Kyoto First Redcross Hospital
***Department of Radiology, Matsushita Hospital

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3次元CTを用いたコンピューター化放射線治療装置の提案

京都第一赤十字病院第一放射線科
小川　史顕　伊藤　浩　南　周子
松下病院放射線科
佐　伯　祐　志

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CTを用いたコンピューターによる放射線治療計画の応用が発達しつつある．このようななかで，我々が従来発表してきた3次元CTを用いた，より精密な治療計画を立てるためのシステムを提案する．3次元CTの3本の直交座標軸を3次元Cross Hair Cursorと定義し，それにより生体内の病変，臓器の3次元空間内における位置を正確に入力する．そしてそれらを基準として計算された線量分布を3次元CT上で観察できるもので，外部照射及び腔内照射における応用が考えられる．

将来，各種粒子線治療が本格的に行なわれるようになれば，このような原理にもとずいた，治療計画のCTと治療装置を組み合わせたComputerized Radiotherapyが用いられる可能性がある．

Introduction

Since computed tomography (CT) was introduced by G.N. Hounsfield in 1973[1], the digital value has led to many methods of image processing by digital computer.

Of these methods, the sagittal and coronal reconstruction program, reported by W.V. Glenn et al. in 1975[2], is usually used in the computer system of contemporary CT units.

The principle of three dimensional computed tomography (3DCT), which is a combination of axial, sagittal and coronal planes, was reported by F. Ogawa et al. as work in progress in 1980[3].

This 3DCT was applied to three dimensional dose distribution displays in external and intracavitary radiotherapy.

Therapeutic unit combined CT system using 3DCT may be useful especially for particle irradiation

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therapy in the near future.

Methods and Results

1) Principle of three dimensional computed tomography[3)4)]

Each slice of axial, sagittal and coronal views in the sagittal and coronal reconstruction system is divided into four rectangles by the theoretical crossing lines of these three planes, to give a total of twelve (3×4=12).

Next, some of these rectangles are transformed into lozenge-shapes, and the right to left, and anterior to posterior relationships are reversed.

Then these pieces are joined together for a three dimensional view.

Theoretically, 15 forms of three dimensional CT can be reconstructed (Fig. 1)[4)].

2) Three dimensional cross hair cursor (3DCHC)

Usually in the computer graphic system, the "cross hair cursor" is used to designate two dimensional co-ordinates (x,y) into the computer system.

We introduce a three dimensional cross hair cursor (3DCHC) which is the three axes of 3DCT, and it can input three dimensional co-ordinates (x,y,z) into computer system (Fig. 2).

This cursor is used to designate the contour or the center of a tumor or a critical organ into the computer system very accurately, by moving the central crossing point with a joy stick (Fig. 3 (a,b,c,d)).

Another application of 3DCHC is to input the co-ordinates of the position of the tips of sources in intracavitary irradiation as mentioned below.

3) Application of 3DCT to the external irradiation dose distribution display

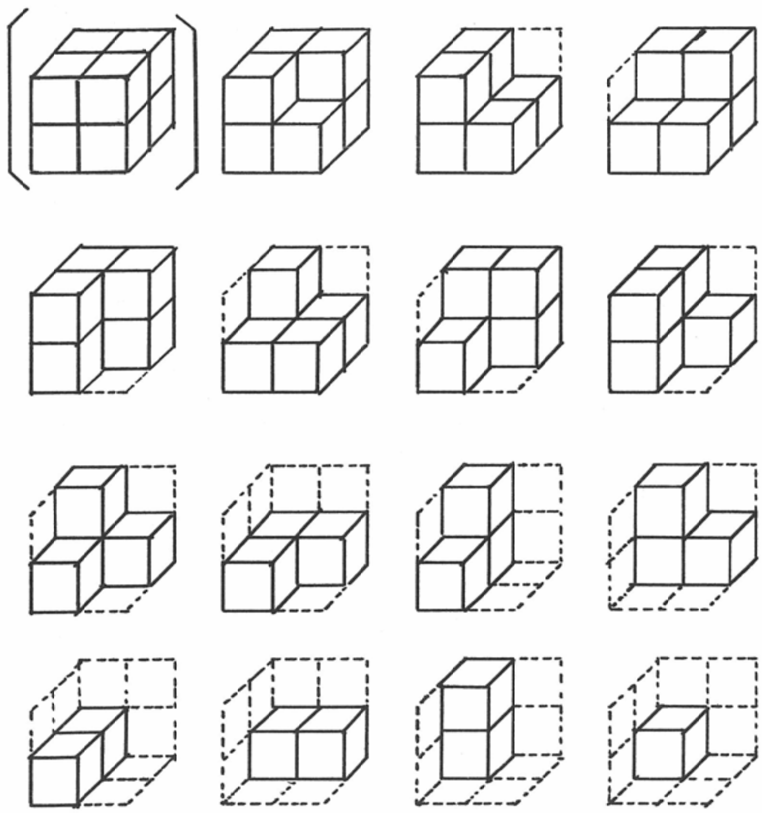

Fig. 1 Models of 15 kinds of three dimensional computed tomography.

