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NEW DEVELOPMENT OF INTEGRATED CT SIMULATION SYSTEM FOR RADIATION THERAPY PLANNING

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INDEXING WORDS

radiotherapy; CT; therapy planning system; three-dimensional treatment planning

SYNOPSIS

In order to put more accurate radiotherapy into practice, a radiotherapy planning system using CT, which is named CT simulation system, has been developed and introduced at Kobe University Hospital. The CT simulation system consists of a CT scanner, an image processing work-station, and a laser marking system. The target area of radiation is determined on each CT axial image or scout view in the work-station. Three-dimensional treatment planning is feasible on the basis of the two-dimensional tumor information in CT axial images. After setting treatment parameters, the contour of the radiation field on beam's eye view and the iso-center position are calculated by computer. This system makes it possible to choose an appropriate irradiation method and an optimal dose distribution. In the present study we examined the fundamental capability of this system. The laser marking system proved to have a very high degree of accuracy. The outcome of a phantom test raised the strong possibility that this system may be applied clinically. In addition to these basic findings, this paper describes preliminary clinical observations that support the good reproducibility of the radiation field projected with the CT simulator. In conclusion, this system is of high value for radiation therapy planning.

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INTRODUCTION

With a view to improving the result of radiation therapy, multiple studies are in progress clinically, including those having biological and physical aspects. Evolvement of medical imaging techniques such as CT and MRI has markedly influenced the concept of radiation therapy including diagnosis of tumor extent, treatment planning, and efficacy evaluation.

The ideal therapy for cancer would consist of a regimen that kills tumor cells without seriously damaging normal tissues. In other words, the objective of radiation therapy is to concentrate the radiation dose at the tumor tissue to reduce normal tissue damage as much as possible. In practical planning, it is necessary to obtain three-dimensional information about the target area and adjacent organs.[12] For this purpose we have developed a system for three-dimensional radiation treatment planning using CT.

This paper describes the outline of this system from the following four angles: hardware, operation for treatment planning, fundamental value, and clinical application.

DESCRIPTION AND HOW TO USE

1. HARDWARE CONFIGURATION

The CT simulation system is composed of three components: CT scanner, work-station, and laser marking system.

CT scanner (GE-9800 Hi-light)

The CT scanner used in this study was model GE-9800 Hi-light. This model is characterized by the GPIB (general purpose interface buss) I/F Board which is installed in the slot of the computer cabinet and connected to the work-station via a GPIB cable to transfer CT image data.

Image processing work-station (Yokogawa Medical Systems (YMS) RT/Marker, Fig. 1)

The work-station is the main component of the CT simulation system. It includes a computer, cathode ray tube (CRT) monitor, keyboard, track ball, and pen plotter. The computer unit is the heart of the RT/ Marker. It is a greatly enhanced personal computer, and is connected to the cabinet. The CPU (central processing unit) comprises Intels 80387 and Intels80387(FPU) to cooperate with it. The memory which is enhanced to 32 M bytes works as a page-memory for display, etc. and as RAM-DISK. The hard-disk capacity is 100 M bits. It contains many kinds of programs and system parameters. The computer unit includes a magnet-optical disk. This 512 M bits' removable disk contains image data and planning data that result from the planning operation. The CRT monitor displays object-oriented windows, which comprise a 2-image pane, hierarchical-main-menu, reply-menu to interact with the user, and title plane. The pen plotter, hp7440A, is used to plot out target figures in the overhead projector (OHP) film which is set up on the shadow tray of the linear accelerator.

