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Beam-Weights Optimization by Using a Correlated-Piling-Method Algorithm

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INTRODUCTION

A new and simple optimization algorithm is proposed to optimize the beam-weights of proton beams in order to form an SOBP for proton cancer therapy. In the field of radiotherapy, it is often necessary to optimize certain physical quantities associated with prescribed dose distributions.[1,2] The physical quantities could be either beam weights of a number of discrete irradiation or geometrical/ electrical parameters of certain beam modulation devices. The existing algorithms applicable to optimize these quantities essentially fall into two categories, namely a serial algorithm and a parallel algorithm. A serial algorithm is characterized by a one-by-one adjustment of the beam weights followed by an evaluation step. The extreme case of this algorithm is evaluation of all possible combinations of the weights. A parallel algorithm is represented by the so-called SIRT (simultaneous image reconstruction technique) method[2] where change of more than one beam weight according to a specific criteria is performed at each step of the optimization process. A serial algorithm is usually of low efficiency but possesses the potential of finding a real optimum of given problems. In this article, a new serial algorithm which explicitly takes into account the correlation of different beam weights is described. It is shown that this method is quite effective when it is applied to the design of a ridge filter used in proton therapy.

METHOD

Let's assume di(z), i=1, 2,... N represent some constituent distributions and D(z) stands for the superimposed distribution. If the weight of each constituent distribution is wi, i=1, 2,... N, then we have:

$$D(z) = \sum_{i=1}^{N} wi \times di(z)$$

where z can be depth in water in the case of one dimensional dose distribution or more complicated variable like a vector. The weight vector {wi, i=1, 2,... N} is usually determined by using certain optimization method so that the superimposed distribution D(z) approaches a prescribed objective distribution as close as possible. The new method presented here simulates

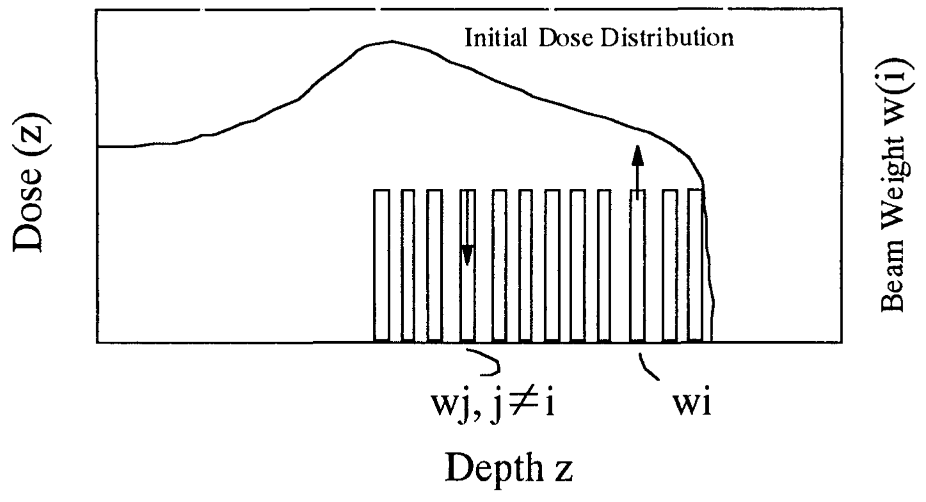

Fig.1 Explanation of the correlated searching algorithm.

what one would have done by adjusting the beam weights manually starting from a set of initial values to improve gradually the dose distribution. The most important feature of this new method is the procedure of adjusting the beam weights for optimization. Figure 1 shows the principle of operation schematically. For each step of searching new value of beam weight, the beam weight to be adjusted is first raised (lowered) by a certain amount, if the distribution is improved according to some pre-determined criteria, then this change of beam weight is retained. Otherwise, a correlated search is performed by decreasing (increasing) serially all the other beam weights with certain amount. This procedure is performed for all constituent distributions and is iterated for a given number of times. Furthermore, in order to save calculation times, the pitch of beam weight adjustment can be set at first quite large and gradually made smaller for later iterations to a predetermined minimum. The objective function can be of any type or form. In the case of an SOBP formation, it can be taken as the flatness of the superimposed dose distribution in a desired region. The objective function can also be set as the least square root of the difference between D(z) and a prescribed objective distribution.

