A study on active scanning path optimization for intensity modulated proton therapy based on improved adaptive genetic algorithm

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INTRODUCTION

For IMPT plan delivery, the scanning spots on each energy slice is irradiated by deflecting the proton pencil beam through the magnets in the order of left-to-right and top-to-bottom, which is called "zigzag" scanning path. But the problem is that, after the inverse optimization process in IMPT planning, the intensity weights of some preset scanning spots are optimized to zero. The zigzag scanning path will still pass by the zero-weight spot position which is already not the optimal path. Unnecessary scanning path will increase the delivery time for patient treatment, and may cause extra spill dose along the path. The scanning path for IMPT plan need further optimization to handle the local zero-weight spots.

AIM

To study the scanning path reduction performance for intensity modulated proton therapy based on a novel improved adaptive genetic algorithm.

METHOD

The treatment planning system (TPS) used in this study is called DeepPlan which is developed for the self-developed proton therapy facilities. The scanning path optimization process of the three-dimensional IMPT planning is logically similar to the travelling salesman problem (TSP) which is a classic Non-deterministic Polynomial problem. The scanning path optimization is achieved through minimizing the total length equation in each energy slice. The improved adaptive genetic algorithm (IAGA) was chosen to solving the scanning path optimization problem in this study. The patient cases adopted were two AAPM TG-119 cases and two corresponding clinical cases. The dose prescriptions were recommended by the AAPM TG-119 report. The scanning path lengths for the four cases using IMPT technique were compared before and after scanning path optimization.

RESULTS

For the two TG-119 cases, the results showed that the IAGA optimized scanning path lengths decreased by 32.39% and 14.36% compared to the initial zigzag scanning path. Similar to the TG-119 cases, the initial scanning path lengths decreased by 25.37% and 31.51% after IAGA optimization for the clinical cases. The IAGA optimized scanning path was able to avoid the "hole" area, and significantly reduced the connected paths between the isolated "islands" area, as shown in the figure.

The IAGA based scanning path module was developed and tested on the AAPM TG-119 cases and clinical cases, as shown in Figure 1. For the two TG-119 cases, the example scanning paths on the corresponding energy slices were randomly selected and exported, as shown in Figure 2. The results showed that, compared to the initial zigzag scanning path, the IAGA optimized scanning path decreased by 32.39% and 14.36%, respectively. The IAGA optimized scanning path avoided the zero-weighted area effectively, therefore reduced the scanning path length on the energy slice. Similar to the TG-119 cases, the example scanning paths for the clinical cases were demonstrated in Figure 3, with the initial scanning path length decreased by 25.37% and 31.51% after IAGA optimization, respectively. The IAGA optimized scanning path was able to avoid the zero-weighted hole area, and further significantly reduced the connected paths between the isolated nonzero-weighted area. Compared to the initial zigzag scanning path, the total scanning path lengths of the four cases for all energy slices of each IMPT plan decreased by 27.17%, 18.72%, 25.36%, and 32.59%, respectively, after IAGA based scanning path optimization, as shown in Table 1.

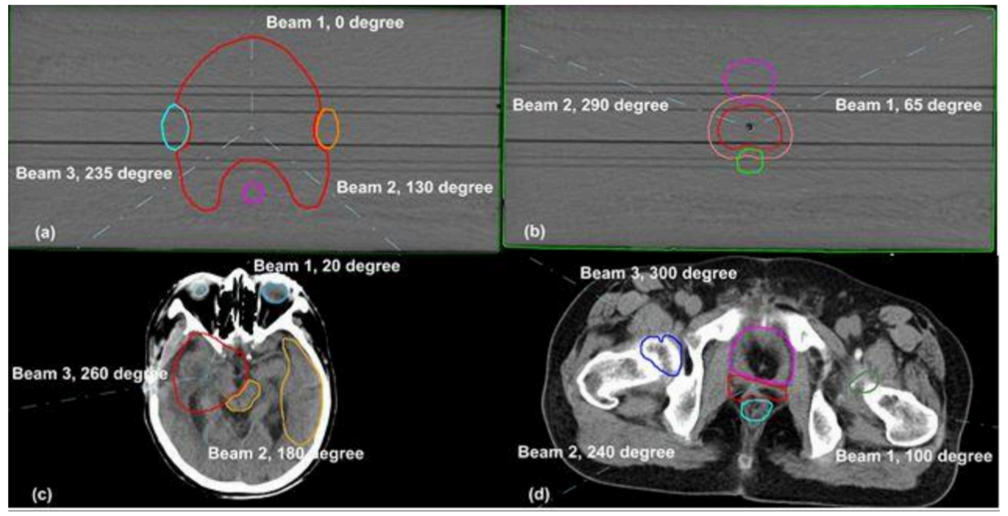

Figure 1. Beam settings for the AAPM TG-119 cases and clinical cases. (a) AAPM TG-119 H&N case. (b) AAPM TG-119 prostate case. (c) clinical N&N case. (d) clinical prostate case.

