Performance evaluation of line scanning method in proton therapy

Y Azuma and K Tateoka
Proton Therapy Center, Sapporo Teishinkai Hospital, 3-1, Kita 33-jo Higashi 1-chome, Higashi-ku, Sapporo, Hokkaido, 065-0033, Japan
yuya.azuma.medphys@gmail.com

Abstract. Proton therapy system (Sumitomo Heavy Industries, Ltd.) in Sapporo Teishinkai Hospital consists of a cyclotron, a rotating gantry and a multi-purpose nozzle. This nozzle can irradiate both wobbler beam and line scanning beam. Performance of line scanning was evaluated in this study. The authors investigated for items related to the beam delivery. Dose linearity was investigated with a water phantom and a large parallel plate chamber with several dose rates. For evaluation of irradiation time precision, a solid water phantom and the large parallel plate chamber were used. Furthermore, several spot patterns were measured by Scintillator/CCD camera system for the estimation of beam position. Dose linearity is found with less than 1.8 % error with varying conditions. Regarding irradiation time, error is also confirmed with less than about 1.4 % in this measurement. Beam position accuracy and beam size constancy is also precise enough to be used in clinical use. In conclusion, it is found that results in this study are good enough for treatment.

1. Introduction
Proton Therapy System (Sumitomo Heavy Industries, Ltd.) in Sapporo Teishinkai Hospital consists of a cyclotron, a rotating gantry and a multi-purpose nozzle. The corresponding energy is varying from 70 to 230 MeV. The multi-purpose nozzle can irradiate both wobbler beam and line scanning beam. Line scanning method is one of the scanning methods in particle therapy [1]. Beam is continuously irradiated and the position, intensity and scan speed of beam are controlled in order to achieve planned dose distribution. It is important to check whether if the machine performance of line scanning method is good enough for clinical use. In this study, the performance of line scanning method of this system in our facility is evaluated.

2. Materials and Methods
Items related to the beam delivery were investigated in reference to the prior research [1, 2]. The subjects are following: dose linearity, irradiation time, beam position, and beam size.

2.1. Dose linearity
Dose linearity was investigated by using a water phantom (Blue Phantom2, IBA dosimetry) and a large parallel plate chamber (StingRay, IBA dosimetry) with several dose rates (10 - 132 MU/s ). In this measurement, the dose was measured with several measurement times (0.2 - 40 seconds). Beam energies in this measurement were 70, 110, 150, 190, and 230 MeV. StingRay was placed at 20 mm depth from water surface.

2.2. Irradiation time
For evaluation of irradiation time precision, solid water phantom (Solid Water HE, Gammex) and StingRay were used. Beam irradiation time was controlled by accelerator system in this measurement. The dose was measured with varying irradiation times (0.1 - 10 seconds). Beam energy was fixed to 230 MeV.
2.3. Beam position and size
In order to investigate beam position accuracy and beam size constancy, 1 spot pattern measurements and 13 spots pattern measurements were carried out. Measurements were repeated three times for each measurement item. Detector used in this measurements was a Scintillator/CCD camera system (Lynx, IBA dosimetry) [3]. Beam energies were varying from 70 to 230 MeV with 10 MeV intervals.

Beam position and size were analysed by fitting with 2-dimensional Gaussian function to obtained data. In this analysis, ROOT software [4] was used. Fitting algorithm in this analysis was default algorithm in this software.

3. Results

3.1. Dose linearity
Figure 1 shows the reading of the StingRay as a function of dose rate. The lines are fitted linear function to the measured data. The maximum difference from fitted linear function is 1.3 % for 190 MeV pencil beam. For 150 MeV pencil beam, the maximum difference from fitted linear function is 1.2 %. The maximum difference of all measurements is 1.8 % for 10 MU/s with 230 MeV beam.

![Figure 1. Dose linearity for 150 MeV (a) and 190 MeV (b) beam. Upper panels show the reading of the detector as a function of dose rate. Lower panels show the difference between measurement and fitted linear function.](image)

3.2. Irradiation time
Figure 2 shows the reading in this measurement as a function of dose rate. The maximum difference from the fitted linear function can be seen in the case that irradiation time is 0.1 s. Stability of irradiation time is confirmed with less than about 1.4 % error in this measurement.