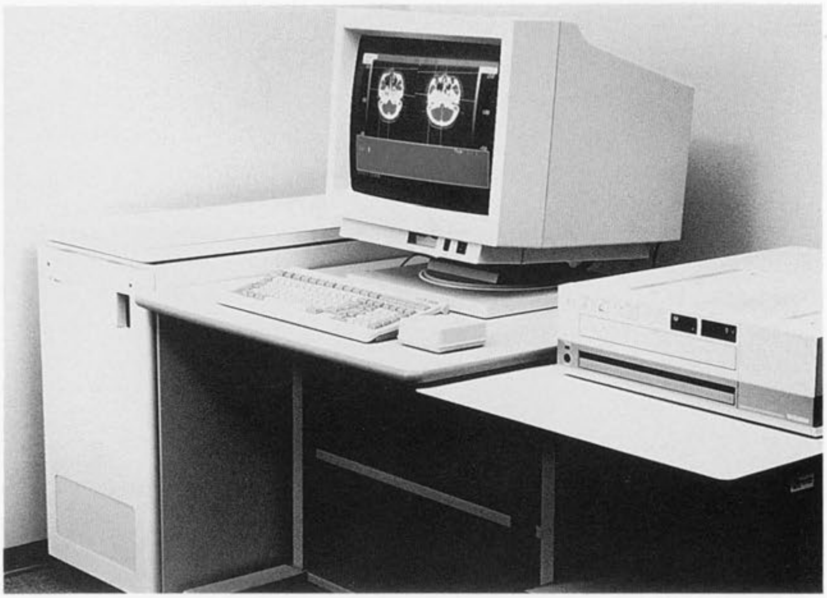

Fig. 1
Image processing work-station and CRT. After determinating the target and setting the parameters for treatment, the position information of the target iso-center and the contour of the radiation field are calculated. The field contour is plotted out with a pen plotter.

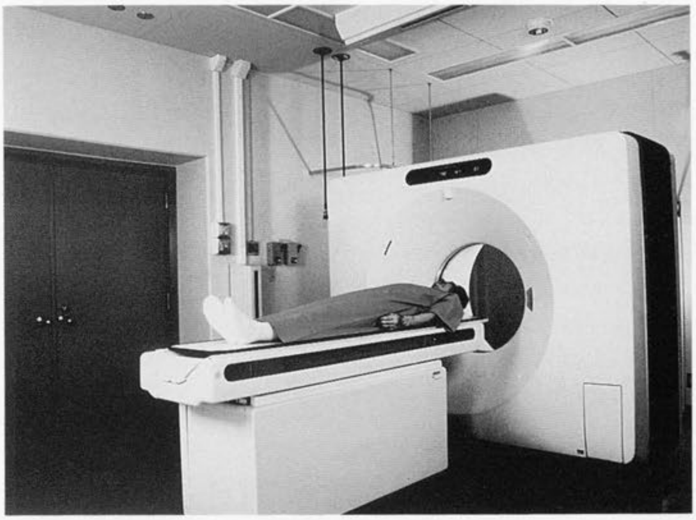

Fig. 2. Laser marker.
Two projectors on both side walls and one on the ceiling. The iso-center is projected and reproduced on the patient's skin with three points.

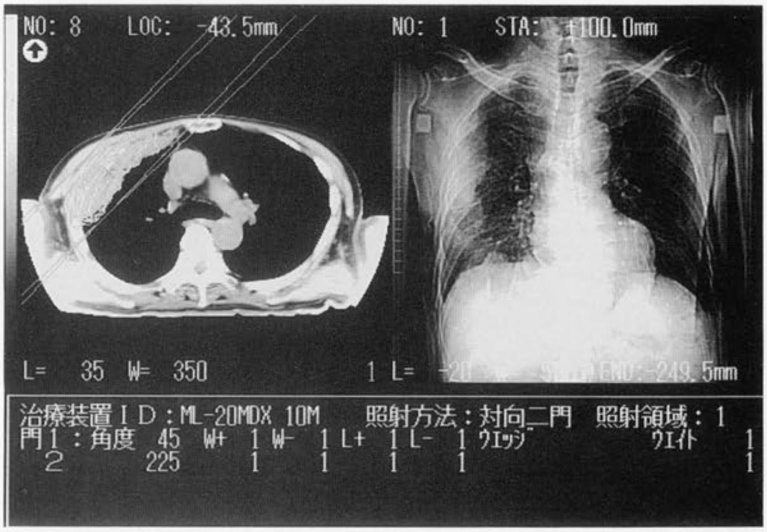

Fig. 3.
CT axial image on CRT. This is a case of lung cancer showing an extensive spread along the pleura.

Laser marking system (YMS RT/Marker Option, Fig. 2)

The CT simulation system supports the laser marking subsystem in the CT scanning room. Three points which reproduce the calculated iso-center of the target for radiotherapy is pointed out on the patient's skin by laser-pointer unit.(Fig 4) The laser marking system contains a computer box, a display, and a laser-pointer unit. The computer box receives the position information of the iso-center from the work-station and controls the laser-pointer unit. Three laser beam pointers are affixed, one on the ceiling right above the CT table and another on each side wall.

