Proton Beam Therapy at Tsukuba

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Abstract - KEK-University of Tsukuba proton-beam-therapy facility, its preliminary treatment results and some requirements for a medical facility are described briefly.

1. PARMS

After completion of the 12-GeV proton synchrotron at KEK, the booster synchrotron utilization facility (BSF) was built. It uses 500 MeV pulsed protons for a pulsed neutron source, a pulsed meson source and medical purposes. There is no medical doctor at KEK, so that a branch of the Particle Radiation Medical Science Center of the University of Tsukuba (PARMS) was built there. It has three projects, proton therapy, proton diagnostics and neutron therapy.

Construction of PARMS facility was directed by Professor S. Suwa, the former director general of KEK. It was started in April of 1980 and was completed in March of 1983. Clinical trial of cancer therapy by proton beams was started in July of 1983 but was discontinued at the end of February of 1984, because of a long shutdown of the 12-GeV PS due to tunneling of TRISTAN, a 30-GeV e^+e^- collider. It will resume next June.

As there was no such facility plan in the original design of the 12-GeV PS, it is impossible to extract a 250-MeV proton beam from the booster synchrotron without disturbing stable injection of the 500-MeV beams into the main ring. Therefore, the 500-MeV protons are degraded to about 250 MeV after deflection into the medical proton beam line. The time-average primary proton intensity is at most 2 μA, and it decreases by a factor of several times 10^{-3} by a carbon degrader and a following spectrometer system. A vertical beam line and a horizontal one were made, the former was used for therapy so far whereas the latter for development of the proton diagnostics.

2. Preliminary Proton Therapy

All cases of proton therapy are shown in the Table. Beam intensities used were about 100 rad/min and irradiation time was 3 ∿ 4 minutes for a patient a day. Only primary tumors without distant metastasis have been treated, otherwise the patients might die before evaluating whether the proton beam is good or not. Although the number of patients was limited so far and times after treatments were short, the effect of proton beam is as expected.

3. Requirements for Medical Proton Facility

Including experiences of the preliminary clinical trials, the following conditions should be fulfilled by a proton therapy facility:

a) Proton energy is 200 ∿ 250 MeV. Tumors in the deep-seated organs are the major targets of the protons.

b) Beam intensity is 100 rad/min or more. Irradiation time of 3 to 4 minutes is maximum permissible duration for patients.

c) The maximum field required is generally as large as 15 x 15 cm, and a field of 8 x 8 cm may be sufficient in most cases.

d) Bragg peak should be expanded to 5 cm. A vertical beam is superior because of easy and reproducible fixture of the patient. However, to obtain high peak/plateau ratios, if possible more than 3, an additional horizontal beam is beneficial, and such a beam is being designed at PARMS.

e) There is a labyrinth which ensures quick access of medical doctors to the patient in a treatment room. A concrete shielding door separates the patient from the doctors at PARMS and it takes too much time to go into the treatment room for an accident.

f) A distance between the patient and a nozzle of the proton beam is more than 50 cm. The space is useful to put additional tools for improvement of dose distribution, and the nozzle should be mechanically strong enough to support the tools.

g) Obviously low neutron contamination is favorable. Although neutron dose is usually less than 1% of proton dose in a target, the whole body of the patient is exposed to the neutrons.

h) Normal operation is 8 hours a day and 5 days a week. A shutdown should not last more than a week but this is not the case for high energy accelerators.

i) It seems difficult in Japan to provide proton facilities in the future unless two medical doctors and two nurses can manipulate a machine without accelerator specialists. The medical doctors are primarily concerned about dose distribution and setting up of the patient, so that the accelerator and beam-handling equipment should be dependable and automated.

4. Ongoing Plans

An analyzer magnet and detectors to measure residual energies have been made for proton CT following the horizontal beam line. The horizontal beam will be used for therapy too.

Emphasis will be put on proton therapy of lesions in the deep-seated organs such as lung, liver and rectum.

Neutron cell biology was started. It will be continued further.

The KEK proton complex will sometimes be operated from the pre-injector to the booster synchrotron for BSF. During this mode of operation, protons are no more accelerated to 12 GeV for high energy physics experiments.

