

A study of quality control method for IMRT planning based on prior knowledge and novel measures derived from both OVHs and DVHs

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Abstract. Intensity-Modulated Radiation Therapy (IMRT) mathematically forms a large-scale optimization problem. The development of an IMRT plan is computationally expensive resulting in time-consuming, inefficient, and difficult to develop high-quality IMRT plans. By combining prior knowledge with proposed novel measures derived from both Overlap Volume Histogram (OVH) descriptors and Dose Volume Histograms (DVHs), a novel quality control method for IMRT planning is proposed to assure the high quality of IMRT plan. Clinical approved nasopharyngeal IMRT plans were employed for the experiments, where the reference plan is firstly retrieved from IMRT plan database for each query case by using measures derived from both OVH descriptors and DVHs. Then the DVHs of the reference plan are served as additional goals for the IMRT plan re-optimization. The experimental results show that the proposed method can effectively pick out those IMRT plans, whose quality could be improved substantially (i.e. the doses of their Clinical Targets Volume (CTV) could be effectively increased) and the dose of their Organs at Risk (OARs) could be reduced after the IMRT plan has being re-optimized. In conclusion, the proposed methods can effectively guarantee the high quality of the IMRT planning.

Keywords: Intensity-modulated radiation therapy (IMRT), quality control, overlap volume histogram (OVH), prior knowledge

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1. Introduction

Compared with the conventional radiotherapy technique, Intensity-Modulated Radiation Therapy (IMRT) has several advantages. It has become widely used as a radiotherapy technique in clinical practice [1–11]. Though, the efficiency of IMRT is dependent on large-scale optimization problems, which may be time consuming and inefficient. Therefore, it is difficult to develop high-quality IMRT plans. The process of assuring the high quality of the IMRT plan and improving the effectiveness of radiotherapy is of important value for clinical applications.

Currently, the quality control of IMRT treatment planning mainly depends on the clinical experience of physicians. But the optimization method, based on the knowledge of IMRT planning, could control the quality of IMRT plans by effectively using the association between geometric distribution and dose distribution included in prior high quality IMRT plans, and it can ensure the high quality of new IMRT plans.

In recent years, knowledge of radiation treatment planning has attracted more and more attention in the field of radiotherapy [3–14]. For IMRT, Wu in [3] proposed a retrieval method based on geometric information of radiotherapy knowledge for quality control of an IMRT plan; Simari proposed a method to predict dose distribution of new cases of an IMRT plan by applying prior IMRT knowledge in [4]. Zhu et al. proposed a quality evaluation tool for prostate adaptive radiation therapy (ART) treatment based on machine learning algorithms in [5]; Zhou proposed a radiation treatment planning system based on radiation treatment plan retrieval, which can effectively improve the quality of the treatment plan and the effectiveness of IMRT planning in [6]. Fredriksson proposed a method that automatically improves upon previous treatment plans by optimization under reference dose constraints in [7]. Chanyavanich et al. demonstrated the feasibility of using a knowledge base of prior treatment plans to generate new prostate IMRT plans in [8]. However, the process of developing more effective measures for IMRT plan retrieval is still an open question. In this paper, two new measures derived from OVHs and DVHs are proposed, where the DVHs of retrieved reference IMRT plan are used for the quality control of query case's IMRT planning. The proposed methods can effectively improve the quality of the IMRT plan and reduce the radiation damage to patients.

2. Quality control method based on OVHs and DVHs

The geometric relationships between organs at risk (OARs) and target could be described by an OVH descriptor, for a given tumor T and OAR O . OVH of the OAR could be expressed as the following equation [3,9]:

$$\text{OVH}(O, T)(t) = \frac{|\{p \in O | d(p, T) \leq t\}|}{|O|} \quad (1)$$

Where $|O|$ is the volume of OAR O and $|\{p \in O | d(p, T) \leq t\}|$ represents the partial volume of OAR whose distance to T is less than t . According to the definition, OVH descriptor could be calculated by expanding or contracting target contour equidistantly.