2. PLANNING OPERATION

The operations for treatment planning are outlined as follows: In general, standard CT scanning techniques are used, except that the patient is laid on the flat surface and allowed to breathe lightly without the necessity of holding his or her breath. This is to simulate the geometrical condition in the treatment situation. The CT information is forwarded to the on-line work-station for image processing. In the work-station the target area is determined from the CT images. The contour of the radiation field and the position of the iso-center for treatment are calculated by computer. The information is forwarded to the on-line laser marking system which indicates the position of the iso-center on the patient's skin. Given below are the further descriptions of each process.

Immediately after the initiation of CT scanning, the information acquired is forwarded to the work- station for image processing. Information forwarding to the work-station finishes upon completion of scanning. The CT scanner (GE-9800 Hi-light), which has the ability to scan 20 slices within 2 minutes, must allow a substantial reduction in planning time. In the next process the target for treatment is determined in the work-station. A case of lung cancer is shown in Fig. 3. The target area is established with a track ball on the axial images of CT slices which are indicated on the CRT (Fig. 5). We call this process ROI (region of interest) drawing process. Six ROI's can be established in one patient. Not only the target area but also the radiosensitive organs are traced on the axial image. In order to select an appropriate radiation method that can avoid irradiation of the radiosensitive organs, the geometric relations of the tumor and adjacent organs should be identified.

Fig. 5.
The ROI (edge of target) is traced with a track ball.
A planning operation is performed with a keyboard.

After ROI drawing is finished, the most appropriate radiation method is selected. We set various parameters such as safety margin, number of ports, beam direction, X-ray energy and wedge filter setting, taking into account the relations between the tumor and the adjacent normal tissues or radiosensitive organs. The fan beam is indicated on each image after the calculation (Fig. 6). In the event that the plan has been found unsuitable, recalculation is done after changing the parameters for the radiation method. In this case, we set the incident angle in the direction of 225 degrees to avoid the lung. This system makes it possible to calculate the iso dose distribution curve, which is indicated in multiple colors on the CT axial image of a certain level included in the radiation field. This enables us to search for a better dose distribution.

After this operation is completed, the target image and the position information of the iso-center of the target are calculated. It takes about one minute to calculate one target image on optimal beam's eye view. Some cases may require no axial CT data, such as whole pelvic irradiation, whole brain irradiation and irradiation of vocal cord tumor, etc. In addition to the axial planning method, our CT simulation system has a scout view planning method. According to the scout view method, an optional shape can be drawn with a track ball and keyboard on the CT scout view indicated on the CRT of the work-station. The scout view planning applies where axial CT data are unnecessary.

The calculated information on the position of the iso-center is forwarded to the laser marking system which is on-line. The iso-center is projected and reproduced accordingly with three points on the patient's skin. The reconstructed target image and the figure of the radiation field is printed out on the film sheet with a pen plotter. We designate this film as computed simulation (CS) film. When this CS film is put on the shadow tray of the linear accelerator, the radiation field is projected and reproduced on the patient's skin surface (Fig. 7). Only three points are marked on the patient's skin to reproduce the iso-center and the contour of the radiation field itself is not drawn as is done in the conventional procedure.

