Investigation of Machine Learning-Based Output Predictions and Clinical Impact of Adaptive Aperture in Proton Therapy

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ABSTRACT: The clinical use of proton therapy for cancer treatment has been growing in the last decade partly due to the availability of technology and encouraging clinical results. The proton therapy has been evolved from the passively scattered technique to the pencil beam scanning (PBS). This evolution brought new beam delivery machines, beam collimation systems, and new optimization methods. Proton therapy delivery is moving away from bulk footprint with three or four proton treatment rooms to more compact single room systems such as Mevion S250i with Hyperscan.

Even though new proton therapy facilities are equipped with the PBS, there are a number of proton facilities around the world which use either double scattering or uniform scanning beam delivery techniques. Due to the complexity of the uniform scanning beam delivery, no commercial treatment planning system is available to calculate output factor and monitor units. Our first goal is to utilize machine and deep learning techniques to build a model which can be used for the calculation of output factor and monitor units for the uniform scanning proton therapy (USPT).

In the PBS delivery technique, a monoenergetic proton pencil beam is scanned laterally across the target volume spot-by-spot and dose in the beam direction is delivered from multiple monoenergetic beams as specified in the patient’s treatment plan. Beam properties such as penumbra are affected by the spot size of the pencil beam. Larger spot sizes will lead to larger penumbra, which in turn may lead to higher dose to critical structures located laterally to the target. Our second goal is to quantitatively access penumbra sharpening and scattering by adaptive aperture under various beam conditions and its impact on clinical cases for the Mevion S250i compact PBS proton therapy system.
A PBS system can deliver highly conformal dose to the target while sparing healthy tissue, but the technique has been more sensitive to dose degradation due to uncertainties in treatment planning and delivery. The Mevion S250i with Hyperscan equipped with adaptive aperture has two different beam collimation techniques: static aperture (SA) and dynamic aperture (DA). SA (single aperture) collimates the outermost contour of the target and DA (multi-layer aperture) collimates each energy layer of the proton beam. Our third goal is to evaluate dosimetric performance of SA and DA for different disease sites.

The spot size and lateral penumbra are larger for Mevion S250i as compared to the other proton therapy systems mainly due to an energy modulation system in the nozzle. The treatment of the lung tumor is complicated by the respiratory motion along with heterogeneities present in the anatomical region. Our fourth goal of this dissertation is to determine the range of motion and evaluate mitigation techniques of interplay effect in thoracic moving targets to which Mevion's PBS system can optimally deliver dose without degradation due to the system's unique characteristics of larger spot size, penumbra, and utilization of adaptive aperture.

In conclusion, utilization of the machine and deep learning techniques for output prediction in USPT has been established. In addition, characterization of adaptive aperture's penumbra sharpening and its clinical impact along with larger spot size for the Mevion S250i PBS proton therapy system have been evaluated.