One optimization aim to IMRT planning is to form a conformal dose distribution. The optimization procedure of IMRT planning could be considered as a procedure of gradually reaching conformal dose

distribution. The closer to target, the OAR will receive the higher the dose. As shown in Figure 1(a), there is a target PTV and two OARs *A* and *B*, and OAR *A* is far from PTV, while OAR *B* is close to PTV. In this case, the dose distribution is supposed to be highly conformal. The isodose lines and the equidistant scaling lines will be two sets of concentric circles centering on PTV. The OVH and DVH distribution curves of OAR *A* and *B* are illustrated in Figures 1(b) and 1(c), respectively. The OVH and DVH curves of OAR *A*, whose distance is a bit far from PTV, should be located under that of organ *B*.

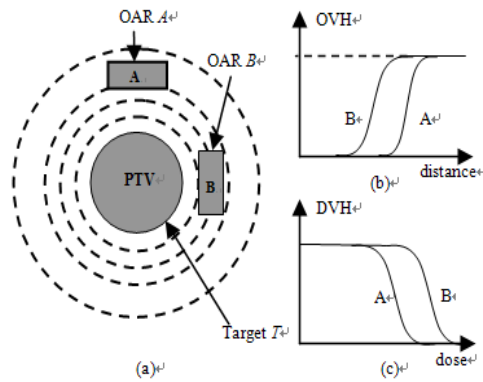


Fig. 1. Quality control schematic diagram. (a) position relationship of PTV, OAR A and OAR B. (b) OVH curves of OAR A and B. (c) DVH curves of OAR A and B.

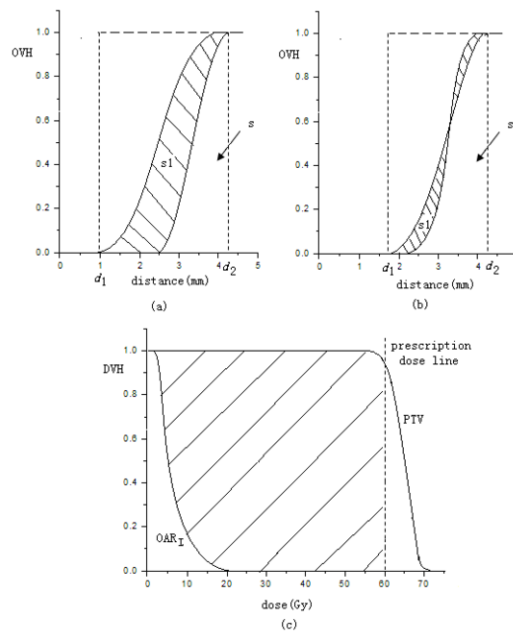


Fig. 2. Illustration of measures for IMRT plan retrieval.

Considering the relationship between OVHs and DVHs, OVHs could be used to control the quality of IMRT planning. Based on the construction of a typical and high quality IMRT planning database, the quality control process of IMRT planning mainly includes the searching of reference plan and the optimization of an IMRT plan for a query case. The steps can be described as follows:

1. Extract the contour of PTV and OARs for the query case. Then calculate each OVH for every OAR by expanding or contracting target contour equidistantly. Finally, choose the OAR, which is nearest to the target as the OAR of interest (OAR), and whose OVH descriptor is denoted as OVH;
2. Search the IMRT plan database and pick out the IMRT plan with the highest quality, whose OVH_I curve is similar to that of the query case, and has a dose distribution with the highest quality. The retrieved plan is denoted as reference plan P_r, where the specific satisfied requirements are as follows:
 - For the OVH_I of the reference plan and that of the query case, s_1 and s should satisfy $s_1/s < 10\%$, where s_1 , d_1 , d_2 represents the area between two OVH curves, the minimum starting point of the two OVH curves, and the ending point where the two OVH curves reach value 1, respectively. Here s is the rectangular area surrounded by starting point and ending point, as shown in Figures 2(a) and 2(b), respectively, where two OVH curves may be separated or overlapped.
 - For the IMRT plans satisfying the above requirement, the plan with a maximum area surrounded by DVH_I of OAR_I, DVH of PTV and prescription dose line (see the shaded area in Figure 2(c)) is selected as the reference plan P_r.
3. Both the DVHs of OAR_I and PTV in reference plan P_r are served as additional objectives for the IMRT plan optimization for the query case.