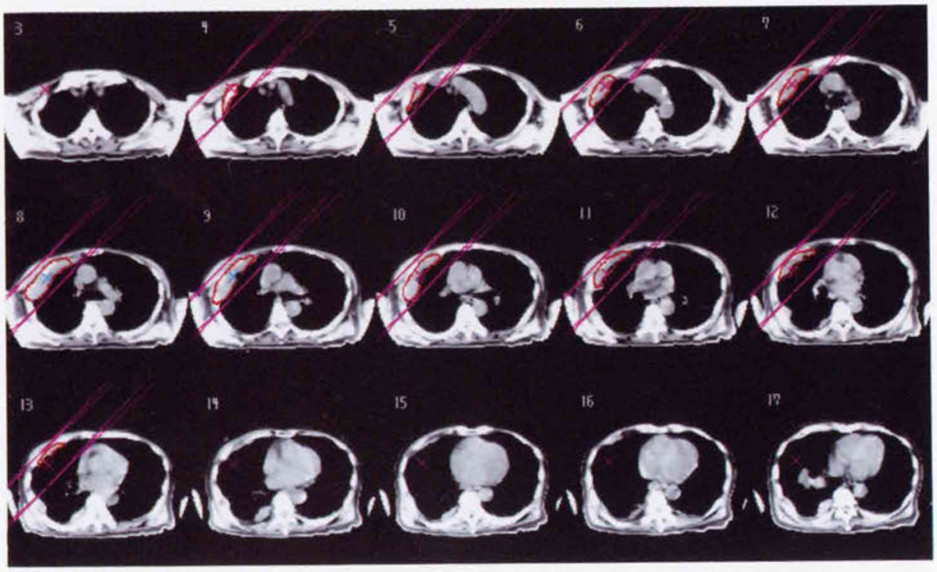

Fig. 6. Calculated beam image shown on each CT axial image.

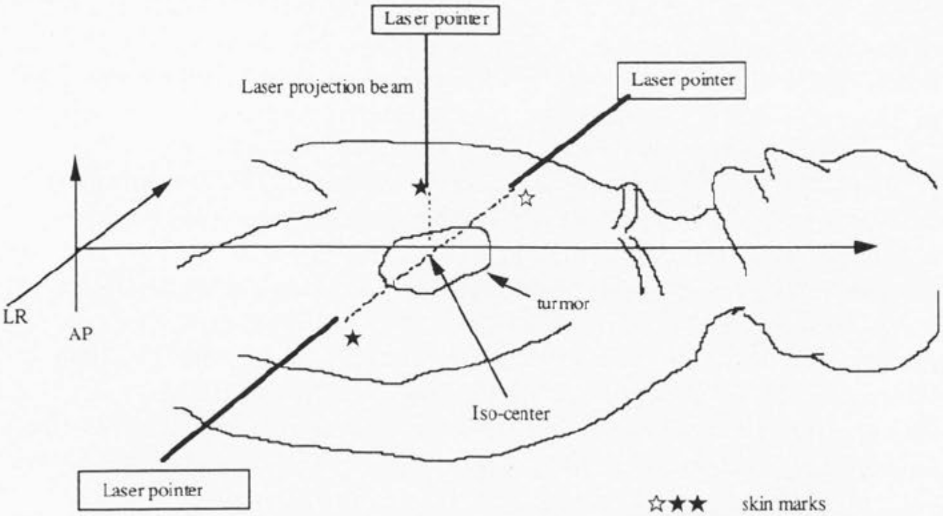

Fig.4.
Geometrical relation of the three laser pointer and the iso-center.

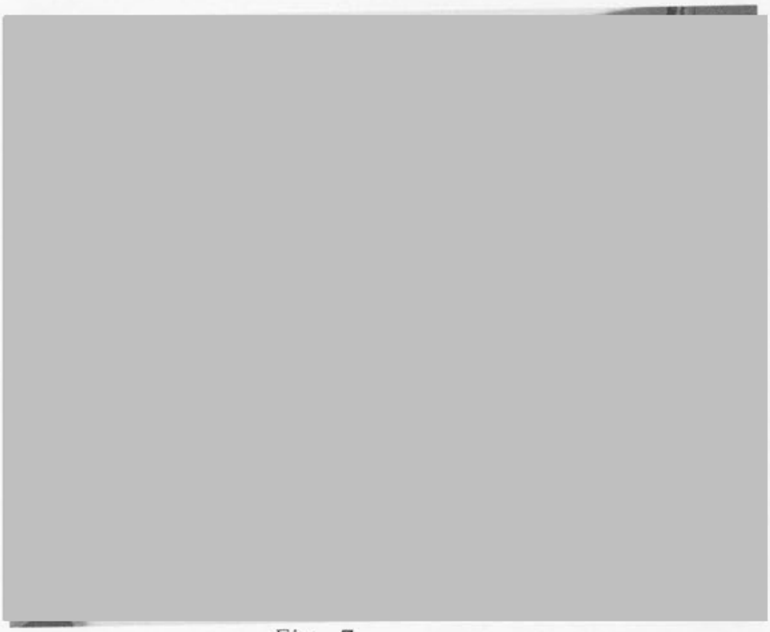

Fig. 7.
The field contour is projected on the patient's skin through CS film.

