RESULTS FROM HIMAC AND OTHER THERAPY FACILITIES IN JAPAN

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Abstract

Since 1994, HIMAC in NIRS has carried out the clinical trial of cancer treatments using carbon beams. Total number of patients has reached to a thousand. Since 1983, University of Tsukuba carried out cancer treatments of about 600 patients with proton beams in KEK. Based on the successful results, new construction of proton therapy facility has just completed in the own university. Hyogo prefecture has also completed the construction of both proton and carbon therapy facility, based on the results of both HIMAC and Tsukuba facility. Another proton therapy facility in Shizuoka Cancer Center is now under construction. All of these are of synchrotron systems. The only one proton therapy facility of cyclotron system started the clinical trial at the National Cancer Center (Kashiwa) at the end of 1998. So far about 50 patients were treated successfully. In this paper, firstly the results from HIMAC using carbon beams and then status of the other therapy facilities will be presented.

1 INTRODUCTION

More than 50 years ago, the late Professor R. Wilson proposed the cancer treatment using proton, helium and heavy ions such as carbon for promoting the construction of the Harvard synchrocyclotron[1]. It was based on the range-energy relation by his own detailed experimental researches and the analytical Bethe's formula. Since 1961, the proton therapy has been carried out by use of this synchrocyclotron. The heavy ion therapy was initiated with helium beam of the 184" synchrocyclotron at LBL in 1962 and then followed with neon beam of the Bevalac at LBL. These pioneering works are developed by various facilities in the world so far.

In the last few years, several ion beam facilities for medical use have been constructed in Japan and some of them are producing preliminary results successfully. Based on such results, strong demand to distribute such facilities is rising up rapidly. Optimization of design for hospital is indispensable for this purpose. Design studies and their R&D dedicated to hospital are now starting.

2 HIMAC IN NIRS

The HIMAC (Heavy Ion Medical Accelerator in Chiba) in NIRS (National Institute of Radiological Sciences) consists of two-stage injector linac and two synchrotrons, horizontal and vertical beam lines for therapy, and additional beam lines for physics and biology as shown in

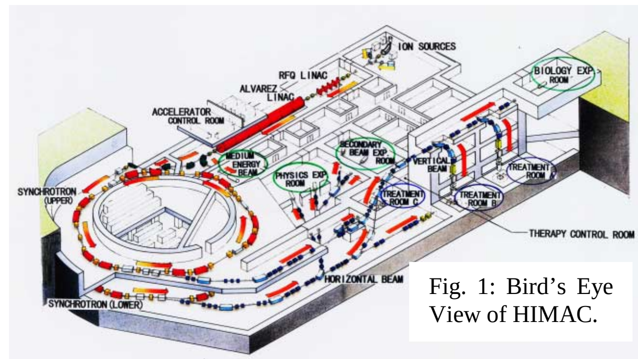

Fig. 1: Bird's Eye View of HIMAC.

Fig. 1[2]. The construction was completed at the end of 1993. Since June 1994, the HIMAC has carried out clinical trial of cancer treatments for various sites of human body using carbon beams, after necessary physical and biological researches for treatments[3]. Total number of treated patients has already reached to about a thousand. The percentage distribution of numbers of patients for each protocol is shown in Fig. 2. Most of the patients are showing expected good procedures in both local tumor control and radiation injury, in spite of their very serious and advanced stages with no other therapy. The superiority of local control rates of tumors and minor complication levels of normal tissues outside the target volumes are clarifying the optimum total doses and numbers of fractionation for various organs and tissues.