3. The experimental results

3.1. Reference plan searching

To verify the feasibility of the quality control method for IMRT planning based on OVHs, a crossover retrieval experiment was performed with 28 clinical nasopharyngeal carcinoma IMRT plans. Each plan was compared with the other plans. If a reference plan could be found, both the DVH_I of OAR_I and DVH of PTV of the reference plan are served as additional objectives for the IMRT plan re-optimization of the query case. The retrieval results of the 28 clinical IMRT plans show that 21 plans could find a reference plan while seven plans could not find a reference plan, for which one plan does not meet with the above retrieval requirement I, and the other 6 plans do not meet the above retrieval requirement II.

3.2. IMRT plan re-optimization

All the 28 plans were divided into 2 groups. One group is the named experimental group, which includes those IMRT plans with reference plans. The other group is named control group, which includes those IMRT plans without a reference plan. To evaluate the feasibility of the proposed quality control method, all the 28 IMRT plans were re-optimized and the optimization results were analyzed. The comparison of V₃₅ Gy and D₅₀ of the left parotid gland between before and after re-optimization are given in Figures 3-6, respectively.

From above results, it can be seen that the received dose of the parotid gland in all cases decreases after re-optimization of the IMRT plan. Also, the received dose of the parotid gland in the cases of experimental group decreased significantly. D_{50} decreased by an average of 3.4 Gy and all V_{35} Gy decreased to be less than 0.3. However, for those cases in the control group, D_{50} only decreased by an average of 1.96 Gy.

For most cases in the experimental groups, the received dose of the right parotid gland, spinal cord and brain stem also decreased in some degree after IMRT plan re-optimization. D_{50} of the right parotid gland dropped by an average of 2.13 Gy, D_{50} of the spinal cord dropped by an average of 0.51 Gy, and D_{50} of the brain stem dropped by an average of 0.01 Gy.

The comparison of DVHs between the before and after re-optimization process of the three OARs for case 2, which includes the right parotid gland, spinal cord and brain stem, are given in Figure 7. Black solid lines and the red dotted lines represent the DVHs of PTV, the left parotid gland, right parotid gland, spinal cord and brain stem before and after re-optimization, respectively. From the Figure 7, we can see that the performance of DVH curves of the three OARs mentioned above improves a lot after IMRT plan re-optimization.

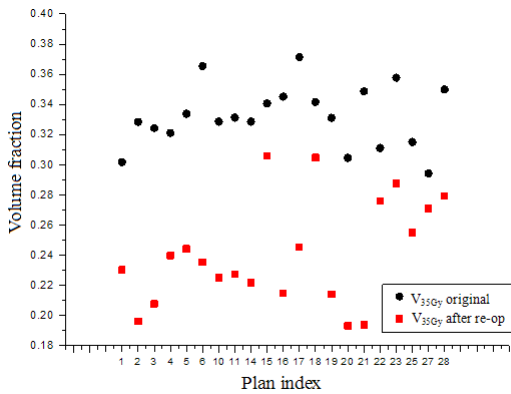


Fig. 3. The comparison of V_{35} Gy of left parotid gland for plans with reference plan.

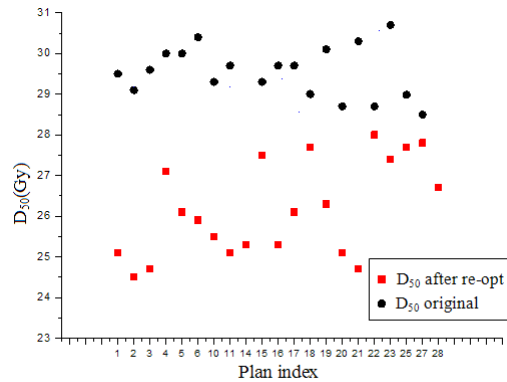


Fig. 4. The comparison of D_{50} of left parotid gland for plans with reference plan.