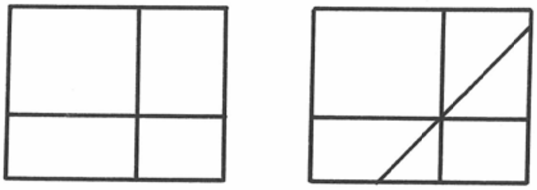

Fig. 2 Usual two dimensional cross hair cursor and three dimensional cross hair cursor.

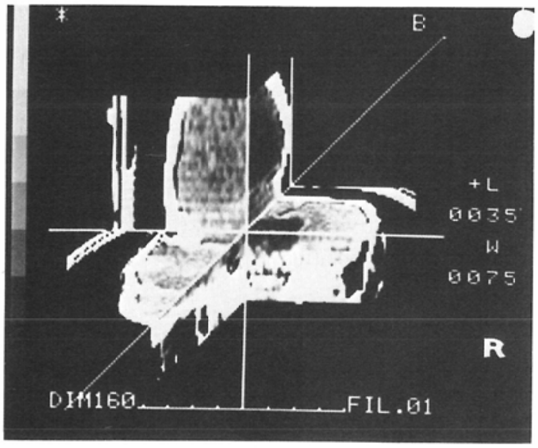

Fig. 3(a) Sample output of 3DCT with 3DCHC of a case with cystic cerebellar medulloblastoma, and the view direction is from the left anterior upper quadrant. The position of right edge of tumor shown by 3DCHC is easily recognizable.

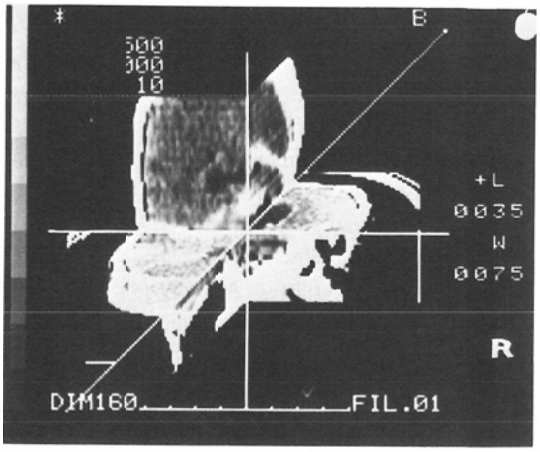

Fig. 3(c) The result of moving the 3DCHC to anterior direction, and it is easy to found the position of anterior edge of tumor also.

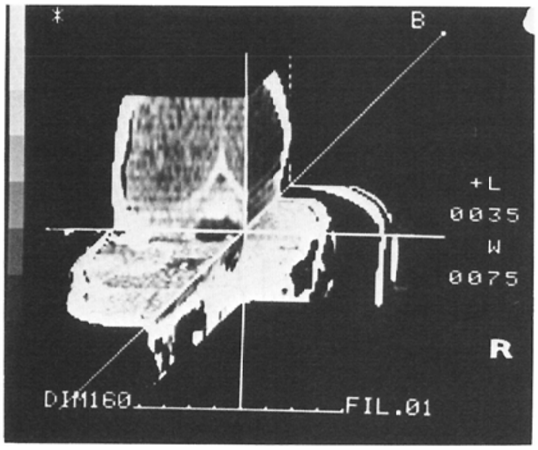

Fig. 3(b) The position of left edge of tumor as a result of moving the 3DCHC to left side by manipulating the joy stick. The three dimensional relationships are easily observed by 3DCT and easy position settings are possible during the manipulation of joy stick.