Typical results of trial are as follows. Figure 3 shows the CT-images of pre- and post-treatments for a squamous cell carcinoma of ethmoid sinus. A large tumor can be found behind the left eye. After five months, the tumor had disappeared and beyond six years such situation has

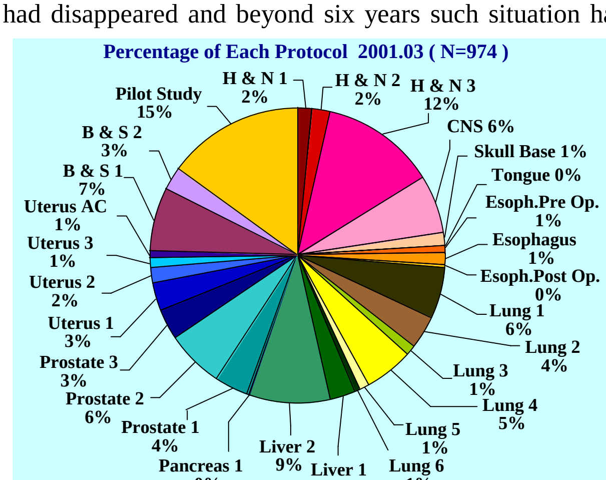

Fig. 2: Percentage of Each Protocol for 974 Patients.

been kept. He is now eighty years old. Figure 4 shows the more dramatic case of malignant melanoma of nasal and para-nasal cavity. Very radiation-resistive large tumor has disappeared so far for four years. The case of large tumor of uterine cervix showed so dramatic shrinkage as to be reduced the target volume even during treatment, as shown in Fig. 5. Bone and soft tissue sarcomata are also very radiation-resistive tumors. The case of Fig. 6 is sacral sarcoma. After four years, not only complete cure

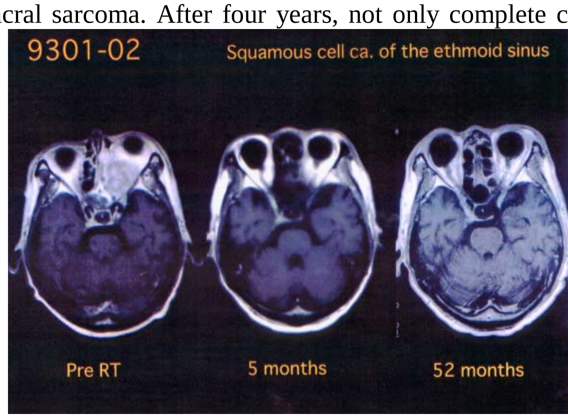

Fig. 3: Squamus Cell Ca. of Ethmoid Sinus.

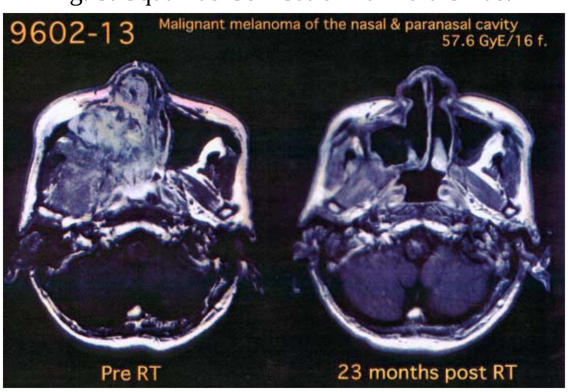

Fig. 4: Malignant Melanoma, Nasal & Para-Nasal Cavity.

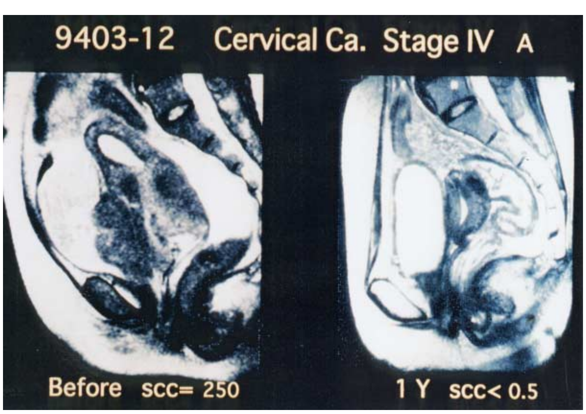

Fig. 5: Uterine Cervix Ca. Pre- & Post-Treatment.

but also new osteogenesis is found to our astonishment. These cases above mentioned are all easily fixable sites.

