

Computer-assisted determination of the usable beam arrangement from similar treatment plans in stereotactic body radiotherapy

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Abstract The goal of this study was to develop a computer-assisted treatment planning system for the stereotactic body radiation therapy (SBRT) based on several similar cases in a radiation treatment planning (RTP) database. Similar cases were automatically selected based on image features from the radiation treatment planning point of view. The beam angles were determined by registration of similar cases to an objective case with respect to lung regions using a linear registration technique. We applied the proposed method to 10 test cases by using an RTP database of 81 cases with lung cancer. As a result, the proposed method suggested usable beam arrangements, which might be equivalent to manual beam arrangements of cases in the RTP database. Therefore, the proposed method could be feasible for automated determination of beam arrangements in SBRT.

Keywords: Radiotherapy treatment planning, Similar treatment plans, Beam arrangement, Image features.

1 Introduction

With the recent advancement of radiation treatment technique, e.g., stereotactic body radiation therapy (SBRT), it has become possible to concentrate very large doses of radiation to tumors, and minimize the doses to surrounding organs by using multiple beams with coplanar and non-coplanar directions [1-3]. Therefore, it is very important to determine the appropriate beam arrangement for the successful implementation of the SBRT. However, a process of treatment planning for SBRT is labo-

rious and dependent on an experience of a treatment planner. The treatment planner makes tradeoff decision between the benefit to a tumor and the risk to the surrounding normal tissues. This is traditionally handled by comparison of several treatment plans developed in a time consuming iterative manner. We address this problem by suggestion of treatment plans, which are automatically determined based on similar cases to each patient in a database including plans designed by senior experienced treatment planners.

The usefulness of similar cases in the field of radiation oncology has been shown in some papers. Commowick et al. used a most similar image in a database for the segmentation of critical structures [4]. Chanyavanich et al. developed new prostate intensity modulated radiation therapy plans based on a most similar case [5]. However, we assumed a most similar case could not necessarily be a most usable case for the treatment planning. The goal of this study is to develop a computer-assisted treatment planning system for SBRT based on several similar cases in a radiation treatment planning (RTP) database. In this paper, we aim to evaluate beam arrangements, which are determined based on 1st to 5th most similar cases to each patient in the RTP database.

2 Methods

2.1 Clinical cases

We built a RTP database including 81 cases (47 males and 34 females) and a test dataset of 10 cases (9 males and a female) with lung cancer who received SBRT. These patients were scanned by using a 4-slice computed tomography (CT) scanner (Mx 8000; Philips, Amsterdam, The Netherlands) with a slice thickness of 2.0 - 5.0 mm, and a pixel size of 0.78 - 0.98 mm. Treatment planning was performed by experienced radiation oncologists on a commercially available RTP system (Eclipse version 6.5 and 8.1; Varian Medical Systems Inc., Palo Alto, USA). Seven to eight beams with coplanar and non-coplanar directions were arranged depending on each patient. All patients received a prescribed dose of 48 Gy at the isocenter in 4 fractions.

2.2 Selection of similar cases

Similar cases to an objective case should be defined from the treatment planning point of view. In the proposed method, the five most similar cases to the objective case were automatically selected in the RTP database by defining the weighted Euclidean distance of image feature vectors between the objective case and each case in the RTP database. The weighted Euclidean distance d_{image} , which is considered a similarity measure, was calculated by:

$$d_{image} = \sqrt{\sum_{i=1}^G w_i (\alpha_i - \beta_i)^2} \quad (1)$$

where G is the number of image features, w_i is the weight of the i -th image feature, α_i is the i -th image feature for the objective case, and β_i is the i -th image feature for each case in the RTP database. In this study, we defined four types of image features, i.e., planning target volume (PTV) location, PTV shape, lung size, and spinal cord positional features. The weights of image features were considered as the importance of image features in terms of the treatment planning. We gave a large weight to the spinal cord positional features for reducing extra dose to the spinal cord. The weights for the PTV location, PTV shape, lung size, and spinal cord positional features were set as 0.3, 0.1, 0.3, and 1.0, respectively.

