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Clustered Pencil Beam Scanning (CPBS) Delivery Technique for Potential FLASH Proton Treatment

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INTRODUCTION

FLASH beams have demonstrated normal tissue sparing effects while maintaining equivalent tumor control *in vivo*. Several published planning studies [1,2] indicated the achievement of very high spot dose rate with high cyclotron output current and increased beam line efficiencies. However, as we demonstrated in this study, although very high cyclotron current can deliver very high spot dose rate for the spot location, the time taken to deliver the entire energy layer-spot structure makes it impossible to reach the effective FLASH dose rate (>40Gy/s) at a point of interest. Since the local dose is mostly affected by surrounding beam spots, we present a Clustered Pencil Beam Scanning (CPBS) delivery technique that focuses on maximizing dose rate for selected regions of interest.

AIM

In a prostate treatment, reduction of rectal toxicity is one of the main objectives where FLASH's normal tissue sparing effect could prove to be beneficial. The aim of this study is to investigate the efficacy of proton therapy unit (Proteus® Plus, IBA) in achieving FLASH condition in selected region of interest (e.g. rectum) by modifying the plan-beamlet-delivery structure.

METHOD

In CPBS technique, beam spots that pass through the rectum were regrouped from the original beam arrangement (Fig 1. a) and delivered as separate clusters (Fig 1. b). The machine log files were obtained and extrapolated to high cyclotron current of 1000nA to simulate FLASH delivery conditions. The spot-to-spot dose contribution to the hot spot in rectum was simulated with Monte-Carlo dose calculation engine Open-MCSqaure (MCS) to derive the dose-time structure and effective dose rate. The energy switching time and magnet spot positioning time were ignored in the calculation.

RESULTS

A. Spot dose contributions

For a prostate patient plan with two later beams, an in-house software was developed to extract the beam spots passing through OAR contour (e.g. rectum).

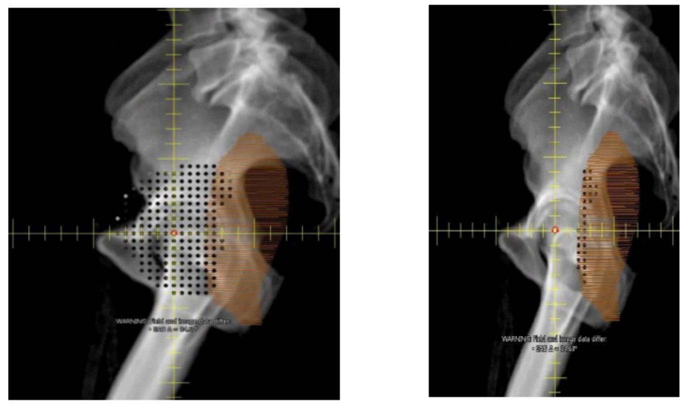

Fig 1. a) All spots in one energy layer ; b) Regrouped spots that are in rectum

Computation of the per-spot-dose in the clustered PBS delivery were performed on MCS. 1e7 proton particles were simulated with beam parameters obtained from in-house proton facility (Proteus® Plus, IBA). See Fig. 2.

B. Machine log file delivery

The machine log file was acquired and analyzed for both fields. The spot delivery of the cyclotron current and spot duration is related to the plan spot MU. When the cyclotron current was extrapolated higher, the spot duration decreased correspondingly.

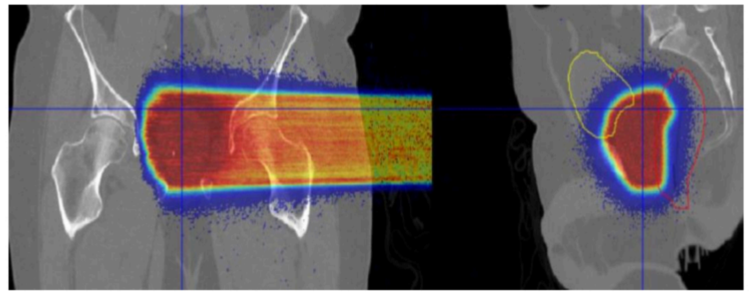

Fig 2. a) Dose distribution for LT LAT beam.

