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A Pilot Study of the Scanning Beam Quality Assurance Using Machine Log Files in Proton Beam Therapy

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The machine log files recorded by a scanning control unit in proton beam therapy system have been studied to be used as a quality assurance method of scanning beam deliveries. The accuracy of the data in the log files have been evaluated with a standard calibration beam scan pattern. The proton beam scan pattern has been delivered on a gafchromic film located at the isocenter plane of the proton beam treatment nozzle and found to agree within ±1.0 mm. The machine data accumulated for the scanning beam proton therapy of five different cases have been analyzed using a statistical method to estimate any systematic error in the data. The high-precision scanning beam log files in line scanning proton therapy system have been validated to be used for off-line scanning beam monitoring and thus as a patient-specific quality assurance method. The use of the machine log files for patient-specific quality assurance would simplify the quality assurance procedure with accurate scanning beam data.

Keywords: Proton beam therapy, Scanning beam, Quality assurance, Machine log file

Introduction

The particle beam therapy including proton beam therapy is a promising treatment modality in radiation oncology. Compared to conventional photon-based radiation therapy, particle beam therapy can achieve a relatively low entrance dose and a negligible exit dose distribution in radiation therapy treatment in general.[1)] Based on these superior dosimetric properties of the particle beam, an escalated or focused radiation can be irradiated on cancer cells while minimizing unwanted damage on healthy tissues in nearby. The evolution of the particle beam therapy can be seen not only in the rapidly increasing population of particle therapy facilities world wide,[2,3)] but also in the wide adaptation of the new scanning beam technology in replacement of the scattering beam technology. In scanning beam particle therapy, highly conformal dose distribution can be accomplished by virtue of its capability of beam intensity modulation. With a highly modulated particle therapy treatment plan, the monitoring and control of the position of scanning particle beam in a treatment nozzle becomes an indispensable part of therapeutic particle beam delivery.[4,5)] In this study, I report on the accuracy of the beam position monitor installed on a scanning beam nozzle and the feasibility of using its machine log files for patient-specific quality assurance.

Materials and Methods

I have used the dedicated scanning nozzle at Samsung Proton Therapy Center[6] and the beam position monitor device in the treatment nozzle. The proton beam therapy system at Samsung Proton Therapy Center is provided by Sumitomo Heavy Industries Ltd. and the technical details of the dedicated scanning nozzle can be found elsewhere.[7,8] The scanning control unit (SCU) controls and monitors proton beam scan speed and beam position. SCU records magnet currents, beam positions, dose counters, and beam-on status in every 60 micro-second and transfers the records to Treatment Control System Console (TCSC) at the end of the beam delivery of a given treatment field. At the same time, the plan information (in machine parameter format) used by SCU is also transferred to TCSC.

In this study, I have used this plan information and recorded log files stored in TCSC. As the raw data saved in the log files are machine parameters, the data had to be processed with nozzle specific calibration specifications. The processed data have been used for the analysis of

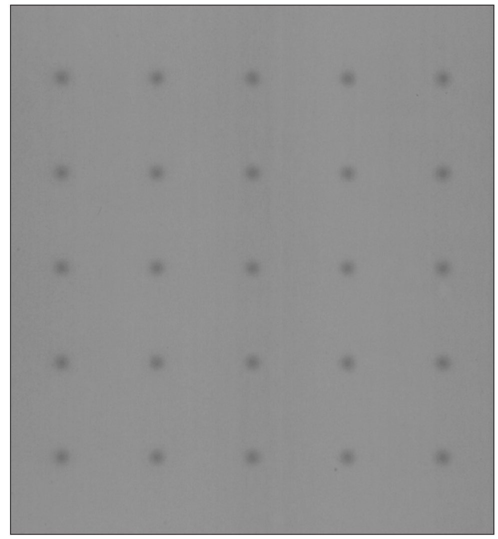

Fig. 1. A scanned EBT3 film irradiated with the standard scan pattern composed of 5x5 points (230 MeV).

