Computer-aided beam arrangement based on similar cases in radiation treatment-planning databases for stereotactic lung radiation therapy

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The purpose of this study was to develop a computer-aided method for determination of beam arrangements based on similar cases in a radiotherapy treatment-planning database for stereotactic lung radiation therapy. Similar-case-based beam arrangements were automatically determined based on the following two steps. First, the five most similar cases were searched, based on geometrical features related to the location, size and shape of the planning target volume, lung and spinal cord. Second, five beam arrangements of an objective case were automatically determined by registering five similar cases with the objective case, with respect to lung regions, by means of a linear registration technique. For evaluation of the beam arrangements five treatment plans were manually created by applying the beam arrangements determined in the second step to the objective case. The most usable beam arrangement was selected by sorting the five treatment plans based on eight plan evaluation indices, including the D95, mean lung dose and spinal cord maximum dose. We applied the proposed method to 10 test cases, by using an RTP database of 81 cases with lung cancer, and compared the eight plan evaluation indices between the original treatment plan and the corresponding most usable similar-case-based treatment plan. As a result, the proposed method may provide usable beam arrangements, which have no statistically significant differences from the original beam arrangements ($P > 0.05$) in terms of the eight plan evaluation indices. Therefore, the proposed method could be employed as an educational tool for less experienced treatment planners.

Keywords: radiotherapy treatment planning; similar planning cases; computer-assisted method; beam arrangements; stereotactic lung radiotherapy

INTRODUCTION

Stereotactic body radiotherapy (SBRT) has been actively performed for early stage lung cancers in recent decades [1]. The survival rate for SBRT has been encouraging, and potentially comparable to that for surgery [2]. The key to successful implementation of SBRT is appropriate beam arrangement, which generally consists of a large number of coplanar and non-coplanar beams [3]. However, the determination of beam arrangements in SBRT is a substantial

and demanding task for inexperienced treatment planners, as well as experienced treatment planners, and affects the critical dose distribution with steep dose gradients. Treatment planning skills are developed by repeated planning in clinical practice, often under the guidance of experienced planners or appropriate textbooks. In this way, treatment planners should memorize many planning patterns and construct an evolving 'database' in their memory, which can then be searched for past cases similar to the case under consideration. However, although a number of automated methods for determination of beam arrangements have been developed [4, 5], there are currently no such methods for determining beam arrangements based on similar past cases. On the other hand, in the field of diagnostic radiology, the presentation of similar cases as a diagnostic aid has been suggested for diagnosis of chest images [6], lung computed tomography (CT) images [7, 8], and mammography images [8–11]. These studies have indicated the feasibility of the usage of similar cases as a diagnostic aid. However, to the best of our knowledge, there are no studies on the feasibility of determination of beam arrangements using similar planning cases in the radiation therapy field. The purpose of this study was to develop a computer-aided method for determination of beam arrangements based on similar planning cases in a radiotherapy treatment-planning (RTP) database for stereotactic lung radiotherapy. The beam arrangement includes not only beam directions but also accelerating voltages, collimator angles, beam weights etc.

MATERIALS AND METHODS

Figure 1 shows the overall scheme of the proposed method, which consists of two main steps. First, similar cases to an objective case were searched, based on geometrical features related to structures such as the location, size, and shape of the planning target volume (PTV), lung and spinal cord. Second, beam arrangements of the objective case were automatically determined by registering similar cases with the objective case, in terms of lung structure regions using a linear registration technique, i.e. an affine transformation
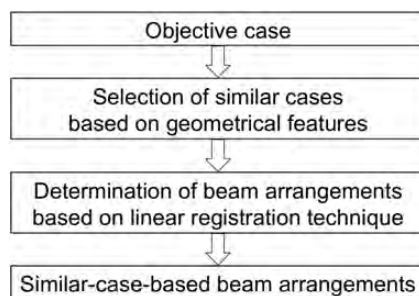

Fig. 1. Overall scheme for the determination of similar-case-based beam arrangements.

[12]. Finally, the similar-case-based beam arrangements were evaluated by plan evaluation indices. Details of the proposed method are described in this section.

