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DEVELOPMENT OF 3-DIMENSIONAL IRRADIATION SYSTEM FOR HEAVY-ION RADIATION THERAPY

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Abstract

A three-dimensional irradiation system using a broad beam was installed at HIMAC facility for a heavy-ion radiation therapy. The thickness of the wedge absorber and the shape of the radiation field made by the multi-leaf collimator were changed during irradiation in order to sweep the Bragg peak only in the target area. In this report we discuss the three-dimensional irradiation system of HIMAC and also results of preliminary irradiation tests using ^{12}C beams.

1 Introduction

It is one of the most important goal of any radiotherapy to shape the treatment volume as exactly as possible to the tumor as the target volume. In most cases a sharp cutoff of the dose is needed in order to spare the surrounding healthy tissue or critical structures to a maximum extent. It is necessary to use a flat-top depth-dose distribution extending several centimeters, even tens of centimeters to encompass solid tumors. For this purpose heavy ion beams are delivered to the treatment volume by the beam scanning method [1] or the broad beam method. The clinical port at HIMAC facility is designed by the latter method and shown in fig.1. The system con-

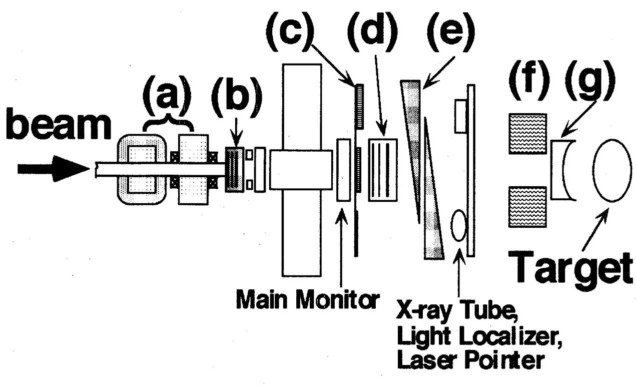

Figure 1: Schematic diagram of HIMAC irradiation port. Devices labeled (a)~(g) are explained in text.

sists of a pair of wobbler magnets (a), a scatterer (b), a ridge filter (c), a range shifter (d), a pair of wedge absorber (e), a multi-leaf collimator (f), a compensator (g) and a monitor system. The wobbler magnets and the scatterer are used for spreading the beam uniformly over the radiation field[2]. For 2-dimensional irradiation, the ridge filter is used to spread the sharp pristine Bragg peak. A spread-out Bragg peak (SOBP) is made by superposing shifted Bragg peaks with suitable superposing ratio. Irregular shape of radiation fields are obtained by blocking the uniform beam with the multi-leaf collimator. Fine adjustment of heavy ion range in patient is performed by the range shifter. And the compensator is used for adjusting position of the distal part of the target.

For a tumor conform treatment, a 3-dimensional irradiation using a synchronized fast sweeping technique is also possible in HIMAC irradiation system and presently developed. This novel technique implies some important advantages. The 3-dimensional dose distribution can be shaped exactly to the tumor volume in order to prevent particles from depositing their biologically very effective dose outside the target volume. Using the sweeping technique, complex 3-dimensional scanning procedure is no longer needed saving irradiation time. And the system can be extended from the present 2-dimensional irradiation system reducing the costs. In the following the principles of the 3-dimensional irradiation are discussed and the first results obtained with the system at HIMAC are presented.

2 Method of 3D irradiation

Figure 2 illustrates the 3-dimensional irradiation system installed in HIMAC. An uniform beam is

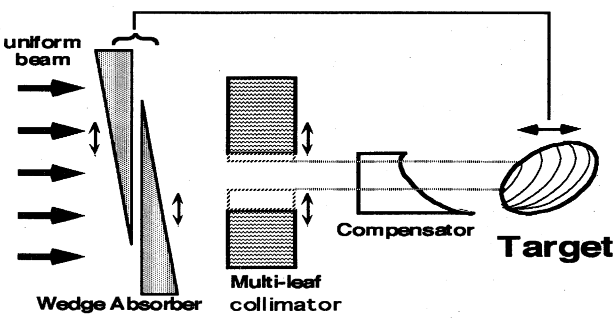

Figure 2: Illustration of Three-Dimensional Irradiation.