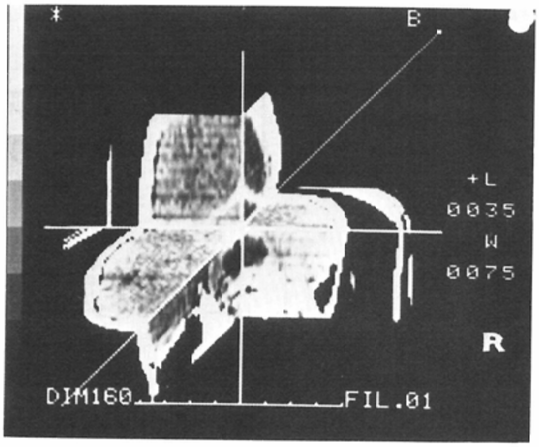

Fig. 3(d) The result of moving the 3DCHC to upward, and it is possible to recognize the upper edge of tumor. Other any information of position is transferable to computer system by the same sort of manipulation.

Fig. 4(a) shows a conventional computer dose distribution display (isodose curves for three-portal irradiation with cobalt-60 γ-ray to an intrapelvic tumor) on the axial plane.

In the two-dimensional planes, it is difficult to know the three-dimensional dose distribution on each side of these planes.

Fig. 4(b) shows 3DCT of the same case, and Fig. 4(c) shows the three dimensional dose distribution in gray scale, and Fig. 4(d) shows isodose curves on 3DCT.

By moving the central crossing point to various positions with a joy stick, we can observe the dose distribution at any portion of the body, and by setting the central crossing point at the center of the tumor, the dose distributions of upper and lower, anterior and posterior, and right and left directions of the tumor

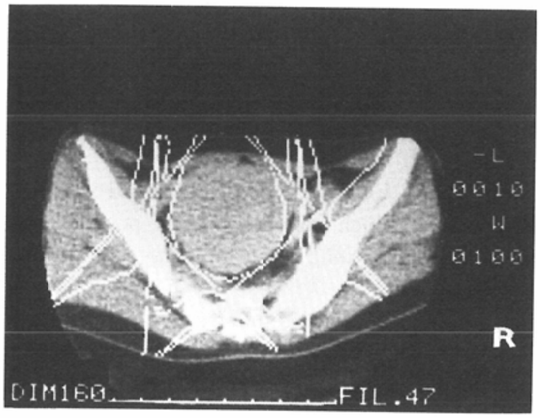

Fig. 4(a) Conventional computer dose distribution display in a case of intrapelvic tumor with three portal irradiation.

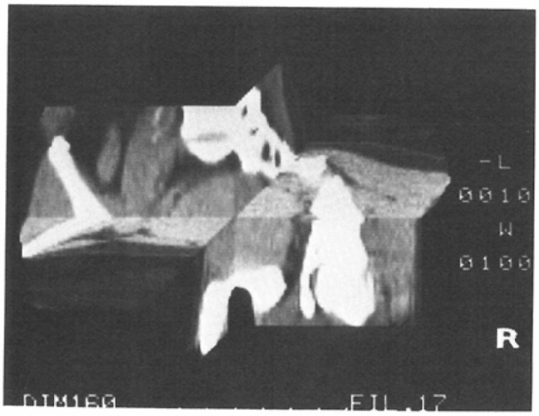

Fig. 4(b) The 3DCT of the same case with the central crossing point at the center of tumor. Three dimensional relationships of bone and soft tissues are easily observed, for example, it is found that the tumor reaches to a part of anterior edge of saccural bone, but dose not touch the iliac bone at both right and left sides. By moving the central crossing point, such clinical informations is easily observed in the whole volume scanned.

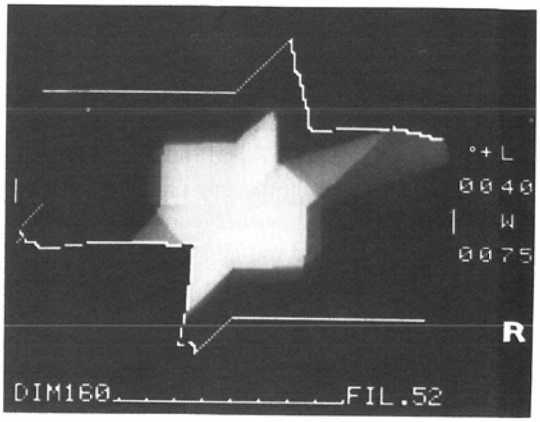

Fig. 4(c) The three dimensional dose distribution in gray scale. The three beams are irradiated from one anterior portal and two right and left posterior oblique portals. The summation of dose distribution by these three beams are displayed on the theoretically identical three dimensional planes with the 3DCT of Fig. 4(b).