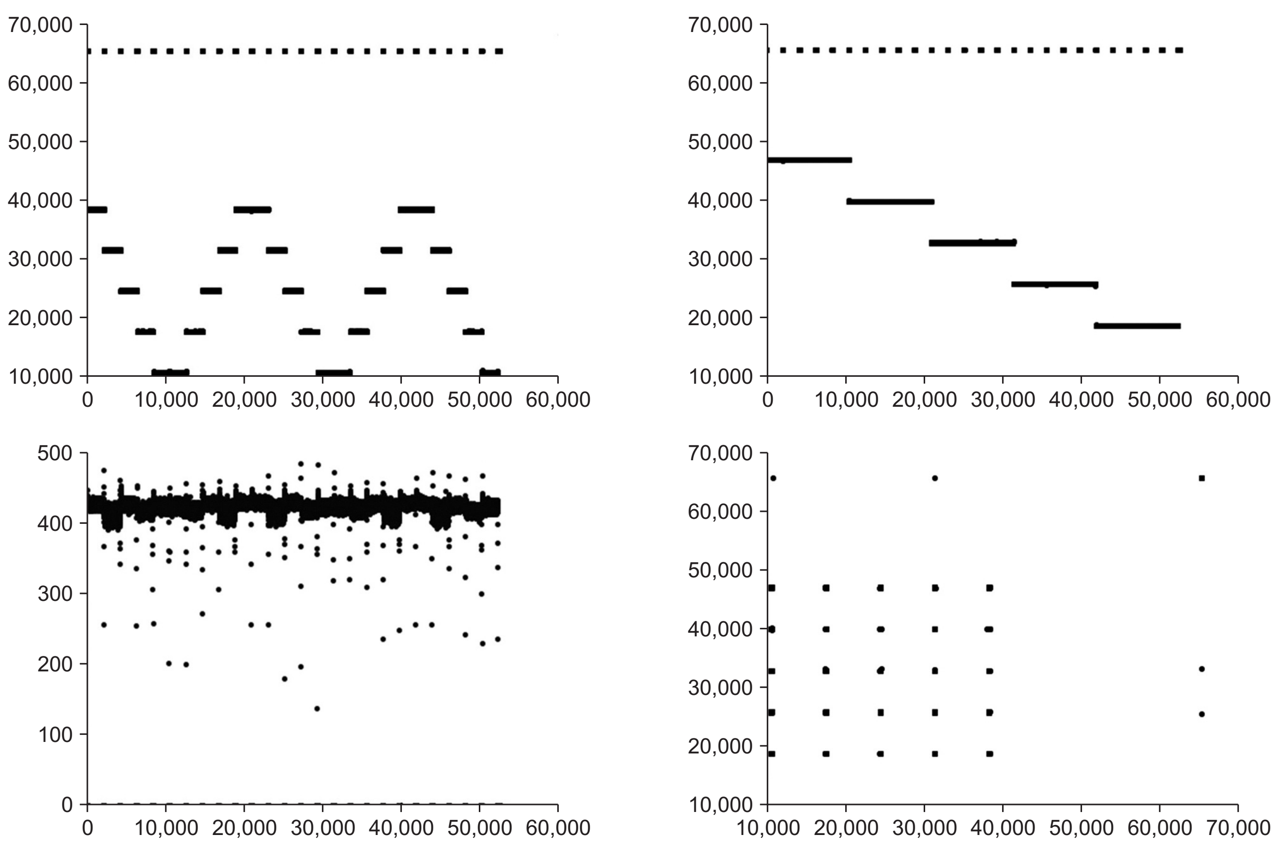

Fig. 2. An example of scanning beam information recorded in the scanning control unit (Top left: x-position in time, top right: y-position in time, bottom left: monitor count in time, bottom right: x-position vs. y-position. Raw data without pedestal/noise reduction).

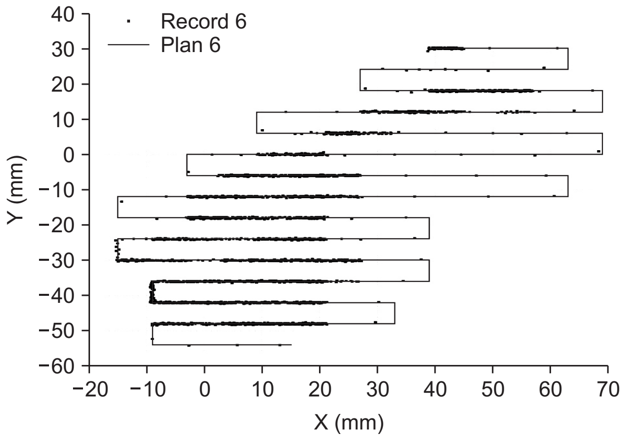

Fig. 3. A scanning beam information recorded in the scanning control unit (one sample layer of a patient beam delivery plan).

machine log files.