Proton beam therapy started at the National Institute for Radiological Science (NIRS) in Chiba-city prior to PARMS trial in some limited extent, because protons are accelerated up to 90 MeV by the cyclotron. Attractive irradiation techniques of spot scanning have been developed.

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Supplementary Note

A thorough survey on medically dedicated particle accelerators was made by Miyakawa Committee of Japan Radiological Society in 1978-1980. It was supported by Science and Technology Agency. The report contains[1]:

1. Study on medical use of particle accelerators.

1.1 Therapy by existing accelerators.

1.2 Diagnostics by existing accelerators.

1.3 Investigations of medical systems with accelerators and their suitable distribution planning.

2. R & D of medically dedicated accelerators and beam-handling equipment.

2.1 Conceptual design of accelerators.

2.2 Development of irradiation and beam-handling equipment.

Following the survey, Inada Committee continued the study and submitted two reports:
Study on developemtn and utilization of medically dedicated particle accelerators for cancer therapy and diagnostics, 1981. Design of Proton Irradiation Facility, 1983 - it was supported by Cancer Study Grants of Ministry of Health and Welfare, and mostly concerned with proton beam facility.

Reference

1. Investigations of medically dedicated particle accelerators (in Japanese), September 1980, Japan Radiological Society.

Table Caption:

List of patients treated by proton beams at PARMS from June 1983 to February 1984. In Improv. + is good, ++ better and +++ best. In Rec. - shows no recurrence.

Organ	Histology	Dose(rad) / (days)	Lesion		Add. treatment	Late injury	Prog.
			Improv.	Rec.			
Skin	Squam. c. ca.	P 8795 / 50	++	−	−	−	Alive (14 ms)
Skin	Bowen disease	P 8800 / 37	++	−	−	−	Alive (14 ms)
Skin	Bowen disease	P 7300 / 23	++	−	−	−	Alive (8 ms)
Tongue	Squam. c. ca.	P 8250 / 47	++	−	−	±	Alive (10 ms)
Tongue	Squam. c. ca.	P 7750 / 46	++	−	−	±	Alive (10 ms)
Buccal mucosa	Squam. c. ca.	P 6350 / 39	++	−	−	−	Alive (10 ms)
Middle ear	Basal c. ca.	P 3700 / 16 E 1980 / 16	++	−	−	−	Alive (7 ms)
Parotis	Adenoca.	P 4700 / 17	++	−	−	−	Alive (8 ms)
Ut. cervix	Squam. c. ca.	P 3850 / 19 Co 3246 / 29	++	−	−	−	Alive (9 ms)
Liver	Hepatocell. ca.	P 3250 / 24 (+ BUdR)	+	−	−	−	Alive (11 ms)
Liver	Hepatocell. ca.	P 2950 / 22 (+ BUdR)	+	−	−	−	Alive (11 ms)
Retroper- itoneal space	Neuroblastoma	P 2550 / 25	+	−	Chemoth.	−	Alive (9 ms)
Brain	Meningioma	P 7250 / 42	++	−	−	−	Alive (8 ms)
Brain	Meningioma	P 6450 / 24	++	−	−	−	Alive (8 ms)
Brain	Astrocytoma	P 5550 / 32 Co 3050 / 28	++	−	−	−	Alive (10 ms)
Brain	Astrocytoma	Co 5060 / 42 P 6400 / 61	+	−	−	−	Alive (8 ms)
Brain	Astrocytoma	P 4700 / 18 Co 2415 / 21	++	+	−	−	Alive (7 ms)
Brain	Glioblastoma mutiforme	Co 3020 / 28 P 5400 / 32	±	+	Operation	−	Alive (10 ms)
Brain	Glioblastoma mutiforme	P 3150 / 24	±	+	Operation	−	Alive (8 ms)
Brain	Glioblastoma mutiforme	Co 1500 / 18 P 5750 / 32	++	+	Radiation	−	Alive (7 ms)
Brain	Glioblastoma mutiforme	Co 4000 / 44 P 4300 / 18	++	+	−	−	Dead (6 ms)
Brain	Glioblastoma mutiforme	P 7650 / 43	++	+	−	−	Dead (7 ms)

P : Proton beam E : Electron beam Co : ^{60}Co γ ray