Clinical cases
This study was performed under a protocol approved by the institutional review board of the University Hospital. We selected 96 patients with lung cancer (right lung: 52 cases, left lung: 44 cases) who were treated with SBRT from November 2003 to April 2010. The patients (60 males and 36 females) had a median age of 76 years (range, 42–92 years), and their mean effective diameter of PTV was 4.0 ± 0.7 cm. Treatment planning was performed by experienced radiation oncologists on a commercially available RTP system using a pencil beam convolution algorithm (Eclipse version 6.5 and 8.1; Varian Medical Systems Inc., Palo Alto, USA). Contours of the gross tumor volumes of lung cancers were manually outlined on planning CT images acquired on a 4-slice CT scanner (Mx 8000; Philips, Amsterdam, The Netherlands) with 16-bit gray levels, a slice thickness of 2.0 mm (95 cases) or 5.0 mm (1 case), and a pixel size of 0.78 mm (29 cases), 0.86 mm (1 case), 0.88 mm (10 cases) or 0.98 mm (56 cases). The internal target volume (ITV) was created individually according to the internal respiratory motion, which was measured with an X-ray simulator (Ximatron; Varian Medical Systems Inc., Palo Alto, USA). The setup margins between the ITV and PTV were 5 mm in all directions. Seven to eight beams, including beams in the coplanar and non-coplanar directions, were arranged, depending on each patient. All patients received a dose of 48 Gy, prescribed at the isocenter in 4 fractions, with accelerating voltages of 4, 6 or 10 MV on linear accelerators (Clinac 21EX; Varian Medical Systems Inc., Palo Alto, USA).

All cases were randomly separated into three datasets, i.e. a dataset comprising the RTP database, a dataset of 5 training cases (right lung: 3 cases, left lung: 2 cases), and a dataset of 10 test cases (right lung: 3 cases, left lung: 7 cases). The RTP database thus included 81 cases (right lung: 46 cases, left lung: 35 cases). The 5 training and 10 test cases were used to determine the parameters for selection of similar cases and for the evaluation of our method, respectively.

Selection of similar planning cases using geometrical features
Beam arrangements are generally determined by considering the geometrical features in an objective case including the tumor, organs at risk (OAR) (such as spinal cord), and normal tissue structures. The geometrical features relevant in making an SBRT treatment plan for lung cancer include the PTV location, the PTV shape, the PTV size, the lung dimension, and the geometrical relationship between the PTV and the spinal cord. Therefore, it was considered reasonable to define similar cases with respect to these geometrical features.

In the first step the RTP database was searched for the 5 cases most similar to the objective case by considering the weighted Euclidean distance of geometrical feature vectors between the objective case and each case in the RTP database. The weighted Euclidean distance was thus considered a similarity measure. The weights of geometrical features were needed in order to consider the importance of the geometrical features from the treatment planning point of view. When applying the proposed method to their own databases, each institute should determine the appropriate weights of the geometrical features based on their own philosophy or policy of treatment planning. The weighted Euclidian distance d_{image} was calculated by the following equation:

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

where G is the number of geometrical features, w_i is the weight of the i-th geometrical feature, α_i is the i-th geometrical feature for the objective case, and β_i is the i-th geometrical feature for each case in the RTP database. Note that each geometrical feature was divided by standard deviation of all cases in the RTP database for normalizing the range of each feature value. In this study, we defined 10 geometrical features, i.e. the PTV centroid in the left-right (LR), anterior-posterior (AP), and superior-inferior (SI) directions, the effective diameter of the PTV, the sphericity of the PTV, the lung dimension in the LR, AP, and SI directions, the distance between the PTV and spinal cord in the isocenter plane, and the angle from the spinal cord to the PTV in the isocenter plane. The weights for geometrical features were empirically set as follows based on the institution's policy of treatment planning by using the 5 training cases with a trial and error procedure so that cases more similar to the objective case could be selected in terms of appearance relevant to the features: the PTV centroid = 0.3, effective diameter of the PTV = 0.1, sphericity of the PTV = 0.1, lung dimension = 0.3, distance between the PTV and spinal cord = 1.0, and angle from spinal cord to the PTV = 1.0. In our program, the weights for geometrical features were normalized when the similarity measure was calculated. However, we believe that it would be more logical for users to set the weights from 0 to 1.0, than to set the sum of the weights equal to 1.0. The PTV centroid was determined by registering the lung structure image of each case in the RTP database with that of a reference case based on the following linear registration technique, i.e. affine transformation [12]:

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

where the transformation parameters $u_{11} \dots u_{34}$ were determined based on feature points. We used a special case of an affine transformation including only the translation and scaling due to two feature points, where the affine transformation parameters u_{12}, u_{13}, u_{21}, u_{23}, u_{31}, and u_{32} were resulted to zero. The remaining transformation parameters were determined by analytically solving simultaneous equations based on two feature points. The vertices of a circumscribed parallelepiped of a lung, including left and right lung regions, were automatically obtained as feature points for calculation of parameters of the affine transformation matrix as follows. First, the minimum and maximum x, y and z coordinates, x_{min}, x_{max}, y_{min}, y_{max}, z_{min} and z_{max}, were obtained in the original coordinate system of the planning CT image from the lung segmented by a treatment planner, and then six planes of $x = x_{min}$, $x = x_{max}$, $y = y_{min}$, $y = y_{max}$, $z = z_{min}$ and $z = z_{max}$ were determined as those of the circumscribed parallelepiped. Finally, two vertices of the circumscribed parallelepiped of the lung region (x_{min}, y_{min}, z_{min}) and (x_{max}, y_{max}, z_{max}) were used as feature points for determination of parameters in the affine transformation matrix. In this study, the circumscribed parallelepiped was chosen to reduce the calculation time for finding the feature points of the lung. As the registration, the PTV centroid of each case, located at (p, q, r), would move to the position (p', q', r') in the coordinate system of a reference case by Equation 2. The effective diameter was defined as the diameter of a sphere with the same volume as the PTV. The sphericity was defined as the roundness of the PTV without a directional dependence, and given by the ratio of the number of logical AND voxels between the PTV and its equivalent sphere with the same centroid and volume as the PTV to the number of PTV voxels. In fact, we employed the sphericity in this study as a similarity measure for finding similar cases in terms of tumor roundness. In future, when determining beam directions, we should take into account the direction of tumor regions as one of the shape features for retrieving similar cases.

Lung dimensions were defined as three side-lengths of the circumscribed parallelepiped of the lung regions in the LR, AP and SI directions. The distance between the PTV and the spinal cord was measured between the centroid of the PTV and that of the spinal cord in the isocenter plane. The angle from the spinal cord to the PTV was defined in the 2D coordinate system with the origin at the centroid of the spinal cord in the isocenter plane, and ranged from $-\pi$ (clockwise) to π (counterclockwise) for a baseline of the posterior-anterior direction. Although only the PTV centroid was determined in a fixed reference coordinate system by registering the lung regions of each case in the RTP database with those of a reference case; other features were calculated on each original coordinate system. This was to consider the relative similarity of the tumor in lung regions, as well as the absolute similarity such as lung dimensions and spinal cord position.

Determination of beam arrangements based on the linear registration technique

In the second step, five beam arrangements (each of which had seven or eight beam directions) for an objective case were automatically determined by registration of five similar cases with the objective case in terms of lung regions using a linear registration technique, i.e. affine transformation [12]. The beam arrangement of the similar case was modified to fit the objective case with respect to lung regions. Please note that linear registration maps straight lines to straight lines, and thus the beam directions, which can be considered as lines with the origin at the isocenter, are uniquely and automatically determined by the registration of the lung regions. First, the affine transformation matrix of Equation 2, registering the lung regions of each similar case with those 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 the lung regions. Second, a beam angle, i.e. beam direction vector, based on a gantry angle θ and couch angle ϕ, was transformed from a spherical polar coordinate system to a Cartesian coordinate system as unit direction vector (a, b, c) as follows:

$$\begin{pmatrix} a \\ b \\ c \end{pmatrix} = \begin{pmatrix} \sin\theta \cos\phi \\ -\cos\theta \\ \sin\theta \sin\phi \end{pmatrix}. \tag{3}$$

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 in terms of lung regions. Finally, the resulting direction vector (a', b', c') in the Cartesian coordinate system was converted into the spherical polar coordinate system as the gantry angle θ' and the couch angle ϕ' as follows:

$$\theta' = \tan^{-1}\left(\frac{\sqrt{a'^2 + c'^2}}{-b'}\right), \tag{4}$$

$$\phi' = \tan^{-1}\left(\frac{c'}{a'}\right). \tag{5}$$

Evaluation of beam arrangements using plan evaluation indices

Five treatment plans were manually made, based on the beam arrangements with other planning parameters (accelerating voltages, collimator angles, beam weight, etc.) derived from treatment plans of similar cases in a radiation treatment-planning system. Users of our system can manually select among the treatment plans provided by the proposed method with their own policies, depending on patient performances. In this study, however, the most usable treatment plan of the objective case was automatically selected

by sorting the five plans based on an RTP evaluation measure with eight plan evaluation indices (which was the Euclidean distance in a feature space between each treatment plan and an ideal treatment plan) for evaluation of beam arrangements determined by the similar cases. The beam arrangement of the similar case except beam directions was used for that of an objective case as they are or after a minor modification of the accelerating voltage if needed.