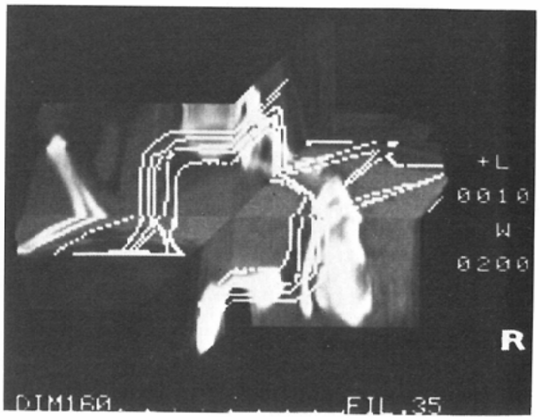

Fig. 4(d) The isodose curves on 3DCT. It is found that the high dose level area is fitted to the tumor in the three dimensional space, and that this irradiation setting is almost acceptable.

are observed in one 3DCT.

This method makes it very easy to define optimal irradiation settings by simulation by changing the condition of irradiation (directions, angles and irradiation fields, etc) continuously.

4) Application of 3DCT to dose distribution display in intracavitary irradiation

The same principle was applied to intracavitary irradiation. Fig. 5(a) shows three dimensional dose distribution around two tandem and two ovoid radium sources in gray scale. Fig. 5(b) shows overlapping of isodose curves on 3DCT.

By using material with appropriate CT density for dummy sources, and by using thin CT slices, we can designate the three dimensional co-ordinates of both tips of sources by moving 3DCHC with a joy stick, and can display three dimensional dose distribution (isodose curves) on the same 3DCT.

With this method used for high dose rate mode of intracavitary irradiation, by adjusting the time of insertion of each source with optimal conditions, one can easily achieve the most effective irradiation.

5) Proposal of computerized radiotherapy unit using three dimensional computed tomography

As an application of this method, we propose a computerized radiotherapy system using 3DCT and 3DCHC (a combined CT and radiotherapy unit : Fig. 6).

The CT and radiotherapy planning system (RTP system) using 3DCT and 3DCHC are controlled by one computer, and another computer controls the therapy unit, which includes patient positioning, movement of the bed (up and down, back and forth, right and left, rotation), rotation of the head of the treatment unit, and control of the irradiation field.

We suppose that the procedures of treatment using such system will be as follows :

1) First, the positioning system perform the body markings at most stable and fitted condition of patient body on the treatment bed, with some fixing equipment if nescessary. The positioning system should be similar one as reported by Kutsutani-Nakamura et al.[5].

2) Then, multiple thin slice CT scans are performed for the volume including the tumor and critical organs, and the computer system monitors the scan positions automatically.

3) The RTP computer defines the contours of body automatically for all scanned slices, the soft ware for this procedure is possible by the large gap of CT value between air and body tissue.

4) Next, using the 3DCHC and joy stick, the information of three dimensional contours and centers

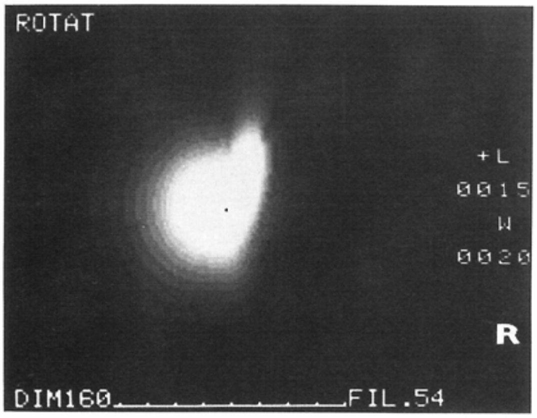

Fig. 5(a) Three dimensional dose distribution of intracavitary irradiation in gray scale.

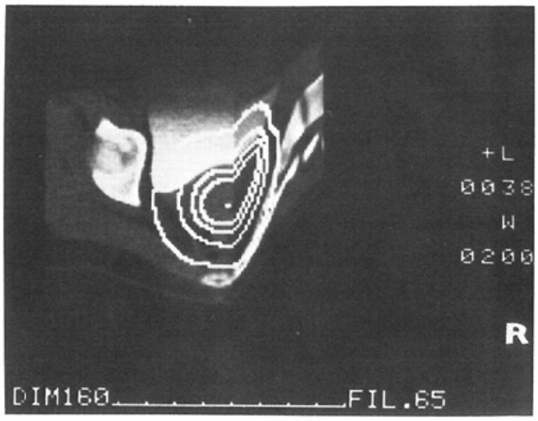

Fig. 5(b) Overlapping of isodose curves on 3DCT of a case identical with Fig. 5(a). It is observed that high dose area is fitted to the volume of uterus three dimensionally, and the dose levels at the urinary bladder, rectum, saccural bone, iliac bone are observed.