2.3 Determination of beam arrangements using an affine transformation

The beam angles of the objective case were determined by registration of similar cases to the objective case with respect to lung regions using the following linear registration technique, i.e., affine transformation [6]:

$$\begin{pmatrix} p' \\ q' \\ r' \\ 1 \end{pmatrix} = \begin{pmatrix} u_{11} & u_{12} & u_{13} & u_{14} \\ u_{21} & u_{22} & u_{23} & u_{24} \\ u_{31} & u_{32} & u_{33} & u_{34} \\ 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} p \\ q \\ r \\ 1 \end{pmatrix}, \quad (2)$$

where the transformation parameters $u_{11} \dots u_{34}$ were determined based on feature points. First, the affine transformation matrix to register the lung regions of each similar case with that of the objective case was calculated based on two feature points, which were automatically selected for the registration in vertices of the circumscribed parallelepiped of lung regions. Second, a beam direction based on a gantry angle θ and couch angle φ was converted from a spherical polar coordinate system to a Cartesian coordinate system as unit direction vector (p, q, r) as follows:

$$\begin{pmatrix} p \\ q \\ r \end{pmatrix} = \begin{pmatrix} \sin \theta \cos \varphi \\ -\cos \theta \\ \sin \theta \sin \varphi \end{pmatrix}. \quad (3)$$

Third, each beam direction vector of the similar case in the Cartesian coordinate system was modified by using the same affine transformation matrix of equation (2) as a registration with respect to lung regions. Finally, the resulting direction vector (p', q', r') in the Cartesian coordinate system was transformed into the spherical polar coordinate system as gantry angle θ' and couch angle φ' as follows:

$$\theta' = \tan^{-1} \left(\frac{\sqrt{p'^2 + r'^2}}{-q'} \right), \quad (4)$$

$$\varphi' = \tan^{-1} \left(\frac{r'}{p'} \right). \quad (5)$$

In this step, five beam arrangements were determined based on the five most similar cases.

3 Evaluation Methodology

The proposed method was evaluated by comparing eight planning evaluation indices between an objective original plan based on the manual beam arrangement and the five plans based on the five most similar cases to the objective case. Moreover, the five plans obtained from the proposed method were sorted based on an RTP evaluation measure with eight planning evaluation indices, which was the Euclidean distance in a feature space between each plan and an ideal plan. In this study, the ideal plan was assumed to produce a uniform irradiation with a prescription dose in the PTV and no irradiation to the surrounding organs and tissues. The usefulness of each plan was estimated by the following Euclidean distance d_{plan} of the planning evaluation vector between the ideal plan and each plan determined by a similar plan:

$$d_{plan} = \sqrt{\sum_{j=1}^N (a_j - b_j)^2}, \quad (6)$$

where N is the number of planning evaluation indices, a_j is the j -th planning evaluation index for the ideal plan, and b_j is the j -th planning evaluation index for the plan based on the five most similar plans obtained by the proposed method. Note that each planning evaluation index was divided by standard deviation of all cases in RTP database for normalizing the range of each index. The eight evaluation indices were the D95, homogeneity index (HI), conformity index (CI) for the PTV, V5, V10, V20, mean dose for the lung, and maximum dose for the spinal cord, whose values for the ideal plan were set to 48 Gy (prescription dose), 1.0, 1.0, 0%, 0%, 0%, 0 Gy, and 0 Gy, respectively.

The planning evaluation indices for the PTV calculated in this study were the D95, HI, and CI. The D95 was defined as a minimum dose in the PTV that encompasses at least 95% of the PTV. The HI was calculated as the ratio of the maximum dose to the minimum dose in the PTV [7]. The CI represented a degree of conformity, defined as the ratio of the treated volume to the PTV. The treated volume is defined as the tissue volume that is intended to receive at least the selected dose and that is specified by the radiation oncologist as being appropriate to achieve the purpose of the treatment [8].

In this study, the treated volume was defined as the volume receiving the minimum target dose.

The planning evaluation indices for normal tissues, i.e., the lung and spinal cord, were calculated as described below. For the lung volume, which was defined as total lung volume minus PTV, a V5, V10, V20, and mean dose were calculated. The V x was defined as a percentage of the total lung minus PTV receiving $\geq x$ Gy. The maximum dose of the spinal cord was also calculated.