Around the diaphragm, however, lung and liver must be applied with the new method of the gated irradiation with respiration combined with positioning CT-image also

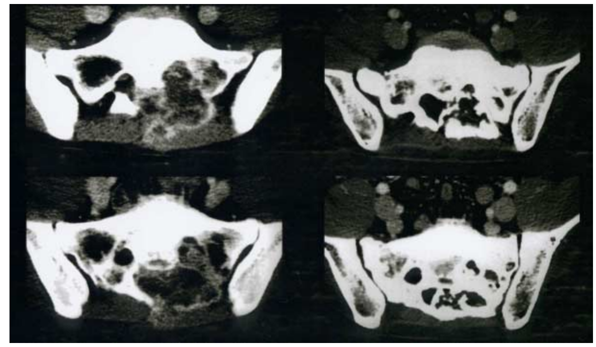

Fig. 6: Sacral Sarcoma, Pre-(Left) & Post-(Right).

gated with respiration[4]. Using this method, both control rates and complications of lung and liver cancers have been widely improved as shown in Figs. 7 and 8.

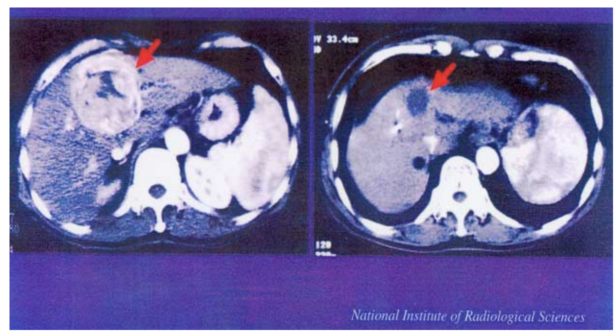

Fig. 7: Hepatocellular Ca. Pre(Left) & Post(Right).

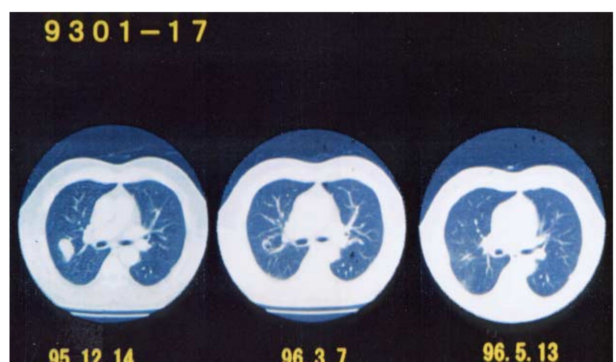

Fig. 8: Non Small-Cell Lung Ca. Pre-, 3 mon. & 5 mon.

It is worthwhile to emphasize the importance of PET (Positron Emission Tomography) in such the ion beam cancer therapy. Diagnosis using PET is of three cases: autoactivation, RI beam irradiation, and injection of RI-labelled compound of methionine or glucose into vein. First two are used for observations of irradiation volumes, and the last is an observation of toxicity of tumor itself. This is particularly important to observe local control effect by comparison of pre- and post-PET images as shown in Fig. 9. Almost all of the patients have been investigated with this diagnosis.

For the targets of complicate shape or too large volume, a patch irradiation method is applied. Figure 10 shows the case of three-patch which saves both eyes.