made by the wobbler magnets and the scatterer in the same way of the 2-dimensional irradiation. "Slightly" spread–out Bragg peak (we call it s–SOBP in this paper) is made by the ridge filter. The s–SOBP is shifted by inserting the wedge absorbers in the beam course. By combination of the two wedge absorbers, the total thickness of the absorber is uniform in the radiation field. A SOBP that should be conformed to a target shape (we call it total–SOBP in this paper) is made by superposing shifted s–SOBP by changing the absorber thickness during the irradiation with suitable superposing ratio. During the sweep of the s–SOBP in the target region, needless part of the irradiation field can be cut by adjusting the irradiation field with the multi–leaf collimator.

In order to realize this conformation therapy, we have to develop the fast movements of the wedge absorbers and the multi–leaf collimator and their synchronism. Specifications of the wedge absorber and multi–leaf collimator installed at HIMAC are shown in fig.3.

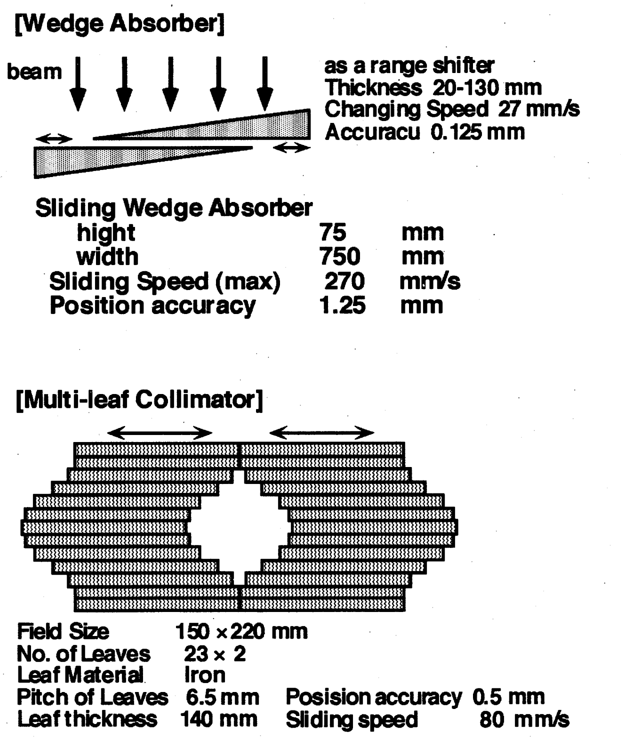

Figure 3: Specification of wedge absorber and multi–leaf collimator.

3 Measurement of dose distribution

The first test of the 3–dimensional irradiation confirming with eyes was carried out using 290 MeV/n carbon beam. The target volume was assumed to be a ball of 7 cm in diameter, which is embedded in Polymethyl methacrylate (PMMA) material. To monitor the beam profile in the target material, a ZnS screen was inserted between PMMA blocks and placed almost parallel but slightly tilted to the beam direction. The movements of the wedge absorbers, the multi–leaf collimator and also the beam profile along the beam axis were recorded by video camera. In each slice scintillation light from the Zns screen lay almost within the target area and results were satisfactory.

For the quantitative test of the performance of the 3–dimensional irradiation, a depth dose distribution was measured for 10 cm width total–SOBP using 290 MeV/n carbon beam. The SOBP was designed to make a uniform biological dose distribution[3] using a thick ridge filter (ridge filter A). The 5 mm width s–SOBP was made by a thinner ridge filter (ridge filter B) that was used to make a uniform biological dose distribution. Three types of radiation fields were made:

(a) 10 cm width SOBP directly made by 2D irradiation using the ridge filter A
(b) 5 mm width SOBP made by 2D irradiation using the ridge filter B
(c) 10 cm width total–SOBP made by 3D irradiation using ridge filter B.