In this study, the ideal treatment plan was assumed to produce perfectly uniform irradiation, with a prescription dose in the PTV and no irradiation in the surrounding OAR and normal tissues. The usefulness of each treatment plan was estimated by the following Euclidean distance d_{plan} of the plan evaluation vector between the ideal treatment plan and each treatment plan determined by a similar case, and designated the 'RTP evaluation measure':

$$d_{plan} = \sqrt{\sum_{j=1}^{J} (X_j - Y_j)^2}, \tag{6}$$

where J is the number of plan evaluation indices, X_j is the j-th plan evaluation index for the ideal treatment plan, and Y_j is the j-th plan evaluation index for the treatment plan based on the five most similar cases. Each plan evaluation index was normalized by the standard deviation in the same manner as the geometrical features based on the RTP database including 81 cases. The eight evaluation indices consisted of the D95, the homogeneity index (HI), the conformity index (CI) for the PTV, V5, V10, V20, mean dose for the lung, and maximum dose for the spinal cord, and their values for the ideal treatment plan were set to 48 Gy (prescription dose), 1.0, 1.0, 0%, 0%, 0%, 0 Gy, and 0 Gy, respectively. We evaluated similar-case-based beam arrangements suggested by the proposed method using Equation 6 based on the Euclidean distance of eight plan evaluation indices. Although we could have applied weights to plan evaluation indices based on planners' preferences, in this study we decided to give a constant weight to each plan evaluation index.

The plan evaluation indices for the PTV calculated in this study were the D95, HI and CI, which are described below:

D95: minimum dose in the PTV that encompasses at least 95% of the PTV.

HI: dose uniformity in the PTV, defined as the ratio of the maximum dose to the minimum dose in the PTV [13].

CI: 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 is specified by the radiation oncologist as being appropriate to achieve the purpose of the treatment [14]. In this study, the treated volume was defined as the volume receiving the minimum target dose.

The plan 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 the total lung volume minus the PTV, a V5, V10, V20, and mean dose were calculated. The Vk was defined as the percentage of the total lung minus the PTV receiving ≥k Gy. The maximum dose for the spinal cord was also calculated.

Assessment of the proposed method

The proposed method was assessed with an RTP database including 81 cases with lung cancer (right lung: 46 cases, left lung: 35 cases) by comparing the original beam arrangements of 10 test cases (right lung: 3 cases, left lung: 7 cases), which were randomly chosen from all 96 cases, with the corresponding most usable beam arrangements determined from similar cases. The test cases were not included in the RTP database, and were not used for determination of the weights of geometrical features. The similar cases were selected from cases that have ipsilateral lung cancers with the test case. The same beam weights and wedges of the similar cases were used for the objective cases. The irradiation fields were adjusted to the tumor using a multi-leaf collimator with an additional margin of 5 mm around the PTV.

RESULTS

Figure 2 shows an objective case with a tumor on the lung wall (Fig. 2a) and the first to fifth most similar cases (Fig. 2b–f) to the objective case. The similar cases geometrically resemble the objective case (Fig. 2a), especially in

terms of the geometrical relationship between the tumor and the spinal cord. Moreover, the tumors are located on the lung wall, because the relative location of the PTV in the reference lung regions was used for the selection of similar cases. Figure 3 shows a treatment plan obtained by the original beam arrangement (Fig. 3a), and five treatment plans determined by similar-case-based beam arrangements (Fig. 3b–f), which were sorted in descending order, based on the RTP evaluation measure. The treatment plans of Fig. 3b, c, d, e and f were derived from similar cases, as shown in Fig. 2b, c, e, f and d, respectively. In this case, the beam arrangements consisted of 7–8 beams, including 3–4 coplanar beams and 3–4 non-coplanar beams. The objective case (Fig. 3a) received an oblique lateral beam, which passed close to the spinal cord in order to increase the conformity of the PTV. On the other hand, the most usable similar-case-based beam arrangement (Fig. 3b) had no lateral beams for avoiding the exposure of the spinal cord, but the second to fifth usable cases (Fig. 3c–f) had lateral beams due to prioritizing the PTV conformity over the sparing of the spinal cord. Figure 4 shows the dose volume histograms (DVHs) of the original treatment plan (Fig. 3a) and the first to third most usable treatment plans determined by the RTP evaluation measure (Fig. 3b–d). The first most usable treatment plan resulted in better PTV conformity, as well as better sparing of the lung tissue and spinal cord, compared with the original treatment plan. DVH curves of the second and third most usable treatment plans were not always better than those of the original treatment plan.
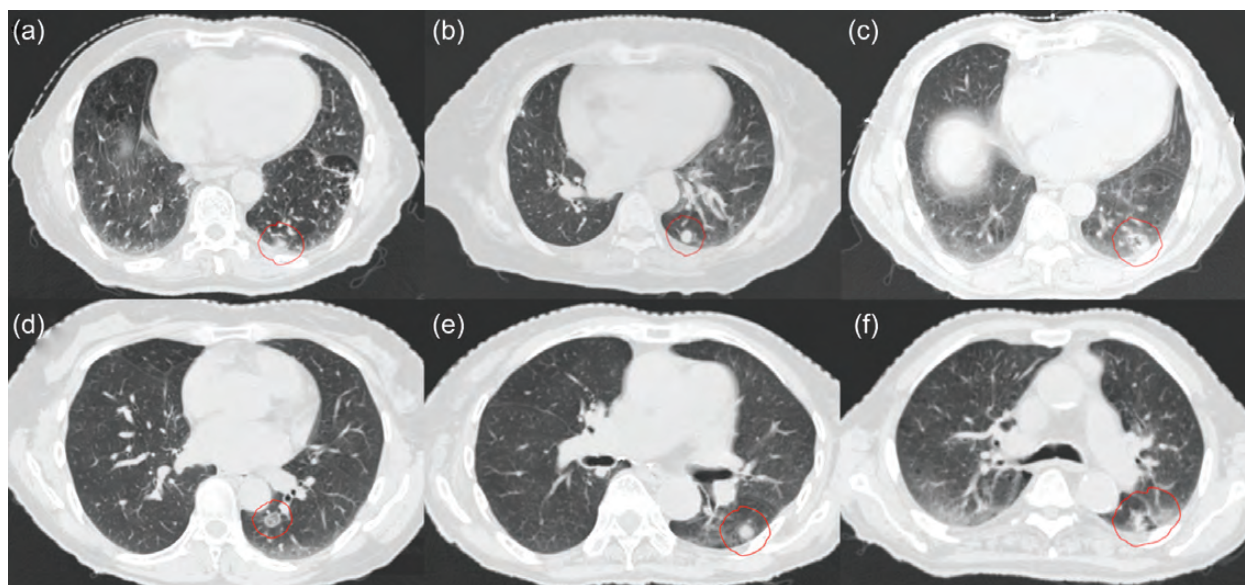

