Patient-specific beam delivery times in a synchrotron-based proton pencil beam scanning (PBS) system

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Purpose: A proton beam therapy system is based on the Bragg peak effect: each proton interacts with the patient mainly along a stright pathway and delivers most of its energy on a specific location, whose depth depends on the initial energy of the incoming proton. This effect allows a much more accurate dose administration on tumors, avoiding healthy tissues. A treatment is delivered by a series of different bunches (spots) of protons with the same initial energy sent along straight lines (pencil beam). These series of spots can be distributed (modifying the initial energy and so the range) covering the tumor volume. The protontherapy system of the Clnica Universidad de Navarra consists on a synchrotron that can prepare a large cloud of protons (spill) that can be accelerated to different energies and redirected to the patient using a rotating gantry that can place these protons in any position inside the patient using magnets.

The purpose of this work is to characterize the beam delivery times for a group of 12 individual patients in a Hitachi synchrotron-based proton PBS system. Our goal is to derive a model that can achieve accurate predictions on the temporal sequences for individual plans. A secondary goal is to retrieve patient-specific temporal sequences to achieve time resolved dose calculations (blood circulation, breathing).

Materials and Method: The treatment plan establishes global requirements for the dose delivery that can be modified on the actual treatment delivery. Our system [1] is a ProBeat-CR (Hitachi) synchrotron that produces beams with 98 different energies, between 70.2 and 228.7 MeV. Values of relevant parameters such as dose rate (MU/s), spot, switch energy and spill change times, are specified by the manufacturer.

The irradiation times are obtained using a digital signal from the PBS console that indicates when the beam extraction is on. The signal is recorded using an oscilloscope with a 100MHz filter and a 31kHz sampling rate. The whole treatment plan is recorded, from the start of the first field to the end of the last field. The retrieved data are compared to the treatment plan, to verify the field sequence, and the timing for the different energy levels, spots and spills. The MU rate is reconstructed from the measured spot time compared to the intended treatment time. The number of spots per spill and energy levels per spill are estimated.

Results: A preliminary analysis in a group of 12 patients reveals that all the parameters are within the manufacturer specifications. Using these data we can derive patient-specific temporal sequences to achieve time resolved dose calculations (blood circulation, breathing). We have analyzed 31 Beams, 95 Energy values (with more than 1500 realizations), 650 Spills and more than 185000 spots.

Conclusions: We verified, on a daily and monthly basis using regular QA procedures, that the system delivered dose complied with the planned dose. Dose and MU delivery accuracy is ensured by the nozzle monitor chambers. Using the data recovered form the Console and the Hitachi Control Room we can record the specific delivery sequence for individual patients. Different signals can be analyzed (for instance, Beam On and Monitor Chamber) that provide data from different time scales. A model has been built to deal with the prediction of delivery times. Using this data we can model the time-resolved dose received by individual patients using on-purpose single energy layer dose distributions computed from Monte Carlo, and can be used to achieve accurate dose determination on circulating blood or breathing cycles.

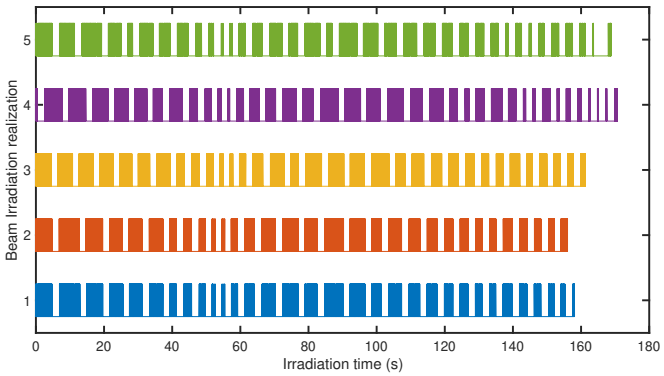

Fig. 1. Different realizations of the same field. Each band in a single realization corresponds to a different spill. The total irradiation time differs between realizations.

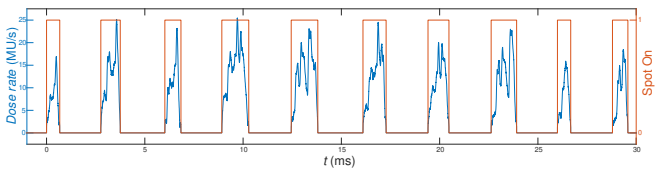

Fig. 2. Real dose rate delivered inside each spot.

[1] JD Azcona, B Aguilar, A Perales, R Polo, D Zucca, L Irazola, A Viñals, P Cabello, JM Delgado, D Pedrero, R Bermdez, R Fayos-Solá, C Huesa-Berral, J Burguete, Rad. Phys. and Chem. **204**, 110708 (2023)

[2] Link to the group webpage:
`https://me-qr.com/T938BIDS`