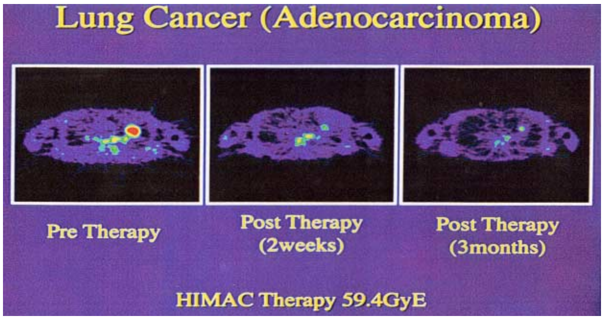

Fig. 9: PET Diagnosis of Lung Cancer using ^{11}C Labelled Methionine.

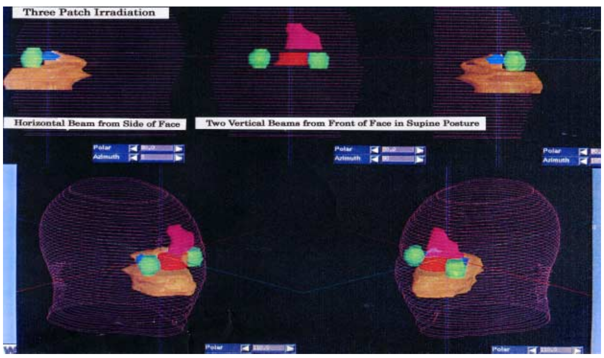

Fig. 10: Three Patch Target Conformation

Recently, new RI beam (^{11}C etc.) course was installed and spot-scanning irradiation into plastic square post was successfully carried out. The PET image as shown in Fig. 11 confirms a feasibility to use ^{11}C beam in the patient treatment with 3D-spot-scanning method within a duration of several minutes[5].

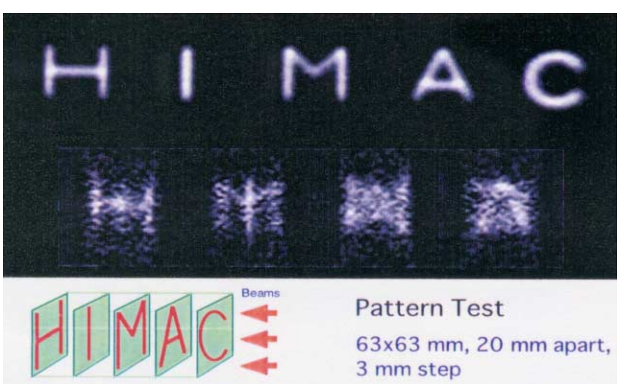

Fig. 11: PET Image of 3D-Spot-Scanning with ^{11}C.

The HIMAC facility itself has worked with almost no trouble during these six years. In daytime of weekdays the facility is used for clinical trial and for basic studies in midnight and weekend. More than 3000 hours have been used for the clinical trials every year. Concerning basic studies, more than 100 groups (biomedicine 70, physics 60) have used various kinds of heavy ion beams of p~Xe, and more than 4000 hours per year have been used.

3 PROTON MEDICAL RESEARCH CENTER, UNIVERSITY OF TSUKUBA

Since 1983, University of Tsukuba carried out cancer treatments also of about 600 patients using proton beams of the 500 MeV booster synchrotron of KEK 12 GeV PS so far. Based on the successful results, new Tsukuba Proton Therapy Facility of the Proton Medical Research Center has been constructed in the own university. The previous facility was shut down in July 2000. The bird's eye view of the new facility is shown in Fig. 12. The size of synchrotron is fairly small 7 meters in diameter.

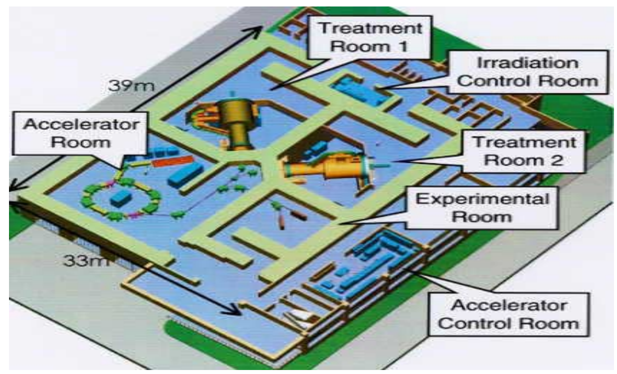

Fig. 12: Bird's Eye View of
Tsukuba Proton Therapy facility.

