Optimization Technique using Ideal Target Model and Database in SRS

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ABSTRACT

The aim of stereotactic radiosurgery(SRS) is to deliver a high dose to a target region and a low dose to critical organ through only one or a few irradiation. To satisfy this aim, optimized irradiating conditions must be searched in the planning. Thus, many mathematical methods such as gradient method, simulated annealing and genetic algorithm had been proposed to find out the conditions automatically. There were some limitations using these methods: the long calculation time, and the difficulty of unique solution due to the different shape of tumor. In this study, optimization protocol using ideal models and data base was proposed. Proposed optimization protocol constitutes two steps. First step was a preliminary work. Some possible ideal geometry shapes, such as sphere, cylinder, cone shape or the combination, were assumed to approximate the real tumor shapes. Optimum variables such as isocenter position or collimator size, were determined so that the high dose region could be shaped to fit ideal models with the arrangement of multiple isocenter. Data base were formed with those results. Second, any shaped real targets were approximated to these models using geometry comparison. Then, optimum variables for ideal geometry were chosen from the data base predetermined, and final parameters were obtained by adjusting these data. Although the results of applying the data base to patients were not superior to the result of optimization in each case, it can be acceptable as a starting point of plan.

Keywords: SRS, stereotactic radiosurgery, optimization, ideal model.

1. INTRODUCTION

The aim of radiotherapy and radiosurgery is to deliver a high dose in the tumor volume while preserving the surrounding healthy tissues. Two ways to achieve this aim are to determine exact tumor volume and to deliver exactly. The former is achieved using fusion images with PET and CT or PET and MRI. The latter is achieved using stereotactic radiosurgery(SRS), conformal therapy or intensity modulated radiation therapy(IMRT) techniques. Among these techniques, SRS is the very precise delivery of radiation to a brain tumor with sparing of the surrounding normal brain. To achieve this precision, special procedures for localization of the brain tumor and surgery planning are necessary. The practical radiosurgery planning requires trial and error methods because the tumor shape is irregular and there are many beam variables. So many mathematical methods such as gradient method, genetic algorithm, and simulated annealing, have been proposed for automatic planning optimization since Hope originally proposed the dose optimization method using computer in 1960s. But there are some limitations: the long calculation time, and the difficulty of finding unique solution due to the different shape of tumor. In this study, heuristic optimization protocol was proposed. The proposed optimization protocol uses ideal models that are typical patterns of tumor shapes and data base predetermined.

2. MATERIALS AND METHODS

2.1. Overall Study Procedure

The object of this study is to propose an optimization procedure which uses ideal models and data base of optimum variables such as isocenter positions or collimator sizes. Figure 1. shows the overall process. Any shape of tumor was first assumed to the ideal model through the geometry comparison, then, optimum variables for ideal geometry were chosen from the data base predetermined, followed by the final adjusting of optimum parameters with the use of real tumor shape.

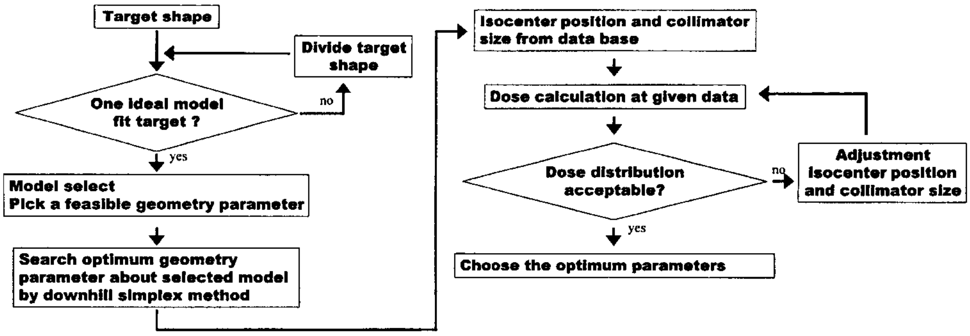

Fig. 1. Overall Optimization Procedure in this study

2.2. Determination of typical pattern of tumor shape

Clinical data were used in order to find out typical pattern of tumor shape. A neurosurgeon contoured the tumor shapes in MR images of 20 patients, who had a SRS operation. Four patterns were chosen in this study. They were sphere, cylinder, ellipsoid and cone. Sphere and cylinder are selected in the most cases.

Fig. 2. Four patterns of tumor shape : sphere, cylinder, ellipsoid of revolution and circular cone

2.3. Data Base construction

Predetermined data base were formed about multiple isocenter parameters such as isocenter positions and collimator sizes which were designed to include ideal model specified percentage(50%) dose volume.

• Spherical and Ellipsoidal ideal model

The dose distribution at high isodose levels shows a spherical pattern in the case of LINAC radiosurgery with single isocenter and evenly spaced arcs. Eliminating arcs from the standard arc set elongates the dose distribution in the direction of the remaining arcs, thus producing an ellipsoidal dose distribution. For this reason, data base were not constructed for these ideal models. Isocenter position was set to the center and collimator size was set to the diameter.

