Intensity Modulated Proton Therapy: influence of starting conditions on the optimized dose distribution

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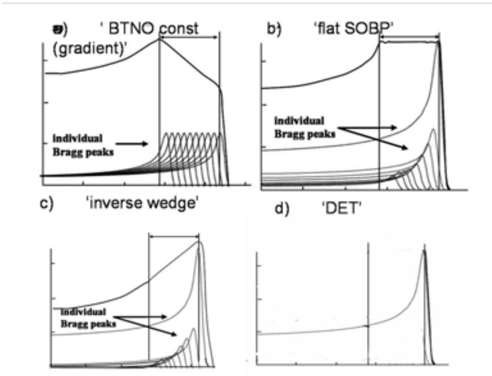
Introduction

Intensity modulated proton therapy (IMPT), which is the proton equivalent of IMRT with photons, consists of the simultaneous optimization of all 3D distributed Bragg peaks from all field directions. Due to the large number of parameters available to the optimization engine and the relatively basic goals of radiotherapy planning (homogeneous dose throughout the target while adhering dose constraints to the surrounding organs at risk (OAR)), it has been previously found for IMRT (but it is even more valid for protons), that the problem of the optimization engine is highly degenerate: that is, there are many fluence profiles that meet the planning aim. Thus the result on the optimization will generally depend on the starting conditions. We want here to demonstrate how manipulation of the starting conditions can be used to 'steer' the optimization to results that can be somewhat defined by the user (e.g. providing a safer plan to be delivered).

Material and Methods

We generate 4 different starting conditions by changing the initial weights of the 3D distributed Bragg peaks (see Figure): **a**) beamlets initially set to the same weight (**constant beamlets**), which leads to an initial dose distribution with a gradient from the proximal to the distal part of the target; pre-weighted set of Bragg peaks, in which the weights are reduced from distal to proximal such as **b**) to deliver a flat 'Spread-Out-Bragg-Peak'(**SOBP**) and **c**) to deliver a gradient from the distal to proximal aspect of the target (**inverse wedge**); **d**) Bragg peaks deposited only on the distal edge of the target volume (Distal Edge Tracking, **DET**) . For 2 patients (a prostate and a spinal-axis chondrosarcoma case) we have calculated different 5-fields IMPT plans, with the same planning dose-volume constraints, by using these starting conditions as input for the optimization engine. We then performed a robustness analysis by introducing a systematic error of 3% in proton range. The plans were compared by means of visual and quantitative DVH analysis for targets and OARs.



Results

The selection of **constant beamlets weights (a)**, as input for the IMPT algorithm, results in a plan very sensitive to range errors (this effect is related to how single fields dose distributions patch "steeply" together within the target). The choice of **DET (d)** is restricted by the dimension of the target volume: for big volumes (i.e. prostate) probably 5 fields are too few to well cover the target. For small volumes and in case of steep dose gradient within the target (e.g. to spare the spine within the target volume) then **DET (d)** and **inverse wedge (c)** provide plans with a good target coverage and very robust to range errors.
The selection of an initially **SOBP (b)** provides a very robust plan in case of target volume not comprehending OARs (e.g. prostate tumor).

Conclusion

Mathematical based optimization techniques are also possible for exploiting IMPT degeneracy, however we believe that 'starting condition based optimization' as proposed here can provide a useful tool for making the optimization of IMPT plans more transparent and understandable to the planner.