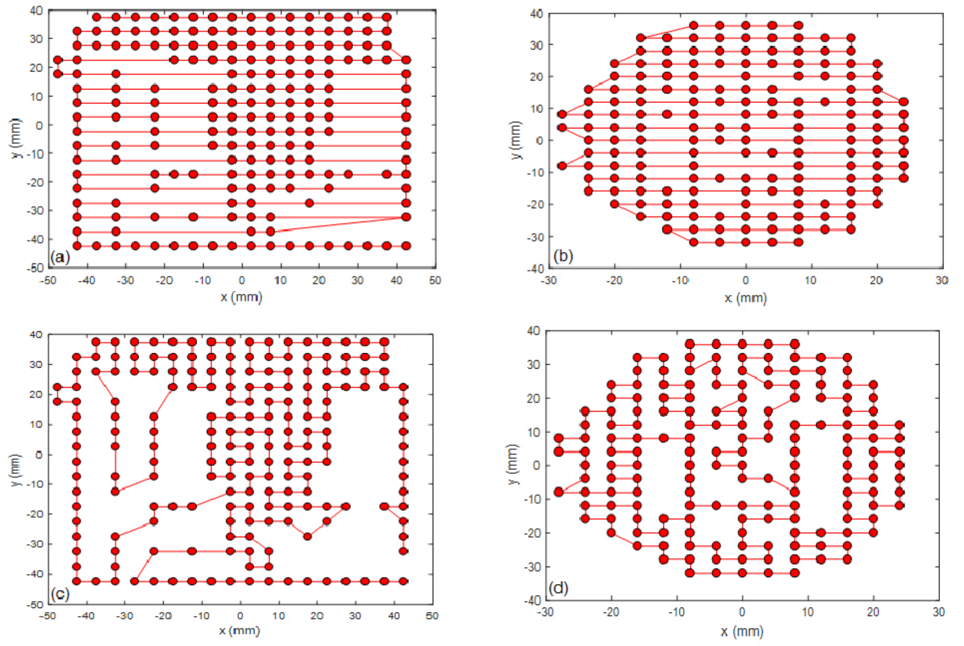

Figure 2. The comparison of beam scanning paths before and after scanning path optimization on the randomly selected energy slice for each AAPM TG-119 case. (a) the initial scanning path on one energy slice of AAPM TG-119 H&N IMPT plan with 193 delivery spots and 1512.40 mm scanning length. (b) the initial scanning path on one energy slice of AAPM TG-119 prostate IMPT plan with 169 delivery spots and 798.19 mm scanning length. (c) the IAGA optimized scanning path on one energy slice of AAPM TG-119 H&N IMPT plan with 1022.49 mm scanning length and 32.39% scanning length reduction. (d) the IAGA optimized scanning path on one energy slice of AAPM TG-119 prostate IMPT plan with 683.59 mm scanning length and 14.36% scanning length reduction.

Table 1. The statistics of total scanning length of each IMPT plan before and after IAGA scanning path optimization for AAPM TG-119 and clinical cases

Test case	Initial scanning length (mm)	IAGA optimized scanning length (mm)	Scanning length reduction rate (%)
AAPM H&N	30072.38	21901.71	27.17
AAPM prostate	17783.08	14454.09	18.72
Clinical H&N	74051.54	55272.07	25.36
Clinical prostate	71081.85	47660.38	32.95

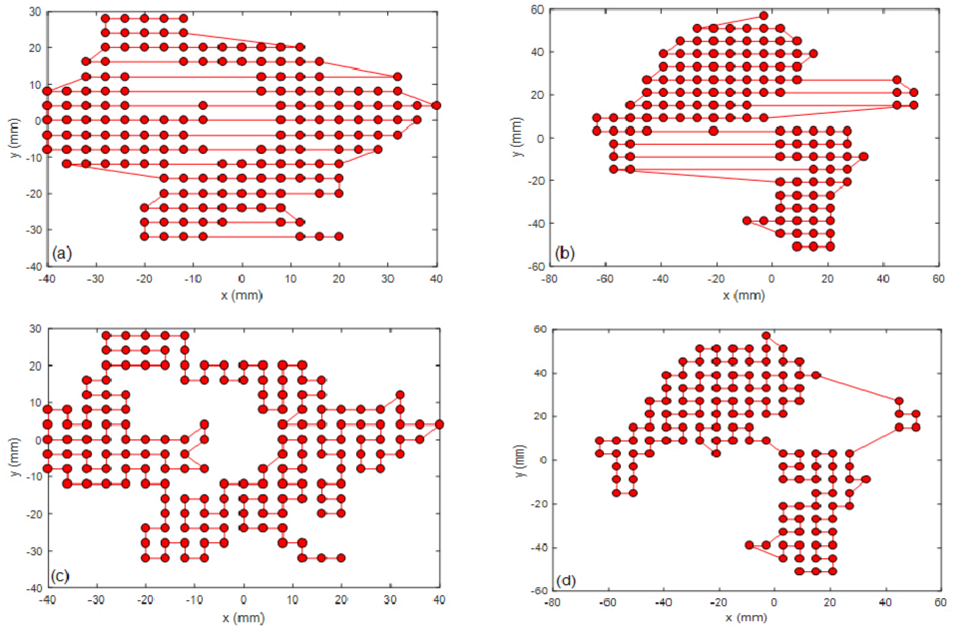

Figure 3. The comparison of beam scanning paths before and after scanning path optimization on the randomly selected energy slice for each clinical case. (a) the initial scanning path on one energy slice of clinical H&N IMPT plan with 168 delivery spots and 910.68 mm scanning length. (b) the initial scanning path on one energy slice of clinical prostate IMPT plan with 133 delivery spots and 1246.72 mm scanning length. (c) the IAGA optimized scanning path on one energy slice of clinical H&N IMPT plan with 679.60 mm scanning length and 25.37% scanning length reduction. (d) the IAGA optimized scanning path on one energy slice of clinical prostate IMPT plan with 853.86 mm scanning length and 31.51% scanning length reduction.

CONCLUSIONS

In this study, an IMPT scanning path optimization method was developed based on the improved adaptive genetic algorithm, and was integrated into a self-developed TPS. The AAPM TG-119 cases' and clinical cases' test results show that the scanning path optimization module for IMPT can reduce the length of the scanning path thus reducing the IMPT plan delivery time. The intensity modulated heavy-ion therapy scanning path optimization method will be investigated in the future.

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