THE CANCER TREATMENT SYSTEM AT HYOGO ION BEAM MEDICAL CENTER (HIBMC)

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Abstract: Hyogo Ion Beam Medical Center is a new ion beam treatment facility which was opened in April 2001. Ion beam treatment at this center comprises an irradiation system, a treatment planning system and a treatment verification system. The irradiation system consists of huge machines that might seem to play a major role in ion beam therapy, however, two other systems also play absolutely important role. Holistic and highly precise functions of these three systems are essential and cooperative work among radiation oncologists, medical physicists, radiological technologists and nurses is more important than anything else in performing this highly sophisticated treatment.

Key words: Proton therapy, Carbon ion therapy, PET

INTRODUCTION

In Japan, the mortality rate due to cancer is increasing every year. In Hyogo Prefecture, cancer has been listed as the main cause of death since 1978. During 1994, the number of deaths from cancer was 12,000 which accounts for 1 in 3 people dying from cancer. As a measure, the Prefectural Government decided in 1987 to wage a campaign for a "Cancerless Hyogo". The interim objective is to reduce the mortality rate due to cancer to below the national average, and a campaign focusing on cancer prevention and education/enlightenment, medical checkups, treatment, research, information and promotion systems has been launched on a middle to long term level.

An important goal of current cancer therapy has now become the well being of those patients that are cured. Targeted application of radiotherapy can be used to preserve normal structures and important functions. However, the treatment of cancer by conventional radiotherapy is still limited by undesired damage produced in normal tissues that are necessarily exposed. Accordingly, as a part of the national "10 year anti-cancer campaign" , the Promotion and Exploratory Committee for Ion Beam Treatment was established in 1992, consisting of experts and prefectural officials (Chairman: Dr. Shuji Kimura, Honorary Director, Hyogo Medical Center for Adults). In 1992, the committee investigated the current state of ion beam treatment for cancer1,2). In 1993 they appointed specialist sub-committees (an accelerator expert group, a treatment expert group) and the Hyogo Prefectural Ion Beam Treatment Facility Plan was drafted. Based on this plan, the treatment and hospital wards were built. On April 1 2001, the Hyogo Ion Beam Medical Center was opened as the first facility in the world to provide both proton and carbon ion beam therapy.

CHARACTERISTICS OF ION BEAM TREATMENT

The advantage of the physical characteristics of the ion beam treatment is that the dose distribution is superior to conventional radiations such as X or γ-rays (photon rays)3). Namely, the ion beam does not strongly interact with structures which are located before a specific site (the Bragg peak) and does not penetrate any further. On the other hand, the energy of conventional radiation deposits more in the shallow part of the body and gradually decreases as radiation penetrates deeply into the body. Moreover, in ion beam therapy the maximum effect peak can easily be adjusted to the target by changing the energy level, thereby deep-seated lesions can be locally irradiated4). The biological effect of proton beams is similar to those of conventional radiation5), while that of carbon ion beams is much stronger6),7). Consequently, the carbon ion beam is more effective against hypoxic cancer cells resistant to X or γ-rays, and shows greater therapeutic effects on these cells. Conventional radiations are effective at the mitotic phase but not at the DNA synthesis phase, whereas the carbon ion beam is expected to be effective during any phase in the cell cycle. Therefore, by making full use of these physical and biological characteristics of the ion beam treatment, it is possible to create the most effective cancer radiotherapy ever8).

Indications of ion beam treatment are: primary tumors, including cancers of the head and neck, the lung, the liver, the prostate and bone/soft tissue sarcomas. As it is a local treatment, it is in principle not suitable for patients with metastases. However, the ion beam treatment is indicated for patients with a single metastatic tumor in the lung or the liver regardless of its histology, if the primary tumor is well controlled.