In each irradiation the physical dose was measured with a standard ionization chamber. The preliminary results for the depth dose distribution are shown in fig.4. Open circles, diamonds and closed circles

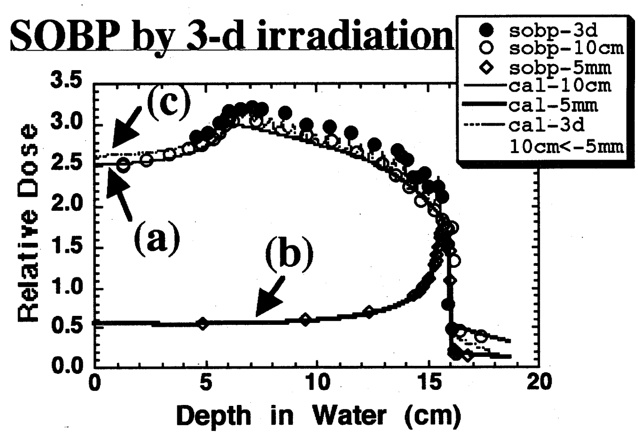

Figure 4: Measured and calculated physical dose distributions.

represent measured physical dose of (a), (b) and (c), respectively. Lines are calculated depth dose distribution[3]. The measured dose by 3D irradiation were slightly larger than those by 2D irradiation. However, measured and calculated results by 3D irradiation were agreed among themselves. This shows that the total–SOBP realized by 3–dimensional irradiation method can be improved by optimizing the shape of the s–SOBP.

To reproduce the 2D SOBP ((a) in fig.4) using the 3D irradiation, a new ridge filter for the modulated s–SOBP of 5 mm in width was designed. Figure 5 shows the calculated results for the physical dose distribution. It is seen that the total–SOBP of the mod-

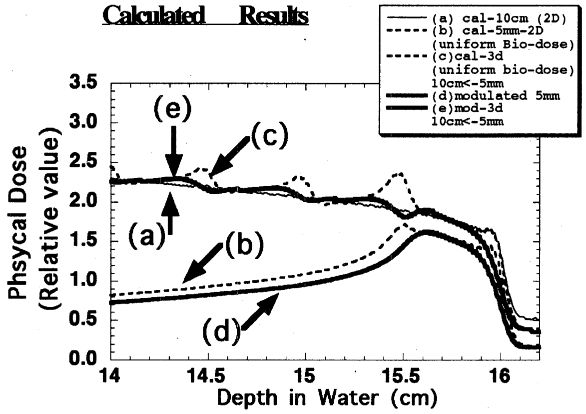

Figure 5: Calculated physical dose distributions (a) for 10 cm field by 2D only, (b) for 5mm uniform biological dose distribution, (c) for 10 cm field by 3D with (b), (d) for modulated 5mm field, (e) for 10 cm field by 3D with (d).

ulated ridge filter is closer to the 2D results (within $\pm$ 4.6 %) than those of the ridge filter B. Needless to say that the further study is needed to optimize the shape of the s–SOBP and other test experiments using the 3–dimensional irradiation method with the modulated ridge filters are planed. In order to evaluate the quality of the radiation field made by the 3–dimensional irradiation (uniformity, penumbra), the monitoring systems for the dose distribution have to be developed. For this purpose we have planed to develop a proportional chamber (for 1–dimensional distribution), a silicon strip detector (for 2–dimensional distribution) and a pile of ionization chambers (for 3–dimensional distribution).

4 Concluding remarks

An irradiation system of 3–dimensional conformation therapy was designed and installed at HIMAC facility. The 3–dimensional irradiation for a ball shaped target of 7 cm diameter was performed using 290 MeV/n carbon beam. The wedge absorbers and the multi–leaf collimator were controlled satisfactorily during the irradiation for conformation therapy. Preliminary results of a dose distribution of the 10 cm SOBP made by superimposing 5mm width SOBP using the sliding wedge absorbers was obtained to check the function of the wedge absorbers.

In order to improve this system, we plan to develop the optimizing methods to design a ridge filter and the dose measurement methods.

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