Minimizing Energy Changes in Particle Therapy using Voronoi Partitions

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Purpose: To develop a treatment planning algorithm that can reduce the number of energy changes for scanning beam particle therapy.

Materials and Methods:

Changing beam energies in particle therapy requires a considerable amount of time; therefore, a high quality treatment plan with minimum number of energy changes is desired. In this research, we explore using Voronoi diagram to achieve this. A Voronoi diagram of a set of objects (**Figure 1**) partitions a metric space into cells with one cell per object, such that each cell contains the region closest to its object.

Our new planning algorithm mainly uses the following key steps: (1) Calculating a Voronoi partition of the target for the given beam angles, such that each Voronoi cell contains the portions of tumor “closest” to its beam. Here by “closest”, we mean to be able to hit a target from a beam angle with minimum penetration of normal tissues and no penetration of critical structures. (2) During optimization, each beam only treats the tumor region within its Voronoi cell. The final dose distribution is optimized using a combination of randomization and non-negative least squares algorithm.

The new planning algorithm has been implemented in C. The proton and antiproton kernels used for treatment planning were generated using FLUKA [1], and contains energy ranges from 75MeV to 175MeV at 1MeV step.

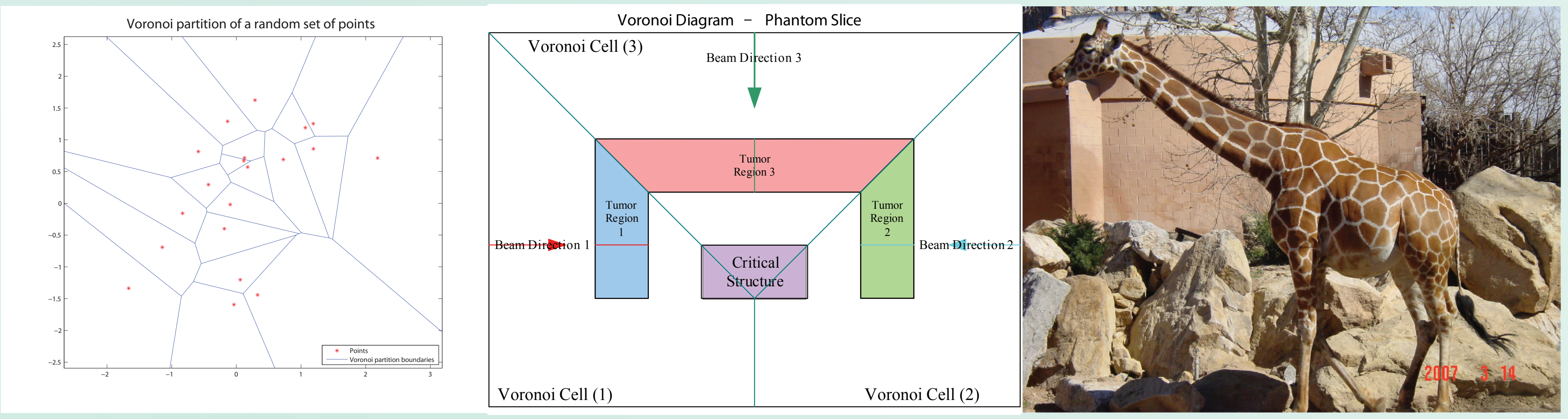

Figure 1. Voronoi Partitions. Left: Voronoi cells of a set of points in a 2D space. Center: Voronoi cells of a 2D slice of a C-shaped tumor phantom. Right: Voronoi cells in nature.

Results:

The new algorithm has been applied to a 3D C-shaped tumor phantom for proton and anti-proton therapies (**Figure 2**). Compared to not calculating Voronoi partition, we can reduce the number of energy changes by 70%, while maintaining similar treatment qualities.

The algorithm has been tested on a real Brain Case provided by our collaborators at the German Cancer Research Center (DKFZ) (**Figure 3**) using two different beam directions.