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CANCER TREATMENT SYSTEM

Ion beam treatment at this center is carried out with a comprehensive system which consists of an irradiation system, a treatment planning system and a treatment verification system. Mitsubishi Electric Corporation produces the irradiation system. As this system consists of new medical devices, Ministerial approval is required for their medical use. Therefore, a clinical trial commissioned by the Mitsubishi Electric Co. is currently being carried out in order to obtain government approval. The treatment planning system consists of a combination of medical devices currently used for radiological diagnosis and treatment planning, and the treatment verification is performed by using a positron emission tomography (PET) camera.

I. IRRADIATION SYSTEM (Fig. 1)

The irradiation system consists of 1. the injector system, 2. the main accelerator, 3. the high-energy beam transport system, 4. the beam delivery system, 5. the patient positioning system, and 6. the control system for the entire device. Two different types of beams are used for treatments at our center, i.e. proton (70-230 MeV/u) and carbon ion beams (70-320 MeV).

The injector system consists of two 10-GHz ECR ion sources, 1 MeV/u RFQ linac, 5 MeV/u Alvarez linac and a debuncher. Operation frequency of the linacs is 200 MHz. The main accelerator is a synchrotron and its circumference is 93 m. The beam is slowly extracted by the third-order resonance scheme. The main accelerator and all irradiation ports are connected by a high-energy beam transport system.

There are 5 treatment rooms; one with horizontal and vertical beam lines, one with a 45-degree oblique beam line (a 15 cm × 15 cm irradiation field), one with another horizontal line (a 10 cm in diameter irradiation field) and 2 isocentric proton gantry lines (a 15 cm in diameter irradiation field). To conform the Bragg peak to a target volume, the beam lines in the treatment room are equipped with a pair of wobbler magnets, beam scatterers, ridge filters, and multileaf collimators. The ridge filter is designed to produce biologically equal effects along the spread-out Bragg peak (SOBP). The collimator is used to define the lateral outline of the target volume. The patient positioning system consists of an adjustable treatment couch with 5- or 6-directional axial movements, a laser pointer to adjust the patient position and an X-ray device in order to place the target precisely by using frontal and lateral fluoroscopy. The entire system is produced by the Mitsubishi Electric Co.

II. TREATMENT PLANNING SYSTEM

The treatment planning system consists of a CT (Toshiba Corporation, Tokyo), an MRI (Philips Electronics N.V., Eindhoven, the Netherlands) and a treatment planning device (FOCUS-M; Computerized Medical Systems, Inc., St Louis, MI (CMS) and Mitsubishi Electric Co., Kobe). FOCUS is manufactured by CMS loaded with a calculation code for the ion beam treatment using the pencil beam method produced by the Mitsubishi Electric Co.\(^{11}\), which consists of a treatment information management server (WS) and treatment planning terminals (WS). The treatment planning terminals are connected with an image fusion terminal (PC) to support treatment planning.

III. TREATMENT VERIFICATION SYSTEM

As charged particles produce short-lived positron-emitting isotopes in tissues, the treated site can be verified by images taken immediately after irradiation using a PET camera (SET-2300W: Shimadzu, Kyoto).

IV. OTHER TREATMENT SUPPORT SYSTEM

Tumors in the liver and the lung move with breathing, though the movement is more stable when a patient breathes out. Thus for radiation therapy the target is usually irradiated during an expiratory phase. In our hospital, a respiratory-gated irradiation system is used for proton and carbon ion radiotherapy\(^{39}\).

DETERMINATION OF TARGET VOLUME

Radiological technologists set up a fixing device using plastic materials in order to immobilize a patient on the CT device, and take CT images of the treatment target site. The center of the CT image closest to the center of the lesion is designated as CT-0 (X, Y, Z=0, 0, 0) and the point on the fixing device is arbitrarily marked as CT-A (arbitrary CT-0). After taking the CT images, the fixing device is removed and MRI images are taken. The CT and MRI images are then sent to an image server in the hospital.