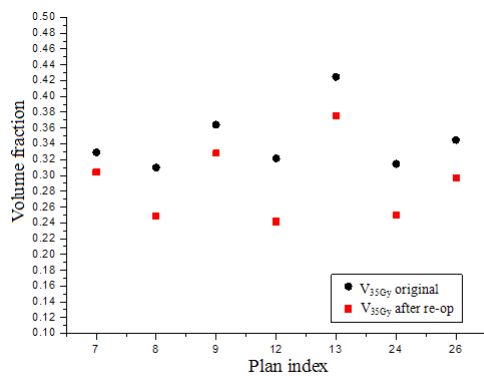


Fig. 5. The comparison of V_{35} Gy of left parotid gland for plans without reference plan.

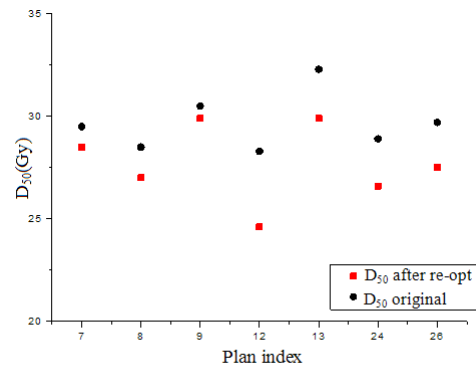


Fig. 6. The comparison of D_{50} of left parotid gland for plans without reference plan.

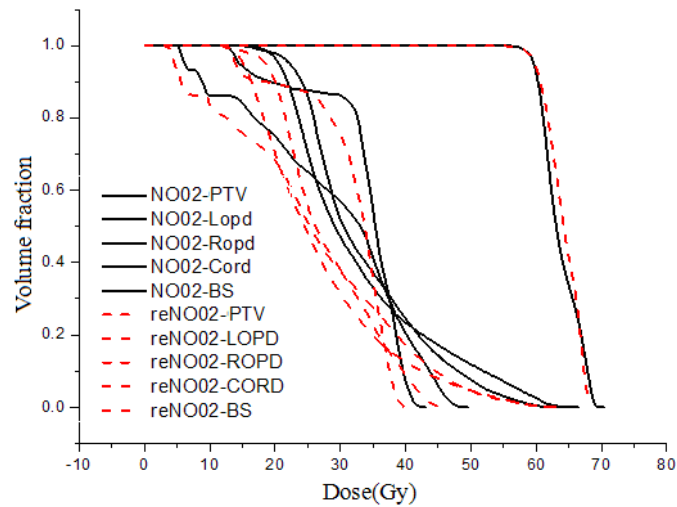


Fig. 7. The Comparison of DVHs for case No. 2.

The experimental results show that the proposed quality control method could effectively pick out those IMRT plans whose quality could be improved measurably. After undergoing re-optimization, the average dose of PTV could be increased while that of OARs decreased. Thus it could be concluded that the quality control method based on the OVH descriptor and prior knowledge can effectively guarantee the high quality of the IMRT plan for new clinical cases and reduce the radiation damage to the patient.

4. Discussion

Based on prior knowledge and proposed novel measures derived from OVHs and DVHs, an IMRT plan quality control method is proposed in this paper. The method employs the expert knowledge of the prior high quality IMRT plan and uses innovative measures derived from OVHs and DVHs to retrieve the reference plan. Then the DVHs of PTV and OAR_i of the reference plan are served as the additional objective for IMRT plan optimization of new clinical cases. Compared with the current methods, the proposed novel measures make it more reliable to find out the best match case, which can effectively guarantee the high quality of the new IMRT plan. However, it should be noted that the performance of the proposed method depends highly on the quality of the IMRT plan database and retrieval efficiency. In the future, studies will be carried out on incorporating other geometric descriptors, such as projection moments and 3D moments, to improve the performance of IMRT plan retrieval. Also, we will perform comparative research of curative effect on pre-evaluation among different radiotherapy technologies (such as static IMRT and volume IMRT) by using anatomical structures of the patient and prior knowledge to facilitate the selection of the best radiotherapy technology for individual tumor treatment.

Acknowledgement

This work was financially supported by Nanjing University of Aeronautics and Astronautics.

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