Fig. 2. An objective case (**a**) with a tumor on the lung wall, and the first to fifth most similar cases (**b–f**), which geometrically resemble the objective case, especially in terms of the geometrical relationship between the tumor and the spinal cord. Red lines indicate the planning target volumes.
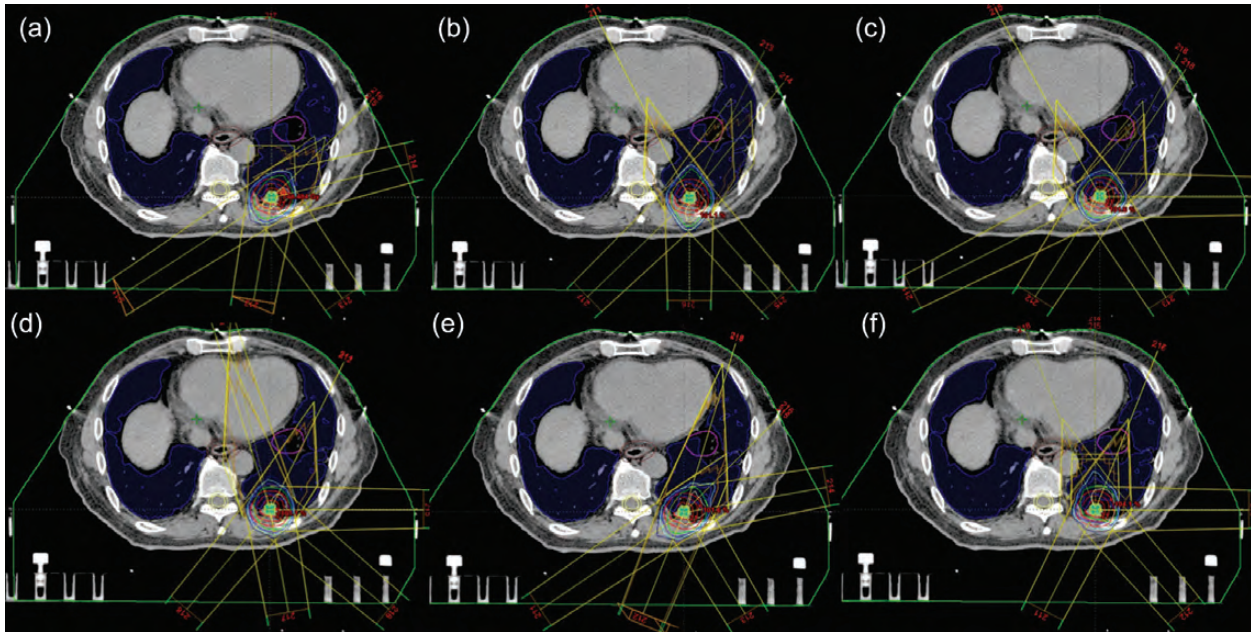
Fig. 3. A treatment plan obtained by the original beam arrangement (**a**), and 5 treatment plans determined by similar-case-based beam arrangements (**b–f**), which were sorted in descending order based on the RTP evaluation measure. The treatment plans of (b), (c), (d), (e), and (f) were derived from the similar cases as shown in Fig. **2** (b), (c), (e), (f), and (d), respectively.
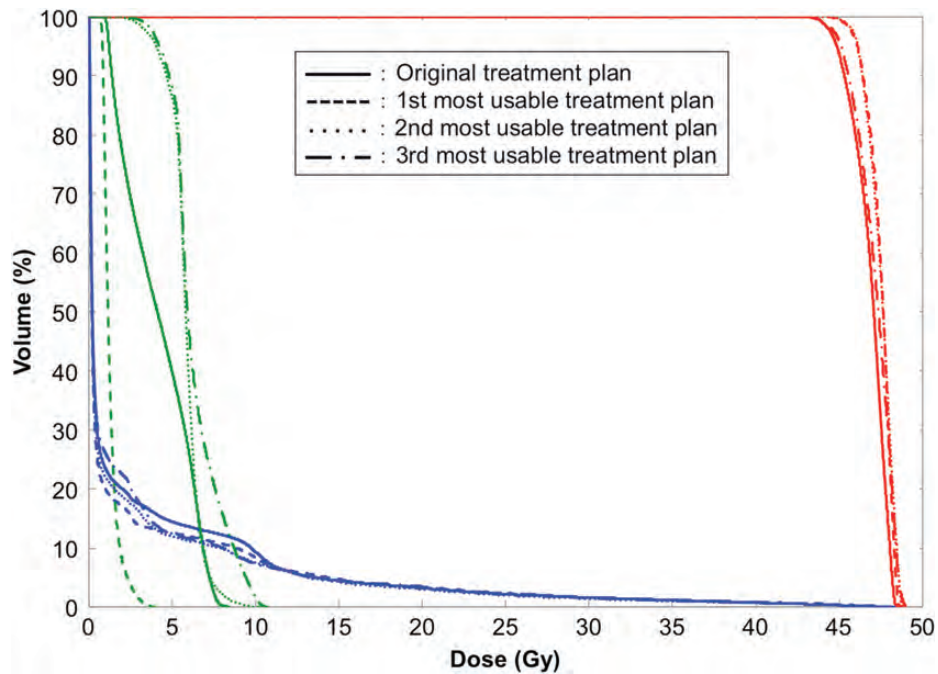