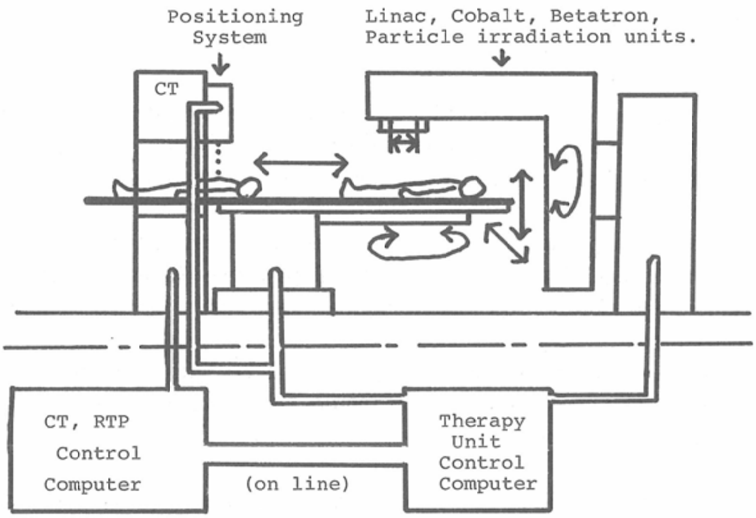

Fig. 6 Computerized radiotherapy unit as a combined CT and radiotherapy unit with the same bed system.

of tumor and critical organs are transfered to RTP system by operator.

5) By RTP system, three dimensionally optimized irradiation settings are surveyed observing the dose distribution on 3DCT.

6) The two computers mentioned above are connected by an on-line cable and the optimal irradiation settings on the CT and RTP systems are reproduced in the therapy unit automatically and very accurately.

7) The information for optimal irradiation settings are stored into the computer memorizing device, and even complexed irradiation procedures can be reproduced automatically.

8) CT scan should be performed at interval of about once per week, and the reduction of tumor volume and the deviation of positions of critical organs require the re-optimization of irradiation settings, and body markings should be renewed at the same time also.

As a result, this method will be especially effective in the future when radiotherapy includes the use of such particles as protons, heavy ions and π-mesons.

Discussion

1) Three dimensional display system for CT images

Many methods of three dimensional observations for CT information have been described.

Surface and contour detection system are the most popular[6], but they present difficulties in the process of pattern recognition since they cannot detect contours of organs and lesions automatically by soft ware, because of low gap of CT value between tumor and normal tissues.

A holographic method has been proposed, but it is not yet clinically practicable.

Our 3DCT cannot display all information in three dimensional space at one time, but can display information on three dimensional and cross sectional planes.

By moving the central crossing point at high speed with a joy stick and using a very high speed computer in the near future, together with the after image effect of human eyes, one can expect complete three dimensional observations.

This method should be very useful in clinical practice[3].

2) Three dimensional dose distribution display system

As an application of these three dimensional display of CT images, three dimensional dose distribution display system for radiation therapy have been reported.

McShan et al.[7] reported a system using interactive colour graphics, and Fujii et al.[8] also reported a system using multiple contour lines on the computer graphics.

These systems are essentially composed by the multiple lines and dark back ground on the CRT display of computer graphics, and the gray scale CT image is neglected.

Our system can display gray scale CT image and isodose curves simultaneously and three dimensionally.

In the practical clinical application, we suppose that the gray scale CT image should be retained on the display system for through observations of relationships between dose distributions and tumor or organs, because tumors and multiple surrounding normal tissues have fine and complexed contours and different radiosensitivities.

In the system without gray scale CT image display, it will be difficult and time consuming effort to input such fine and complexed contours of multiple tumors and organs by digitizer or light-pen, and will be difficult to use in clinical practice.

3) Others

We suppose that future particle irradiation system will require very fine and accurate irradiation system, and the recent industrial "Robot" technology will be of use for this purpose.

If the NMR-CT be used for RTP system, the "volume scan" will enable more easy to apply the three dimensional display system, and it will also provide reduction of irradiation dose to critical normal tissue and more clearly visualization of tumor contours.

Finally, the problem of optimization of dose distribution is difficult in general, but if therapy unit combined with CT system be achieved, the dose distribution with high dose areas at tumors and low dose areas at critical organs may be reconstructed by the therapeutic beams using the inverse CT principle.

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