FUNDAMENTAL STUDY

It is necessary to examine closely the accuracy of each component of this system for clinical use. Therefore, the following fundamental evaluation of this system was carried out.

1. Materials and Methods

Accuracy of laser marking system

The difference between the position entered into the laser marking system and that actually pointed with laser beams was surveyed at 60 points on each axis.

Phantom test

The accuracy of calculation of the position information of the iso-center was investigated because this is the most important primary function of this system. Right-angled isosceles triangles with two sides of 4 cm each were established as an imaginary target on the Mix-DP phantom. The difference was surveyed between the original iso-center of the imaginary target and the calculated iso-center that was projected with laser beams, since this was considered to reflect the total accuracy of the CT scanner, work-station and laser marking system. The difference was surveyed at 8 points by changing the position of the target.

Reproducibility of radiation field

We evaluated the reproducibility of the radiation field in clinical application. A specific scale device was designed and placed on the shadow tray of the linear accelerator (Fig. 10). Scale points were projected on the verification film through the scale device (Fig. 11). Periodical verification filming using films with scale points was performed on 68 patients (with 30 lesions in the head and neck, 26 in the chest, 12 in the abdomen and pelvis)planned using CT simulation and the initial film was compared with the subsequent ones. The deviation of the iso-center of the radiation field was quantified in reference to the scale points. The same process was applied to 16 cases for whom planning was done with a conventional X-ray simulator (7 lesions in the head and neck, 6 in the chest, 3 in the abdomen and pelvis). 68 patients with CT simulation were marked only tree points, but 16 patients with conventional X-ray simulation were drawn the radiation contour itself.

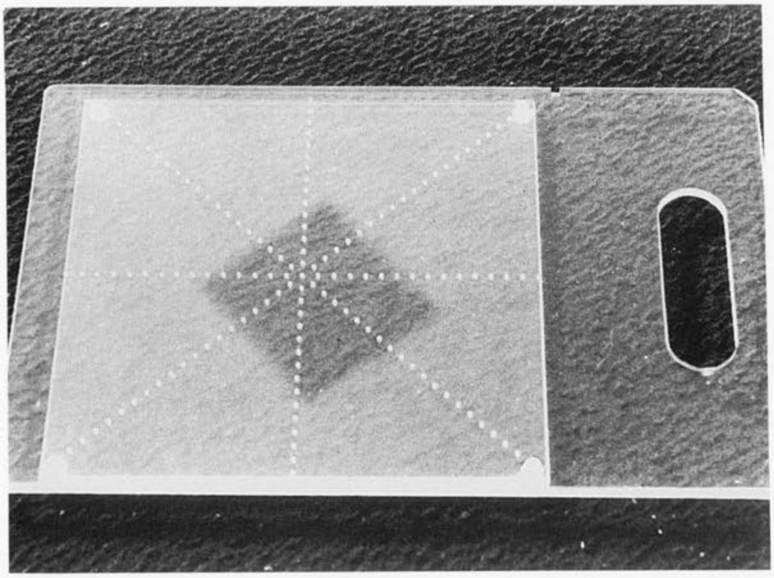

Fig.10 Original scale device.

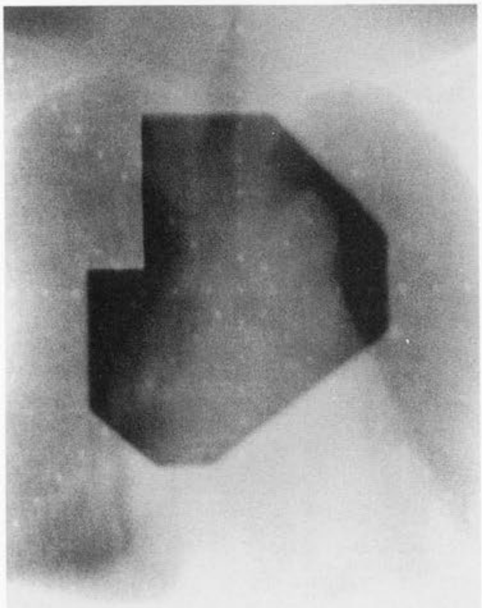

Fig. 11. Verification film obtained with a scale device

2. Results

Accuracy of laser marking stem

The results acquired are summarized in Fig. 8. The open circle shows the position pointed with laser beams. Errors were found at 15 of 60 points examined. But, the difference from the entered position was within 0.5 mm (0.25±0.25 mm, mean±SD). Thus, our laser marking system proved to have a very high degree of position reproducibility.