Fig. 4. Dose volume histogram comparison between treatment plans based on the original beam arrangement (solid lines) and similar-case-based beam arrangement (dotted lines): planning target volume (red), lung (blue) and spinal cord (green).

Table 1 shows the mean ± standard deviation (SD) of the plan evaluation indices in 10 test cases obtained from the dose distributions produced by original beam arrangements and similar-case-based beam arrangements (of the most usable treatment plans, as determined by the RTP evaluation measure). There were no statistically significant differences

Table 1. Mean ± standard deviation of the plan evaluation indices in 10 test cases obtained from the dose distributions produced by original and similar-case-based beam arrangements

	Original beam arrangement	Similar-case-based beam arrangement
PTV		
D95 (Gy)	45.5 ± 0.47	45.8 ± 0.62
Homogeneity index	1.13 ± 0.03	1.13 ± 0.04
Conformity index	1.70 ± 0.15	1.74 ± 0.18
Lung		
V5 (%)	16.0 ± 6.30	14.4 ± 4.98
V10 (%)	9.96 ± 4.52	9.10 ± 3.08
V20 (%)	3.98 ± 1.46	4.06 ± 1.29
Mean dose (Gy)	3.03 ± 1.11	2.90 ± 0.93
Spinal cord		
Maximum dose (Gy)	6.13 ± 3.62	8.21 ± 7.23

There were no statistically significant differences between the original beam arrangements and similar-case-based beam arrangements ($P > 0.05$).

between the original beam arrangements and the similar-case-based beam arrangements ($P > 0.05$) in terms of the eight plan evaluation indices.

DISCUSSION

In general, the RTP database in each hospital has been generated, intentionally or unintentionally, by experienced planners after many trials, and incorporates a lot of their knowledge and skills. The aim of this study was to make use of these records of knowledge and skills. Therefore, we proposed a computer-aided method for determination of beam arrangements using similar past cases in an RTP database. The proposed method could provide several usable beam arrangements based on similar cases in the RTP database. In Fig. 3b–f, the 5 usable similar-case-based beam arrangements are presented. Although the plan evaluation indices were calculated for the evaluation of the treatment plans based on the similar-case-based beam arrangements, the indices may not cover all aspects of the dose distribution. Therefore, users can manually select one of the treatment plans within their own policies, instead of the most usable treatment plan being selected automatically using plan evaluation indices.