4 HARIMAC, IN HYOGO ION BEAM MEDICAL CENTER

Hyogo prefecture has also completed the construction of new both proton and carbon therapy facility at the end of 2000, based on the results of both HIMAC and previous Tsukuba proton facility. Clinical trial will be started in May 2001. One of unique features is oblique 45^{o} beam line for carbon beam. The newest diagnostic devices including treatment-planning system, PET system etc. have been installed in this facility.

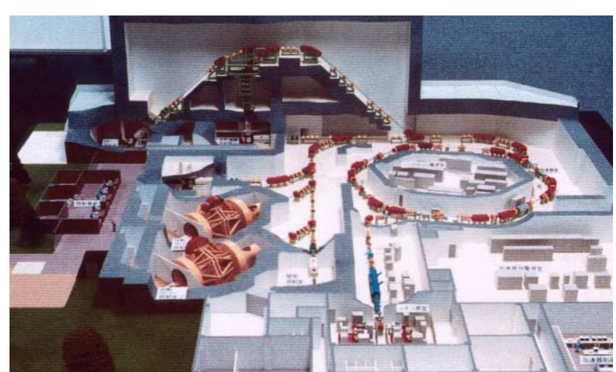

Fig. 13: Bird's Eye View of HARIMAC.

5 W-MAST IN WAKASA WAN ENERGY RESEARCH CENTER

The name of W-MAST is the abbreviation of Wakasa Multipurpose Accelerator with Synchrotron and Tandem. Accelerator itself has been completed already in 2000, and a treatment system is now under construction.

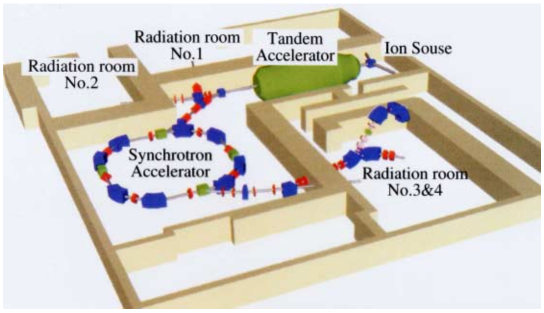

Fig. 14: Bird's Eye View of W-MAST, Wakasa Bay.

6 SIZUOKA CANCER CENTER

Another proton therapy facility is now under construction as a main facility of the newly established Shizuoka Cancer Center. Machine has been completed in a factory. Synchrotron is a ZGS type of 6m in diameter.

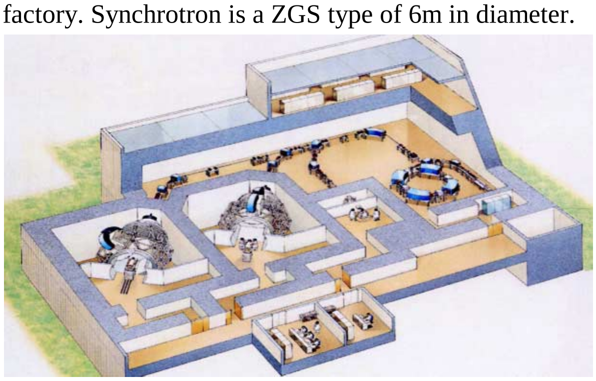

Fig. 15: Bird's Eye View of Proton Facility, Shizuoka.

7 PROTON THERAPY FACILITY, NATIONAL CANCER CENTER HOSPITAL EAST

The only one proton therapy facility of cyclotron system in the National Cancer Center Hospital East (Kashiwa) has started the clinical trial at the end of 1998.