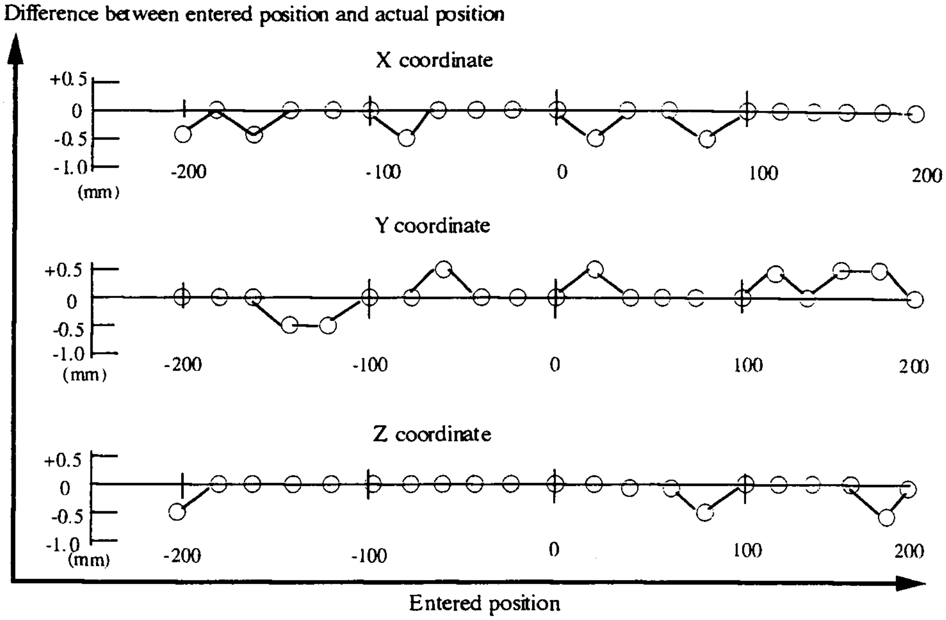

Fig. 8

Evaluation of accuracy of laser marking system. The open circle shows the position of the beam point. The difference between the actual and entered positions is measured at 60 points.

Phantom test

Fig. 9 illustrates the findings in the phantom test. The maximum difference was 1.8 mm on the X coordinate (0.5 mm on the average), 1.3 mm on the Y coordinate (0.6 mm), 1.5 mm on the Z coordinate (0.5 mm). The minimum difference was zero mm, whichever coordinate might be concerned.