Although SBRT has been widely used for the treatment of lung cancer in clinical practice, treatment-planning skills are required for determination of the appropriate beam direction for SBRT, which consists of a number of beams with coplanar and non-coplanar directions. Our proposed

method can automatically determine beam arrangements based on the treatment plans of similar cases. If inexperienced, or less trained, treatment planners with respect to SBRT employ the proposed system using an RTP database of experienced planners, the quality of radiotherapy could be normalized among planners with different levels of experience. The proposed system could thus be used as an educational tool for treatment planners with limited SBRT experience.

Figure 5 shows the histograms of d_{image} in three test cases with right lung cancers (Fig. 5a) and left lung cancers (Fig. 5b). The means ± SDs of d_{image} for right and left lung cancer cases were 1.03 ± 0.37 and 1.28 ± 0.39, respectively. There are the small number of more similar (smaller d_{image}) cases to the test cases with the RTP database used in this study. In addition, the d_{image} was distributed with almost the same SD in the right and left lung cancer cases. Figure 6 shows the distribution of the d_{plan} for 50 treatment plans in 10 test cases. The mean ± SD of the d_{plan} was 6.54 ± 1.95. The distribution of the d_{plan} ranged widely from 3.0 to 12.0. Figure 7 shows the relationship between the d_{image} and the d_{plan} for 50 similar-case-based treatment plans in 10 test cases. The total correlation coefficient between the d_{image} and the d_{plan} was –0.52, but there seems to be little correlation between them in each test case. The mean ± SD of the correlation coefficient in each test case was 0.13 ± 0.37. The reason for this would be related to the dependence of similar-case-based beam arrangements on the quality of the treatment plans in the RTP database. In each test case, the most similar case did not always suggest the most usable beam arrangement. Therefore, we should study a similar-case-based optimization method for beam arrangements, including beam weights and wedges for the objective case, in future work.

The number of similar cases to be presented to planners can be determined by the preference of treatment planners. However, if planners used a relatively larger number of similar cases than 5 cases, dissimilar cases could be selected as 'similar' cases due to limited number of cases in the RTP database. In addition, it would be time-consuming for treatment planners to determine the suitable beam arrangement from too many options in routine clinical use of the proposed method. Therefore, treatment planners could change the number of similar cases, which is a flexible parameter, to adapt to each clinical situation.

The essential parameters in the proposed method were the weights of the geometrical features in Equation 1, which were needed for considering the priority of the various geometrical features from the treatment-planning point of view. In this study, we empirically determined the weights for the geometrical features as follows, based on the institution's policy of treatment planning. We used five training cases with a trial and error procedure so that the cases most similar to the objective case could be selected
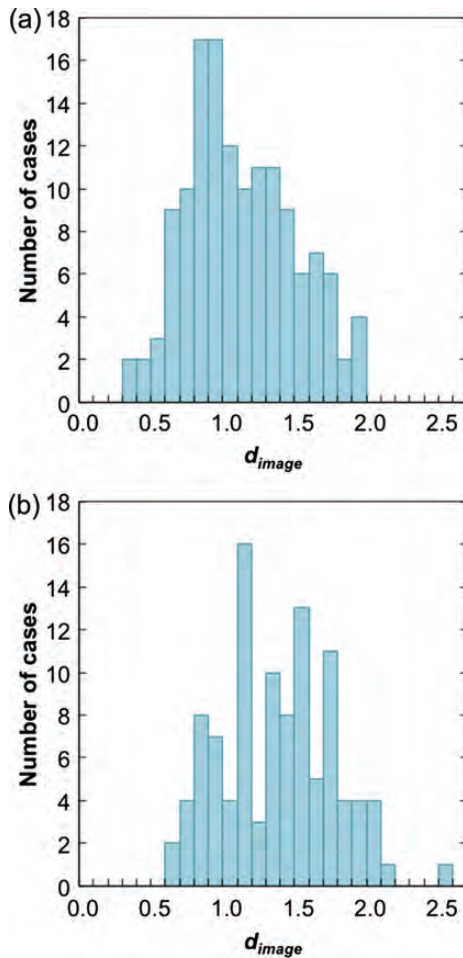
Fig. 5. Histograms of the d_{image} for selection of similar cases in three test cases (**a**) with right lung cancers and (**b**) left lung cancers.

Fig. 6. Histograms of the d_{plan} for evaluation of similar case-based beam arrangements in 50 treatment plans of 10 test cases.