• Cylinderical ideal model

Multiple isocenters were positioned with fixed isocetner separation (1.0 or 1.2 times of collimator size) on the axis of cylinder. Collimator size was 1.0 or 1.5 times of the diameter of the base plane and was the same about each isocenter. Data base were formed about isocenter position, collimator size and isocenter separation.

• Circular cone ideal model

First, one isocenter was positioned at the inner center with collimator size which was the diameter of the inscribed sphere. Then, isocenters were arranged in the remain space.

2.4. Dose Calculation Model

Dose calculation algorithm is needed for constructing data base. There are many dose calculation models. One of them is a single isocenteric dose model which is based on the measurement of 6MV LINAC for circular collimator. This model is exact but requires many parameters and long calculation time. So, we use a spherical dose model in this study. It is induced from the reference head and the single isocentric dose model. This model have only two beam parameters, a radial distance(r) from the isocenter and collimator diameter(C). Calculation time of this model is fast and the result is acceptably exact.

$$D_S = 1 - s_1 \exp[-s_2 \times (C/2 - r) - s_3 \times (C/2 - r)^2] \quad \text{for } r \le C/2$$
$$= s_4 + (1 - s_1 - s_4)\exp[-s_5 \times (r - C/2)] \quad \text{for } r > C/2$$

Eq. 1. Spherical dose model. Where C is collimator size; r is a radial distance from the isocenter

2.5. Decision of the similar pattern

It is possible to include target by one bulky ideal model, but non-target structure to be included by it is lager than target structure. Then target structure is divided into a few parts. After a division of the target region, a pattern is selected for each part. After a pattern selection, geometry parameters must be defined. Then, downhill simplex method (Nelder-Mead) with a initial solution that is a function of a pattern of ideal model and geometry parameters to be defined by human is used to decide the final parameters. This optimization method requires only function evaluations not derivatives so it is effective and is computationally compact. The considered geometry parameters are height, radius, angle of rotation and translation in the rectangular coordinate system. Planner selects initial solution that includes divided region. Then, downhill simplex method finds out the optimized solution within a range of each parameter. The cost function in this study was defined Eq. 2.

$$\text{cost} = -V_C + \omega_1 V_N + \omega_2 V_U$$

Eq. 2. Cost function. Where V_C : tumor volume covered by ideal model,
V_N : normal volume covered by ideal model, V_U: target volume uncovered by ideal model,
w_1, w_2: weighting factor (>0)

2.6. Parameter selection and adjustment

If the ideal model is determined, the most important parameters are a kind of model, height and radius. Isocenter positions and collimator sizes are looked up in data base about these parameters. Then, isocenter positions are transformed by geometry parameters of ideal model. Dose distribution is calculated and normalized by maximum. If dose distribution is not acceptable, parameters are adjusted and the process was executed, again.

3. RESULTS

To test optimization procedure, one imaginary target was assumed U shapes. U shape was in $-1.5<x<1.5$, $-0.6<y<1.2$, $-0.5<z<0.5$, and U shape was on the xy plane. U shape was divided into three parts by two different methods, and each part was approximated to cylinder ideal models. Then, dose distribution was calculated using 9 isocenters. (Fig. 3.)

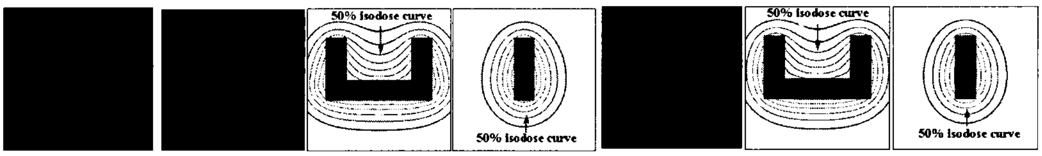

Fig. 3. Optimization procedure for U shape target. Target shapes divided into three regions by a different manner , dose distribution on xy plane at z=0 and on yz plane at x = -0.8cm.

Although the dose distributions were not good, targets were approximately included in specified isodose curve(50%) and acceptable dose distributions would be obtained by a little adjustment of isocenter positions and collimator sizes. In this case, target was divided into 3 parts by two different methods. Each dose distribution was similar but the right result in Fig. 3 is better. Like this, many planning results are obtained by changing target division method and more attractive results can be obtained. Geometry parameters were obtained within less than 1 minute by downhill simplex method. This means that this optimization procedure is very fast.

4. CONCLUSION

In this study, the new optimization protocol using data base and ideal models was developed. Although the produced dose distribution was not fully satisfied due to the limits of the data base, the proposed protocol proved the feasible approach for the optimization. It can be said that the use of data base in optimization problem is novel and effective. If the target patterns are more subdivided and the data base, particularly based on clinical data, are formed better, the optimization result itself will be remarkably improved and furthermore it could be implemented clinically.

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