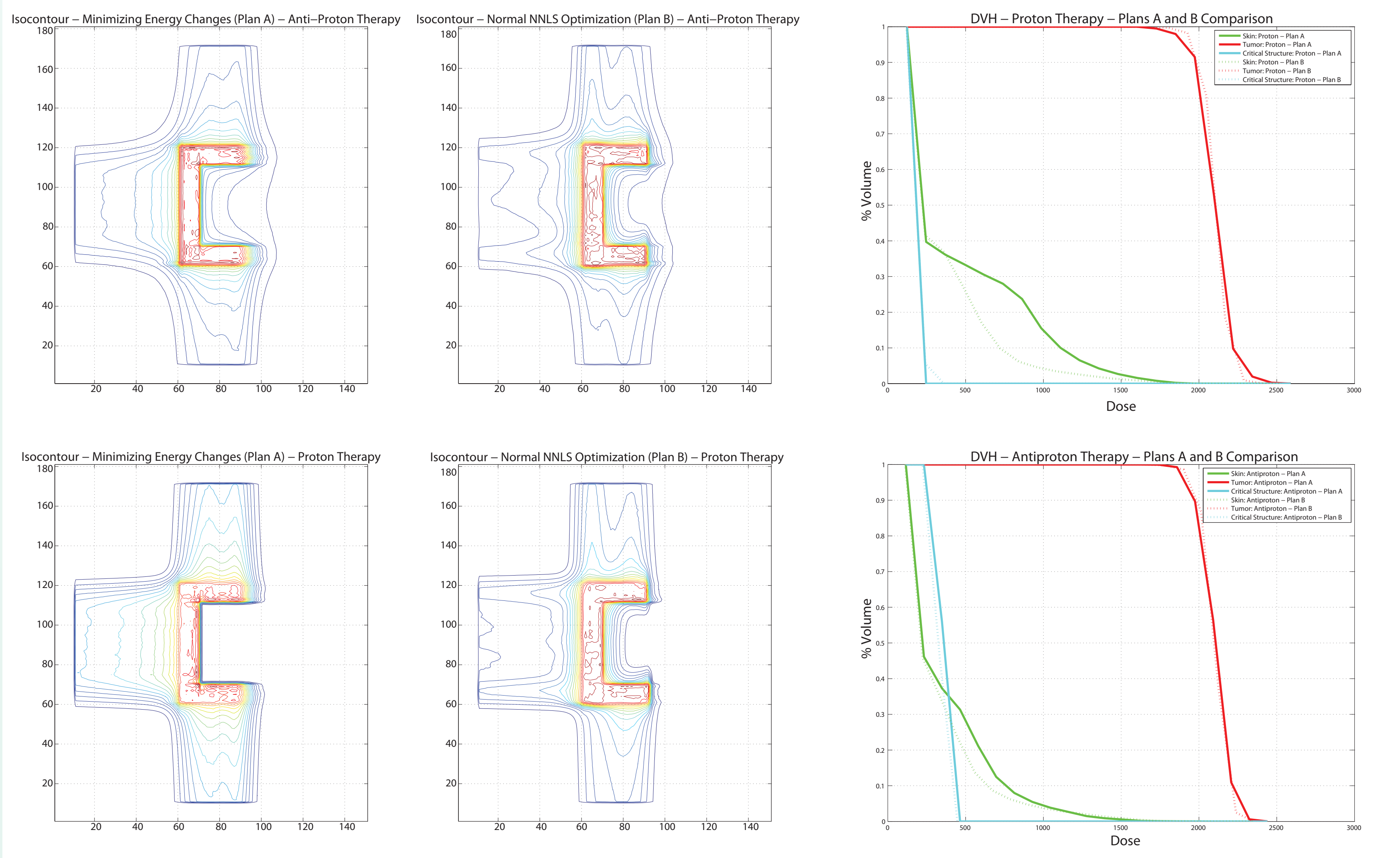

Figure 2. Proton and Anti-proton treatment plans for a C-shaped tumor phantom. Top and Bottom Rows: Comparison Normal treatment planning vs. Voronoi partitioning.