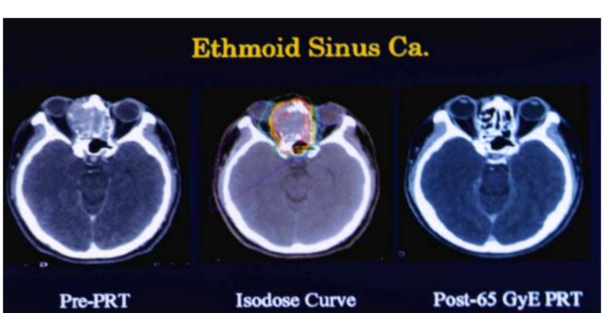

Fig. 16: Ethmoid Sinus Ca, Pre- & Post-Treatment.

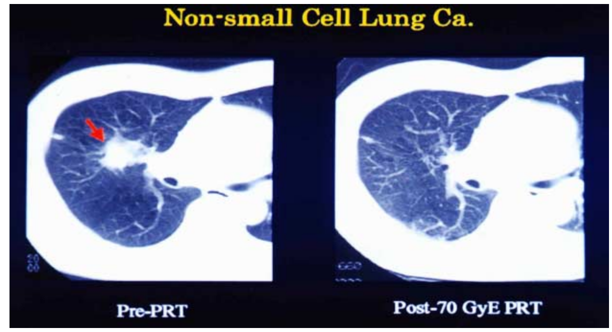

Fig. 17: Non-Small Cell Lung Ca, Pre- & Post-PRT.

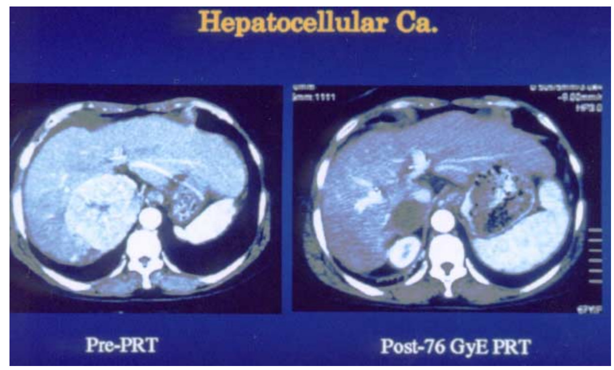

Fig. 18: Hepatocellular Ca. Pre- & Post-PRT.

So far about 50 patients of head & neck, lung and liver cancers were treated successfully. Some typical results are shown in Figs. 16, 17 and 18.

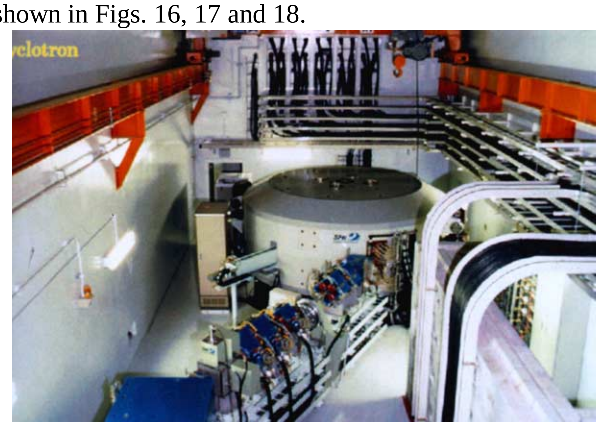

Fig. 19: View of Cyclotron Vault, NCC-HE.

Basic design is of Dr. Y. Jongen (IBA) and the same as of the new facility in MGH[6]. The cyclotron corresponds to the 2nd one following to the 1st in MGH. Construction was carried out by Japanese factory (Sumitomo H. Ind.) in a technological collaboration with the IBA as shown in Fig. 19. Machine itself is of very interesting design and is going to achieve its aimed performance after several technical improvements.