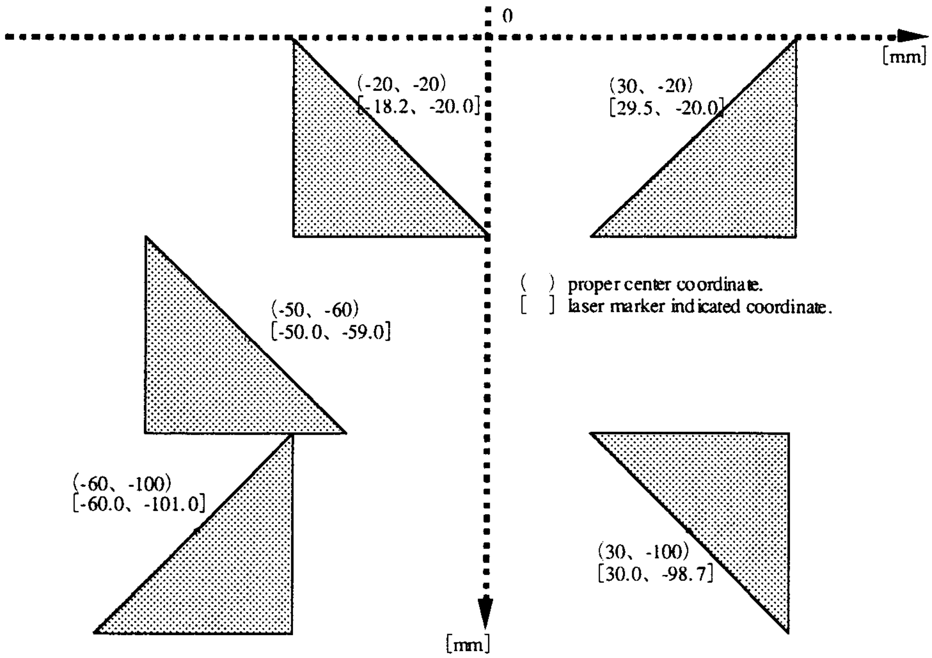

Fig. 9
Parentheses show the ideal position of the iso-center.
Brackets show the calculated position of the iso-center.

Reproducibility of radiation field

The results obtained are shown in Fig. 12. In the group subjected to planning with the CT simulation system, the average iso-center deviation was 3.9 mm in all cases, 4.5 mm (the mean value 6.7 mm) in the head and neck, 3.7 mm (4.5mm) in the chest, and 3.3 mm(6.0mm)in the abdomen and pelvis.In the group subjected to planning by conventional X-ray simulation, the mean deviation of the iso-center was 3.8mm in all cases, 4.2mm(3.3mm) in the head and neck, 3.5mm(2.4mm) in the chest, and 3.8mm(4.7mm) in the abdomen and pelvis. No significant differences were found between the two groups.

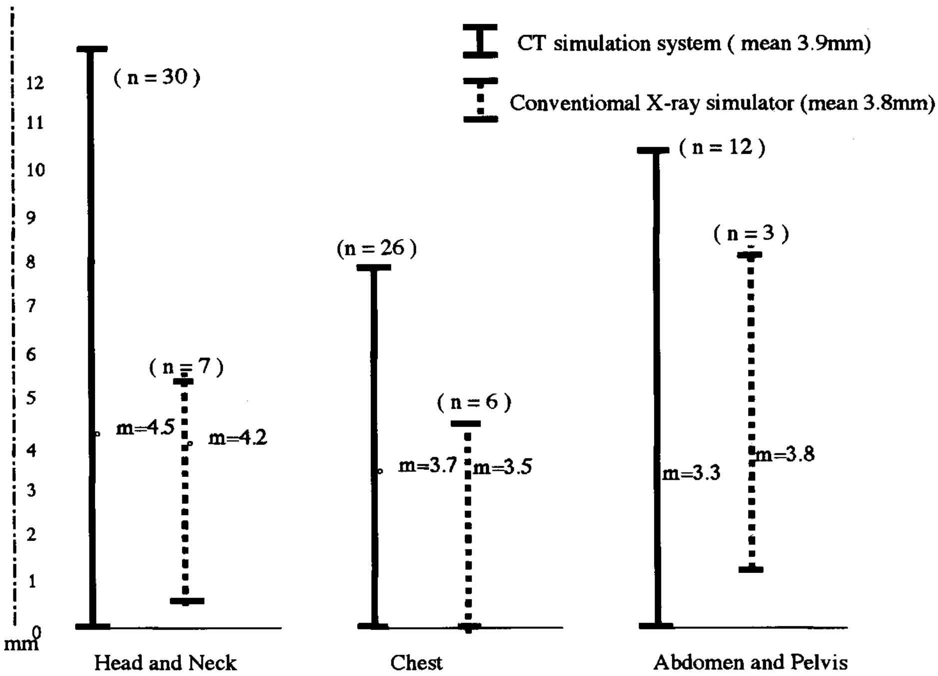

Fig. 12.
Accuracy of iso-center reproducibility in the radiation field. No significant difference is seen between the CT simulation system and the conventional simulator.

DISCUSSION

The concept that providing the CT information for radiotherapy have been reported.[5,6,10,12,13] Several methods that the anatomical information obtained from the CT can be transferred accurately to treatment geometry have been developed and employed.[2,9] CT makes it possible to grasp the three-dimensional tumor extent constructed from two-dimensional images[12]. We can define the tumor extent more accurately by CT simulation than by conventional X-ray simulation, which is a two-dimensional planning method. The excellent spatial resolution of CT contributes to its high advantage over the conventional technique. The more accurate the definition of the target, the more appropriate radiation procedure can be chosen.