First, I have validated the accuracy of beam positions recorded in the beam position monitor (BPM). This is in principle a crosscheck of the BPM calibration. A gafchromic film (GAFCHROMIC EBT3, International Specialty Products, Wayne, NJ)[9] has been located at the isocenter position orthogonal to the vertical beam direction. The standard calibration plan with 5×5 spots positioned at 5 cm distance grid has been prepared and delivered on the gafchromic film as shown in Fig. 1. The film has been scanned using EPSON Expression 11000XL scanner and the actual beam position has been read in. The scanned spot profiles have been fitted with a single Gaussian function to extract the accurate center position of each spot. In principle, the spot profiles should be described by Moliere's multiple scattering theory.[10] But as the main discrepancy from a Gaussian model lies in tail regions, a single Gaussian model would be satisfactory to extract the centroids of spot profiles. The analyzed spot positions have been compared with the planned positions to verify the calibration of BPM. The recorded data from the BPM log file of the standard calibration plan are shown in Fig. 2 (raw data without noise reduction).

After verifying the calibration of the BPM, I have analyzed the recorded machine log files of pre-treatment quality assurance beam delivery of selected five fields (5 cases) treated with the dedicated scanning nozzle. One of the sample log file is shown in Fig. 3 (Case 1, Layer# 1: the blue dots denote the measured beam position in every 10 events and the red lines denote the planned beam path). The accumulated data have been analyzed using a statistical analysis to estimate any systematic error in the data.

Table 1. The summary of pre-treatment QA log file analysis. The "ds" stands for the displacement of the recorded position from the planned position. For a given field (case), the entire energy layers (number of layers) have been analyzed.

Cases	Number of layers	Average of ds [mm]	Standard deviation of ds [mm]
Case 1	15	0.09	0.09
Case 2	17	0.11	0.10
Case 3	23	0.15	0.07
Case 4	18	0.10	0.11
Case 5	11	0.06	0.14

Results

In the verification of BPM accuracy, the resulting beam positions have been compared with the panned values. The positions found to agree within ± 1.0 mm that combines additional contributions from setup uncertainties. In addition, I have checked the machine log file recorded in the control unit of BPM and the deviations of the beam position from the plan were found to be less than 0.2 mm.

Based on the validation of BPM calibration, the recorded machine log files of pre-treatment QA have been analyzed as shown in Table 1. The BPM log files of the selected five cases with various energy layers have been analyzed statistically. I did not find any significant systematic uncertainty in the data and none of the beam position was deviated more than 0.2 mm from the planned value. This can be expected as the tolerance of BPM for beam position is 0.2 mm.

Discussion

In normal operation of the proton beam therapy system, BPM monitors the beam position in the scanning nozzle, and at the same time uses the position information as inputs for the position feedback system and the safety interlock system. The position feed-back system controls the scanning magnets to keep the beam position on the planned beam path and if the beam position is off by a distance greater than the tolerance, the safety interlock system will stop the beam.[5)] As BPM has such an important role in proton beam therapy, it has a high precision and accuracy by design. Furthermore, the stability of the system must be guaranteed.

The log files of a given treatment field include all the energy layers of the field. As the energy modulates the depth of the proton beam, number of energy layers in a given field would imply a measurement in the same number of depths. One of the distinguishing characteristics of line scanning beam from spot scanning beam is that the monitor unit (MU) of the beam is given for a certain length of line segment not for a certain spot of the beam. Furthermore, the MU of a line segment must be decided by the combination of scan speed and dose rate at the moment of delivery. In this study, an absolute dose of each line segment cannot be determined from the BPM log file information. However, as the scan speed has been implicitly included in the position information, the accuracy of the absolute dose could be inferred from the result of positional accuracy. In addition, if an additional information from the Irradiation Control Unit (ICU) would be correlated to the BPM data, the absolute dose could be reconstructed. This possibility will be investigated in a future study.

I have cross-checked the accuracy of BPM in scanning beam delivery and checked out any possible systematic uncertainty of the system. Overall, I have verified that the use machine log file for patient-specific quality assurance is feasible and robust. Nevertheless, as this study has performed at gantry angle zero, there is still a possibility of propagations of gantry angle dependency of the nozzle properties. In general, any gantry angle dependency must be corrected at the early stage of commissioning and validation of the nozzles. Although there was no significant gantry angle dependency found at Samsung PTC, the log file analysis can be a useful measure for a future investigation on gantry angle dependency.

Conclusion

In conclusion, the high precision scanning beam log files in line scanning proton therapy system have been validated to be used for a patient-specific quality assurance method. The use of the machine log files in scanning beam related quality assurance will simplify the quality assurance procedure while keeping high precision.

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Conflicts of Interest

The authors have nothing to disclose.

Availability of Data and Materials

All relevant data are within the paper and its Supporting Information files.

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