4 Results and Discussion

Figure 1 shows dose distributions obtained from (a) an original beam arrangement of an objective case, (b) beam arrangement based on the most similar case, and (c) the most usable beam arrangement based on the 4th most similar case. The value of HI, CI, and spinal cord maximum dose were 1.10, 1.65, and 5.37 Gy, respectively, for the original beam arrangement (Figure 1a). On the other hand, they were 1.13, 1.84, and 6.16 Gy, respectively, for the beam arrangement based on the most similar case (Figure 1b). And also, they were 1.08, 1.58, and 4.90 Gy, respectively, for the most usable beam arrangement (Figure 1c). Therefore, the most usable plan has better conformity to the tumor and better sparing of the spinal cord compared with the beam arrangements based on original and also the most similar case.

Table 1 shows the planning evaluation indices obtained from the dose distributions produced by original beam arrangements, beam arrangements based on the most similar case, and beam arrangements of the most usable plan determined by the RTP evaluation measure. In terms of the homogeneity index and conformity index, there were statistically significant differences between the original beam arrangements and beam arrangements based on the most similar case ($P < 0.05$). On the other hand, there were no statistically significant differences between the original beam arrangements and the most usable beam arrangements ($P > 0.05$) in all planning evaluation indices. Therefore, the most usable beam arrangement could be feasible compared with the beam arrangement based on the most similar case.

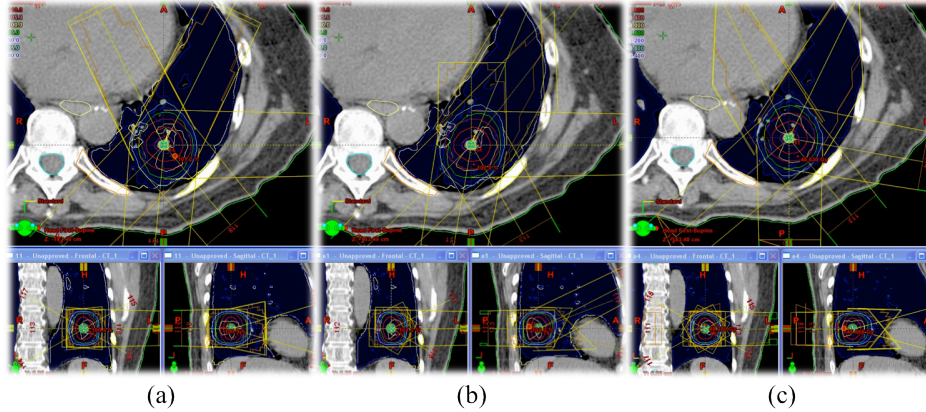


Fig. 1. Dose distributions obtained from (a) an original beam arrangement, (b) beam arrangement based on the most similar case, and (c) the most usable beam arrangement.

Table 1. Average planning evaluation indices in ten test cases obtained from the dose distributions produced by original beam arrangements, beam arrangements based on the most similar case, and beam arrangements of the most usable plan determined by the RTP evaluation measure.

| | Original beam arrangement | Beam arrangement based on the most similar case | Beam arrangement of the most usable plan |
|-------------------|---------------------------|---|--|
| PTV | | | |
| D95 (Gy) | 45.5 ± 0.47 | 45.4 ± 0.61 | 45.8 ± 0.62 |
| Homogeneity index | 1.13 ± 0.03 | 1.15 ± 0.04 | 1.13 ± 0.04 |
| Conformity index | 1.70 ± 0.15 | 1.80 ± 0.18 | 1.74 ± 0.18 |
| Lung | | | |
| V5 (%) | 16.0 ± 6.30 | 15.7 ± 5.04 | 14.4 ± 4.98 |
| V10 (%) | 9.96 ± 4.52 | 9.54 ± 3.35 | 9.10 ± 3.08 |
| V20 (%) | 3.98 ± 1.46 | 4.16 ± 1.40 | 4.06 ± 1.29 |
| Mean dose (Gy) | 3.03 ± 1.11 | 3.04 ± 0.94 | 2.90 ± 0.93 |
| Spinal cord | | | |
| Maximum dose (Gy) | 6.13 ± 3.62 | 5.19 ± 4.94 | 8.21 ± 7.23 |

5 Conclusions

We have developed a computer-assisted determination of the usable beam arrangement from similar treatment plans in SBRT. Furthermore, we have studied the feasibility of beam arrangements, which are determined based on 1st to 5th most similar cases to each patient in the RTP database. As a result, the proposed method may

provide usable beam arrangements, which have no statistically significant differences with the original beam directions ($P > 0.05$). Therefore, the proposed method can assist radiation treatment planners in determination of beam arrangements in SBRT.

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