RESULTS

Fig.2 gives such an example, where an SOBP in a water phantom is formed with 28 proton beams with 5mm pitch in range. Fig.2-(a) shows the original proton dose distribution (a Bragg peak). Fig.2-(b) is a plot of the optimized beam weights obtained by using the new algorithm. Fig.2-(c) is the SOBP dose distribution achieved as the result of optimization. The achieved flatness of dose distribution reaches ±0.93%. The initial change-step of beam weight during optimization is 30 and the final step size is 1. The initial beam weights of all the elementary

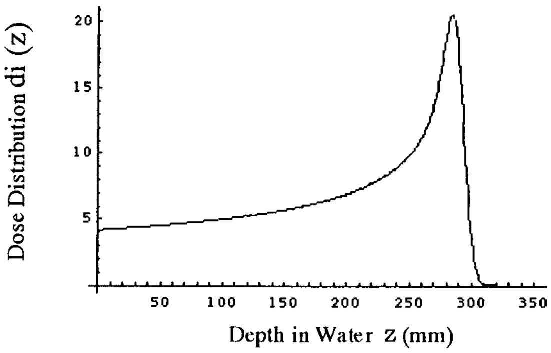

Fig.2-(a) The elementary dose distribution of a proton beam used to form the SOBP described in the text.

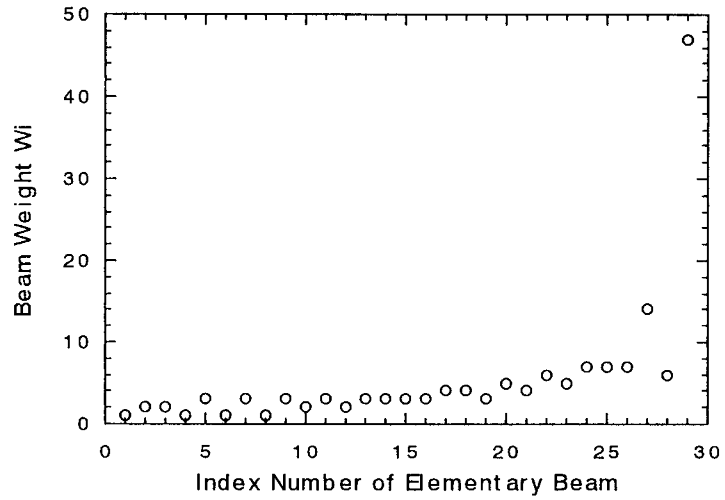

Fig.2-(b) Beam weights Wi of each elementary beam obtained by the optimization method described in the text.

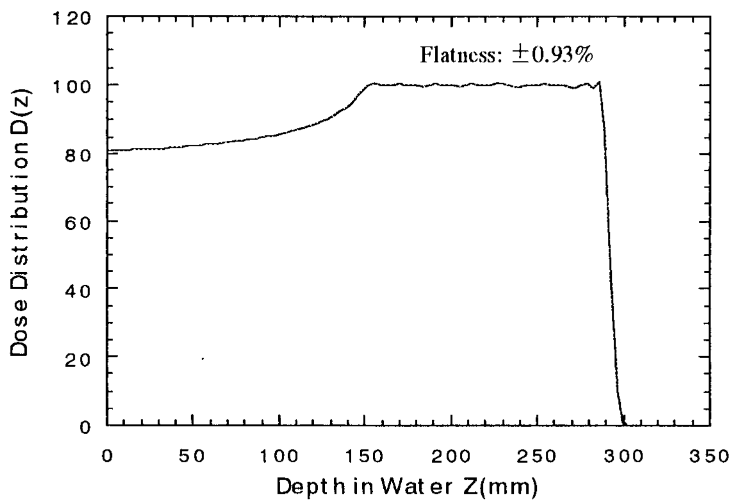

Fig.2-(c) SOBP dose distribution obtained by the optimization method described in the text.

beams are set to 60. The maximum weight is restricted between 0 and 60 during the optimization. The calculation time is a few seconds with a Fortran code running on a Ultra Sparc workstation.

DISCUSSION

The proposed simple optimization algorithm takes into account the correlation between weights of different elementary beams. This feature is important if one is dealing with elementary (constituent) dose distributions like a Bragg curve which has large spatial non-locality. In particular, the long tail region of a Bragg curve might overlap in space with other Bragg curves lying at shallower depth as shown in Fig.2-(a). Therefore, it is natural to consider correlation between different weights when adjusting the beam weight of each constituent beam. It should be pointed out that this method is not only effective for optimization of beam weights as shown in the previous example, but also effective for optimization of other quantities like the maximum beam energy of each constituent beam. Furthermore, the speed of convergence can be improved further by introducing a lookup table which records the extent of correlation between pairs of constituent beams at the initial stage of the optimization loop. Consequently, the optimization code will know where to find the correlation at a later iteration stage avoiding unnecessary searches. This may be essential when one needs to optimize a huge number of quantities. This new method may also be used in combination with other existing optimization tools as a final refining tool.

CONCLUSION

A new optimization method, the correlated-piling-method (CPM) algorithm is presented. The effectiveness of this new method is shown by successful application to the formation of an SOBP dose distribution with 28 single Bragg dose curves in a water phantom. The very satisfactory homogeneity of the dose distribution obtained and the fast speed of convergence suggests that the proposed optimization method can be used in a variety of applications.

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