On the basis of the rationale described above, we have developed a three-dimensional radiotherapy planning system utilizing the information acquired by CT. We can catch an accurate grasp of the geometrical relations of tumor and radiosensitive organs using this system. The CT simulation system is expected to provide new indications for radiotherapy: it may benefit those patients to whom conventional X-ray simulation is considered difficult to apply. For example, using this system, we could successfully treat eyelid tumor, which is thought to contraindicate radiotherapy. In this particular case we were able to irradiate only the eyelid thanks to the accurate determination of the target avoiding lens irradiation. An additional merit of our system is that we can escalate the irradiation dose in boost irradiation with planning based on the precise definition of the target area which reduces adjacent tissue damage as much as possible and, in turn, brings about good local control.

In some basic studies made prior to the clinical introduction of our CT simulation system we evaluated its accuracy. With respect to the laser marking system, a very high grade of position reproducibility was achieved as shown in the results. In the phantom test, which was carried out to assess the accuracy of the iso-center information obtained by this system, the maximum difference between the original and imaginary targets was 1.8 mm. This value is equivalent to only about 1 pixel of CT. The minimum difference was zero mm. These data must have included possible differences due to errors in drawing ROI's on the CRT and those incidental to the laser marking system. Accordingly, we judged the values cited above to suggest that the CT simulation system must be highly reliable and would be well applicable at a clinical level.

One of the unique characteristics of this system is that the patient is marked with only three points to reproduce the iso-center of the radiation field.(Fig.4) The contour of the field is not drawn on the patient's skin as is done in the conventional method. Does it suffice to have only three points to secure the good reproducibility of the radiation field during treatment?[11] In order to answer this question, comparison was drawn between our simulation method and conventional modality with respect to the reproducibility of the radiation field. Byhardt et al report that the portal films were reviewed for 337cases and the radiation field placement errors rate was 15% (deviated greater than 5mm from the planning films)and

10%(greater than 10mm).[1] As shown in our results, three points' marking for iso-center on the patient's skin proved to be sufficient enough to maintain the clinically valuable reproducibility during treatment. We expect three points' marking to help reduce the patient's mental burden. Howsoever our simulation system might be excellent, it can not be applied clinically without the help of an adequate fixation device for the maintenance of the radiation field. We use a mouthpiece and some types of immobilizers for head and neck irradiation, but some apparatus have to be devised for the irradiation of the chest, abdomen, and pelvis.

At the introduction of the CT simulation system , only the axial method was available and it took about an hour to perform the entire procedure from the start of CT scanning to the finish of planning operation. Since then, however, the planning time has been reduced to 10 - 30 minutes due to the improvements in software for the work-station. The scout method has also become available. We usually use this method in routine radiotherapy planning in laryngeal cancer and uterine cervical cancer cases. It takes only 5 - 15 minutes to complete the planning operation according to this method. Nowadays, radiotherapy was planned by use of the CT simulation system in all cases.

The high accuracy of this system in treatment planning has been ideal in radiotherapy because of various factors including those related to the patient inter- face. For example, patient motion and the change of posture or motion over the affected part can be a cause of poor reproducibility. If a difficulty is encountered in defining accurately tumor extent by CT, we suspect it to be due to a geometrical error in establishing the target. In case there is no difference in density between normal tissue and a tumor, or in the case of a micro lesion that escapes detection by CT, it is a must to combine this method with another imaging modality such as MRI.

Of course, MRI is also available for three dimensional definition of tumor extent. As a matter of fact, it has already been taken up to develop an MRI simulation system.[4,6] However, MRI has demerits: MRI is expensive, treatment planning with MRI requires more time than that with CT, and MRI is less widespread than CT. In consequence, CT simulation is favorably compared with MRI simulation at least for the present. The CT simulation system can be introduced easily by adding a work-station and a laser marker to the CT system already installed in the hospital. It goes without saying, however, that assessment of the result of radiotherapy planned with this system and performed on a good number of patients should be done before establishing its clinical availability.

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