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MULTIPLE FIELD OPTIMISATION FOR PROTON THERAPY

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Intensity modulation in radiation treatment planning for photons has great potential for tailoring dose distributions in particularly challenging cases. Here we describe some preliminary work into the application of such methods to proton therapy.

INTRODUCTION

For many years, proton therapy has led the way in delivering precise, conformal radiation therapy and varying degrees of intensity modulation are, in fact, inherent in its delivery. As an example, for the delivery of proton therapy on the PSI gantry, which came into operation this year, we routinely deliver many hundreds of individually weighted Bragg peaks [1]. However, the calculation of Bragg peak intensities is presently performed for single field directions and such that the dose to the target volume is homogenous [2]. Recently, it has been shown that for photon therapy, the delivery of a number of angularly spaced, individually inhomogenous fields can produce a homogenous dose across the target volume and reduce the dose to neighbouring organs at risk when these fields are combined [3]. Inspired by this work, we have developed methods for the simultaneous optimisation of Bragg peaks from multiple field directions and have investigated the effects of varying peak intensities in either two or three dimensions.

METHODS

For both 2-d and 3-d optimisations, our starting point is a set of Bragg peaks distributed in space such that the target volume is completely covered. These peaks may come from a variety of different field directions and are spaced regularly in water equivalent space for any one field direction. Initially, weights are assigned using a pre-determined weighting scheme in which all peaks lying at a given water equivalent depth are assigned the same weight. The weight is varied in depth in such a way as to produce a flat distribution. For 2d optimisation, this relative weighting in depth remains unchanged throughout the optimisation procedure, with only the weights of the beams in the plane orthogonal to the field direction being modified. In essence, this is the proton equivalent of the approach taken for photon intensity modulation described in [3]. In contrast, for the 3d approach, a free optimisation of all individual Bragg peaks is performed. The calculation of dose for both cases is performed using pre-defined dose kernels, calculated in water. These take into account both the effects of multiple Coulomb scattering in the water and the initial phase space of the beam. Inhomogeneities within the patient are modelled from the patients CT and are taken into consideration by transforming each Bragg peak and dose grid point into water equivalent space.
An iterative least-squares optimisation algorithm has been used for both cases [2], which is based on an algorithm described by Pedroni for dynamic pion therapy [4] and is similar to the more recently reported technique of Bortfeld [3]. The cost function for this can be defined as

$$\chi^2 = \sum_{i=1}^{N} g_i^2 \left[P_i - D_i\right]^2 \qquad 1$$

where P_i is the prescribed dose to dose grid point i, D_i is its calculated dose, g_i is a weighting factor for the grid point and there are N such grid points. From this, the weight for an arbitrary pencil beam, j, after the k+1th iteration can be calculated from

$$w_{j,k+1} = w_{j,k} + \frac{\sum_{i=1}^{N} g_i d_{i,j} \left[P_i - D_{i,k}\right] f_{i,j,k}}{\sum_{i=1}^{N} g_i^2 d_{i,j}^2} \qquad 2$$

where the damping factor, $f_{i,j,k}$, has the form

$$f_{i,j,k} = \frac{w_{j,k} d_{i,j}}{D_{i,k}} \qquad 3$$

and $d_{i,j}$ is the un-weighted dose contribution of spot j to dose grid point i. Interestingly, in contrast to the technique described by Bortfeld, we have found that the damping factor $f_{i,j}$ is necessary to ensure convergence.

RESULTS AND FURTHER WORK

We have applied both 2-d and 3-d optimisation to a number of different treatment geometries applied to a nasopharyngeal tumour and examples of the resulting individual fields and combined dose distributions are shown in figures 1 and 2. The initial results look very promising and we aim to develop the methods further to model more accurately the PSI delivery system and to investigate the feasability of delivering such treatments in practice.

REFERENCES

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