Fig. 7. Relationship between the d_{image} for selection of similar cases and d_{plan} for evaluation of similar case-based beam arrangements.

in terms of appearance relevant to the features: the PTV centroid = 0.3, the effective diameter of the PTV = 0.1, the sphericity of the PTV = 0.1, lung dimension = 0.3, the distance between the PTV and spinal cord = 1.0, and the angle from the spinal cord to the PTV = 1.0. We gave greater importance to the geometrical features related to the spinal cord in order to reduce the extra dose to the spinal cord, whereas shape features were given lower importance, because we believe that shape should play a more minor role in selection of similar cases. The weights were empirically determined using five training cases, so that the cases most similar to the objective case could be selected based on the planning viewpoints, i.e. the philosophies and policies regarding treatment planning, of a radiation oncologist (YS) and a medical physicist (HA). Therefore, when applying the proposed method to their own databases, treatment planners should first determine the appropriate weights of the geometrical features based on their own philosophies or policies regarding treatment planning. Nevertheless, it
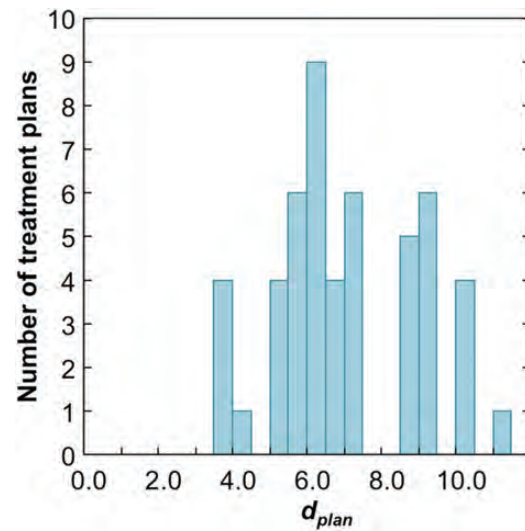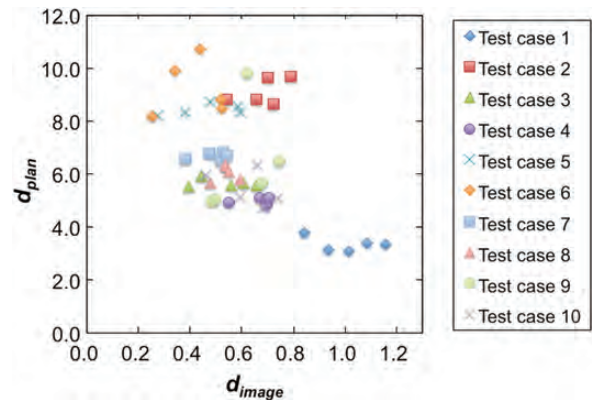
would be useful to develop the optimization method for the weights in Equation 1 so as to reduce planning time in future work, so that the planners' philosophies and policies can be incorporated into the optimization method, while retaining flexibility.

It would be very important to evaluate the results of the proposed method displayed in Table 1 from a clinical standpoint. According to our results, the proposed method may provide usable beam arrangements with little statistical difference from cases in the RTP database, as shown in Table 1. However, 56% of the plan evaluation indices were improved by the proposed method, compared with those of the original treatment plans. From the clinical point of view, the proposed method might not always suggest the

most usable treatment plans, because the quality of similar-case-based treatment plans depends on that of treatment plans in the RTP database. Therefore, the quality of the database might influence similar-case-based beam arrangements; if inappropriate treatment plans were included in the database this could be one of the limitations of the proposed method. In this study the original beam arrangements were determined by experienced radiation oncologists in our hospital, and the radiation oncologists approved all treatment plans as clinically acceptable. Even so, we need to consider some threshold values for the RTP evaluation measure to avoid selection of inappropriate treatment plans. In future works, we would like to build a more reliable RTP database by reviewing the clinical outcome of each case, and/or adding the treatment plans that were developed by the experienced radiation oncologists in regional center hospitals, and develop a method for avoiding selection of inappropriate treatment plans.

Many kinds of similarity measures have been developed for identifying similar cases in the field of diagnostic radiology [15]. We used the weighted Euclidean distance, which is one of the simple similarity measures [15], for selection of similar treatment plans, because the users of the proposed method can easily change the weights of the various geometrical features, depending on their treatment philosophies. However, other similarity measures may identify more similar treatment plans. Therefore, in future work we should investigate the efficient similarity measure for the selection of similar cases from the treatment-planning point of view. Moreover, for the assessment of the proposed method, the beam weights and wedges were set at the same values as the similar cases, but this may not be optimal for the objective case. Therefore, it will be necessary to optimize beam weights and wedges for the objective case in future work.

CONCLUSIONS

We have proposed a technique to determine computer-aided beam arrangement for stereotactic lung radiotherapy based on similar planning cases in an RTP database of experienced planners, and have investigated its feasibility. The results have shown that the proposed method provides usable beam arrangements with little statistical difference from cases in the RTP database. Therefore, our proposed method could be used as a tool for educating less-experienced treatment planners from an RTP database of more experienced planners. The quality of radiotherapy could thus be normalized among planners having different levels of experience in SBRT.

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