8 SOME CONSIDERATIONS BASED ON THE EXPERIENCES IN HIMAC AND UNIV. OF TSUKUBA

The successful results in the treatments of lung and liver cancers of both HIMAC and Tsukuba emphasize the necessity of the gated irradiation with respiration into an area of breast and upper-abdomen. Most of the facilities in Japan are installed with such the devices.

Small numbers of fractionation such as four in the carbon beam treatments in the HIMAC protocol (Liver-2) result in almost the same control rates and complication levels as of larger numbers of fractionation, say twenty~thirty. Reduction of fractionation brings about higher efficiency of a facility and then lower treatment cost.

Toxicity change observed with PET after treatment shows much quicker response than size change observed with X-ray CT. Even in the case of recurrence after disappearance of target tumor, increase of PET signal gives earlier information of recurrence than of X-ray CT image. Emphasized importance of PET diagnosis requires installation of related facilities such as small cyclotron which produces short-life positron-emitters.

The distribution of utilized maximum depths in human bodies with HIMAC carbon beams has two peaks as shown in Fig. 20. The deeper peak corresponds to the cases of only prostate and uterus treatments with horizontal beams. An analogous distribution is seen in the results of Tsukuba proton beam treatments in pelvis area.

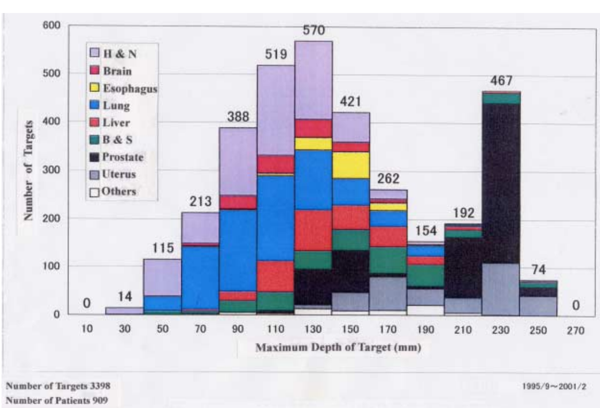

Fig. 20: Distribution of maximum Depths in HIMAC.

Utilized ranges of vertical beams into the same area are much shorter. These results suggest that the maximum range of 30 cm is not always necessary.

Recent successful results of proton therapy stimulate the developments of higher technologies in photon therapy such as the IMRT (Intensity Modulated Radiation Therapy). For the evolution of charged particle beam therapy in competition with such the advanced photon therapy, various kinds of specifications such as necessary energy, necessary area of irradiation, necessity of rotating gantry, etc. must be discussed in detail and then small sized designs for hospital should be proposed.

To make accelerator smaller design, some element researches such as pulse high-field synchrotron magnet, high-field permanent magnet for FFAG etc. are starting in Japan.

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Table 1: List of Medical Accelerators in Japan

Name/ Institution	Main Accel.	Particle	Energy MeV/u	Oper.	Beam Courses				
					Horizon.	Vert.	45°	Rot.Gant.	Research
HIMAC/ NIRS	Synchrotron D~40m ×2	P~Xe	800 (q/m=1/2)	1994 June	2 ^{12}C	2 ^{12}C			5 p~Xe
PTF/NCC (Kashiwa)	Cyclotron D_{magnet}~4m	proton	235	1998 End	1			2	
HARIMAC/ Hyogo	Synchrotron D~30m	proton ^{12}C	230 320	2001 May	1 ^{12}C	1 ^{12}C	1 ^{12}C	2	1
PTF, PMRC/ U.Tsukuba	Synchrotron D~7m	proton	250	2001				2	2
PTF/CC Shizuoka	Synchrotron D~6m	proton	235	2002	1			2	
W-MAST/ Wakasa-Bay	Synchrotron D~10m	proton	200	2002		1			1