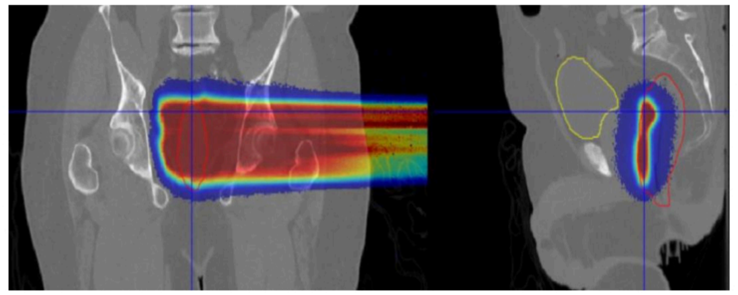

Fig 2. b) Dose distribution from only spots through rectum.

C. Dose-time structure analysis

Of the two lateral beams for proton prostate treatment, the number of spots passing through rectum were 208 and 212 out of LT LAT 1755 and RT LAT 1771 spots. Using log file derived pencil beam spot duration 256.88 ms*nA/MU and cyclotron current of 1000 nA, the individual spot contributes dose at a rate of 125.4+/-348.3 Gy/s. The effective dose rate to the rectum was 62.2 and 72.3 Gy/s. Without using the clustered PBS delivery, the effective dose rate was 13.0 Gy/s for both fields.

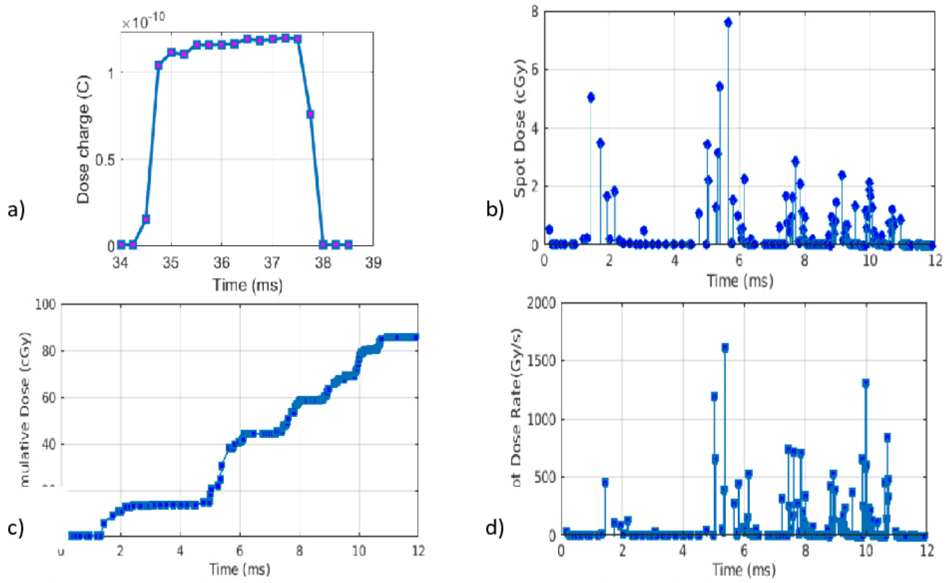

Fig 3. a) Dose collected in machine log file of a 0.5MU beam spot; b) the spot-to-spot dose-time structure delivered to a hot spot in rectum at 1000 nA cyclotron output current; c) cumulative dose-time structure to the point; d) the dose rate from each spot to the hot spot vs. time.

CONCLUSIONS

The dose-time structure was constructed on spot-to-spot dose contribution to the point of interest. The dose and dose rate delivered to the point of interest (POI) vary by spot. We demonstrated localized fast delivery in rectum with CPBS technique to take advantage of FLASH tissue sparing effect. Demonstrations of this technique on multiple patients are in progress. The energy switching and spot positioning time in current proton PBS system can add >100ms latency in the delivery and thus achieving FLASH dose rate is not yet clinically feasible. However, this study shows a proof of concept of achieving FLASH dose rate with modified beamlet delivery structure which can be further investigated to propose a new paradigm of PBS plan optimization towards FLASH therapy.

REFERENCES

[1] van de Water S, Safai S, Schippers JM, Weber DC, Lomax AJ. Towards FLASH proton therapy: the impact of treatment planning and machine characteristics on achievable dose rates. Acta Oncol (Madr). 2019;58(10):1463-1469. doi:10.1080/0284186X.2019.1627416

[2] van Marlen P, Dahele M, Folkerts M, Abel E, Slotman BJ, Verbakel WFAR. Bringing FLASH to the Clinic: Treatment Planning Considerations for Ultrahigh Dose-Rate Proton Beams. Int J Radiat Oncol Biol Phys. 2020;106(3):621-629. doi:10.1016/j.ijrobp.2019.11.011

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