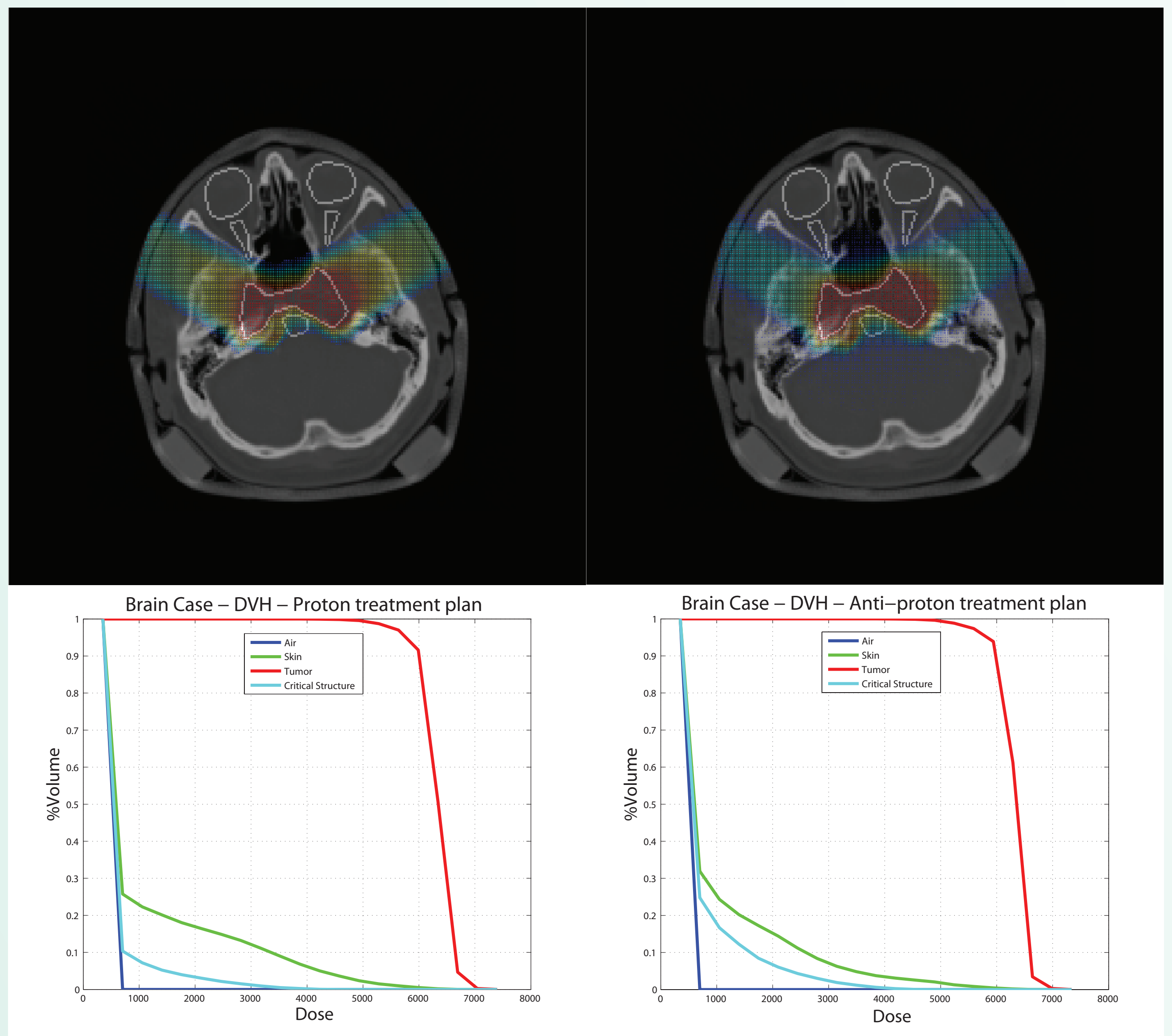

Figure 3. Brain Case using Voronoi Partitions. Left Column: Proton treatment planning. Right Column: Anti-proton treatment planning.

Conclusion:

A particle therapy planning algorithm that can reduce energy changes by 70% has been developed. As part of our ongoing research, we are testing the algorithm for different anatomical considering heterogeneous tissues.

Acknowledments:

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References:

[1] Fasso A., Ferrari A., Ranft J., and Sala P.R.,"FLUKA: a multi-particle transport code", CERN-2005-10 (2005), INFN/TC_05/11, SLAC-R-773.