TREATMENT PLANNING

Treatment planning is carried out on the treatment planning system as follows: CT and MRI images are loaded into the treatment planning system. These images are sent to the image fusion terminal through the treatment planning terminal and merged into a CT-MRI image using FocalFusion\(^{10}\). Using FocalEase, CTV is drawn on the MRI part of the CT-MRI image, and then the outline is transferred to the CT image. In the same way, the outlines of each organ are drawn
on to the CT image. After the CTV and critical organs are drawn, the image is sent to the treatment planning terminal. The PTV is then automatically drawn. The center of the PTV is designated as the isocenter. Accordingly, the X, Y, Z coordinates of the isocenter are defined relative to the CT-O, which are designated when the CT images were taken. The direction and the energy of the beam, the ridge filter, etc. are defined. Frontal and lateral DRR images which are used in treatment rehearsals are also generated at the same time. Fig. 2 shows the 3D images of the treatment plan for a patient with liver cancer and the frontal DRR.

**TREATMENT REVIEW**

The treatment plan is discussed by radiation oncologists, medical physicists, radiological technologists and nurses at the conference room where the hospital information system (Yokogawa Electric Corporation, Tokyo) is freely accessible. If any question arises, re-planning is ordered. If not, the plan is finally approved. The approved data are then transferred to the hospital information system.

**REHEARSAL**

The day before the actual treatment, a rehearsal takes place for a patient. The positioning of a patient fixed on a treatment couch is adjusted by a laser pointer. The laser pointer is adjusted to the CT-A on the fixing device. Since the real CT-O is in general slightly different from the CT-A, this difference is adjusted manually on the DRR images. The CRT of the positioning image server displays 4 panels (Fig. 3). The left panel shows the reference images and the right panel shows the X-ray images on the treatment day. At the rehearsal, the frontal and lateral DRR images taken at the treatment planning are displayed on the left panel, and then the frontal and lateral X-ray images taken during positioning of a patient are displayed on the right panel. When these images match completely, the X-ray images are stored as a reference.

**TREATMENT**

In the same way as the rehearsal, the position of a patient fixed on a treatment couch is adjusted by a laser pointer. When the live X-ray images appeared on the right-hand panel match the reference images on the left-hand panel, irradiation is started.

**VERIFICATION OF THE EXPOSURE FIELD**

Verification of the exposure field is carried out on the
Fig. 3 The target is automatically adjusted by moving the treatment couch through comparison of reference images on the left panel with actual images on the day on the right panel.

Fig. 4 CT-PET image of the patient with liver carcinoma. The radiation site matches the treatment plan on the right side.

treatment verification system as follows: immediately after the treatment, the patient is moved into the PET room, and emission and transmission images are taken as soon as possible. CT images taken before the treatment and the transmission image are merged into a fusion image and the transmission image is then substituted by the emission image. The exposure field is verified by the resulting CT-PET image (Fig. 4)\textsuperscript{12}.

DISCUSSION

The ion beam treatment was initially performed by devices developed for physical use. However, after 1990, the devices became available in hospitals as a result of downsizing of accelerators. A number of new facilities are being built for the ion beam treatment in the dawn of the 21st century, especially in Japan\textsuperscript{13}. Hyogo prefecture has established the first ion beam treatment facility in western Japan.

At this center, proton and carbon ion beam treatments are available. From May to November, 2001, a clinical study of proton beam treatment for 30 cancer patients was carried out. The whole system works well with no serious problems and the preliminary results obtained so far seem very encouraging. They will be reported in another paper soon. The pencil beam method used for the treatment planning system leads to greater precision in treatment than the conventional broad beam method\textsuperscript{14}. The positioning for daily treatments is very important and is conducted by radiological technologists. The regulation standard of the positioning precision is within 1 mm, but the actual precision at our center is currently 0.5 mm on average. The usefulness of PET for treatment verification has been tested by phantom experiments and established clinically. The exposure field of protons was confirmed three-dimensionally using the PET.
verification system. The PET image obtained immediately after therapy demonstrated to be very useful for the verification of the treatment planning.

From our clinical experience, it is concluded that the procedures of conventional radiotherapy, in particular those of the treatment planning, can also be applied to ion beam therapy and a closely cooperative team work among radiotherapists, medical physicists and technicians is essentially important for the success of the treatment.

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REFERENCES