![Figure 2. Irradiation time for 150 MeV (a) and 190 MeV (b) beam. Upper panels show the reading of the detector as a function of dose rate. Lower panels show the difference between measurement and fitted linear function.](image)
Figure 2. The upper panel shows the reading of the detector as a function of irradiation time. The lower panels show the difference between measurement and fitted linear function.

3.3. Beam position and size
Figure 3 shows the standard deviation of pencil beams in the 1 spot pattern measurements. In 1 spot pattern measurements, the pencil beam was irradiated to the isocenter. Standard deviations of beam position for any energies are less than approximately 0.15 mm.

Figure 3. The standard deviation of pencil beam position in the 1 spot pattern measurements.

Figure 4 shows beam size (sigma of Gaussian fitted to pencil beam profile) as a function of energy in the 1 spot pattern measurements. Figure 5 shows standard deviation over beam size. Concerning about constancy of the spot size, the fluctuations are less than 0.2 % of 1 sigma of Gaussian.
4. Discussion

These results are comparable to the results of the preceding facility [1, 2]. The impact of beam positional errors on the dose distribution was investigated. Dose distributions were simulated by summing Gaussians [5]. Dose differences between no positional error case and some positional error case were investigated for various sigma of Gaussian, Gaussian interval, and positional errors. Figure 8 shows an example. Figure 8(a) is the case of none of positional error. Figure 8(b) is the case with some of positional error. Positional error affects dose distribution.
Figure 8. Dose distributions by summing Gaussians. The sigma of Gaussian is 6 mm. The interval of Gaussians 5 mm. The dose distribution without positional error (a) is flat. On the other hand, the dose distribution with some positional error (b) becomes uneven.

Figure 9 shows the maximum dose difference as a function of positional error. For the same interval case, the larger the sigma of Gaussian is, the smaller the maximum difference is. For the same sigma case, the wider the interval is, the bigger the maximum difference is. The distribution becomes robust for positional error of beam when the sigma is larger and the interval is narrower. If the interval is set to be 5 mm and the sigma is around 6 mm (typical spot size of beam in water at Bragg peak), the maximum difference is about 1% with 0.5 mm positional error.

It is important to consider the robustness for the beam positional error and set the interval of proton beam line in the treatment planning.

Figure 9. The maximum dose difference as a function of positional error. The open circles are 9 mm sigma and the closed triangles are 6 mm sigma. The black lines and the red lines are 5 mm interval and 8 mm interval, respectively.

5. Conclusion
Performance of line scanning method for proton therapy in our hospital was investigated. These results are comparable to the results of the preceding facility. It is found that results are good enough for treatment.

6. References
[1] Kohno R, Hotta K, Dohmae T, Matsuzaki Y, Nishio T, Akimoto T, Tachikawa T, Asaba T, Inoue J, Ochi T, Yamada M and Miyanaga H 2017 Int. J. Particle. Ther. 3 No. 4 429–38
[2] Gillin M T, Sahoo N, Bues M, Ciangaru G, Sawakuchi G, Poenisch F, Arjomandy B, Martin C,
Titt U, Suzuki K, Smith A R and Zhu X R 2010 Med. Phys. 37 154–63

[3] Farr J B, Dessy F, De Wilde O, Bietzer O and Schönenberg D 2013 Med. Phys. 40 072101- 1–8

[4] Brun R and Rademakers F 1997 Nucl. Inst. & Meth. Phys. Res. A 389 81–6

[5] Das I J and Paganetti H 2015 Principles and Practice of Proton Beam Therapy, AMERICAN ASSOCIATION OF PHYSICISTS IN MEDICINE MEDICAL PHYSICS MONOGRAPH NO.37. (Madison, Wisconsin: Medical Physics Publishing, Inc.)

Acknowledgments
The authors are grateful to Aizawa Hospital (Matsumoto, Japan) for advising us in the commissioning of proton therapy system. Furthermore, we thank to the support from Sumitomo Heavy Industries, Ltd. in the commissioning.