Comparison of Target Approximation Techniques for Stereotactic Radiosurgical Plan

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The aim of radiosurgery cures a patient to deliver the lower dose at the normal organ and the higher dose at the tumor. Therefore accuracy of the dose is required to gain effect of radiosurgery in surgical planning. In this paper, we developed the methods of target approximation for a fast treatment planning. Nominally, the stereotactic radiosurgery(SRS) using Linac and Gamma knife produces spherical dose distribution through circular collimators using multiple arcs and 201 holes on semi-spherical helmet by ^{60}Co. We developed an automatic radiosurgical plan about spherical packing arrangement. To automatically plan the SRS, new planning methods based on cylinder and cube structure for target shaping was developed. This approach using heuristic and stochastic algorithm is a useful radiosurgical plan without restrictions in the various tumor shapes and the different modalities.

Key words: Stereotactic Radiosurgery, Target approximation

INTRODUCTION

Stereotactic radiosurgery (SRS) is a technique to deliver a high dose to a particular target region and a low dose to the critical organ using only one or a few irradiations while the patient is fixed with a stereotactic frame. It is tedious to find a specific condition to satisfy this object. In this study, the treatment planning techniques were developed and compared the cube with cylinder methods for reconstruction of irregularly shaped target.

MATERIALS AND METHODS

1. Target approximation by Cylinders

The previous study approximated the tumor volume using a cylinder, and automatically packed the isocenters inside the cylinders1. In this study, following three methods were used mainly, one step, create new target coordinates using the target characteristic, two step, development of a cylinder piling method for reconstruction the target, three step, development of sphere packing in each cylinder with the object of including each cylinder within a 40% isodose level.

The frame coordinates system was used in the conventional planning. The planning results may be different even though targets have the same shape. To settle this problem, a virtual axis was created within the target, and the cylinders were piled up around this axis. If the length of the longest line is L, then the target is located between $z=L/2$ and $z=-L/2$ after a coordinate translation from the frame coordinates to new target coordinates. The cylinders were positioned to reconstruct the target according the following methods (Fig. 1).

(1) One cylinder, with a height of h, was located to include the target volume located from $z=-L/2$ to $z=h-L/2$.

(2) Another cylinder was located to include the target volume between $z=2h-L/2$ and $z=h-L/2$

(3) Other cylinders were located using the same manner until all the target volumes was included by the cylinders.

(4) The spheres were packed differently using the following rules due to the relationship between the cylinder diameter (D_c) and the sphere diameter (D_s).

① $D_c<1.5\times D_s$: One sphere was positioned at the center of the cylinder.

② $1.5\times D_s\leq D_c<2.155\times D_s$: Three spheres were positioned at a uniform distance from the center and adjoined the neighbored spheres.

③ $2.155\times D_s\leq D_c$: The spheres were placed at the position to inscribe the cylinder and joined to the neighbored spheres. One sphere was removed if the spheres overlapped, and the remaining the spheres were rearranged to a uniform distance off each other while inscribing the inner cylinder.

2. Target approximation by cubes

The another study approximated the tumor volume using a cube, and automated multi-isocenter arrangement was

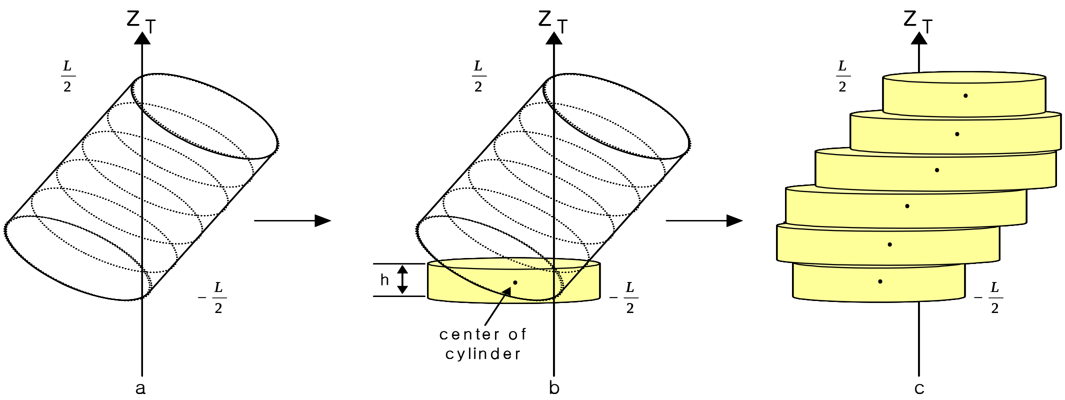


Fig. 1. Target reconstruction method using cylinder. (a) The target was transformed to the target coordinates. (b) Determine the diameter of the cylinder, D_c to include all target volume from z=−L/2 to z=−L/2+h. The z coordinates of the cylinder center was $(h-L)/2$ and the bottom of the cylinder was parallel to the xy plane. (c) Represent the result of the construction target by cylinders.

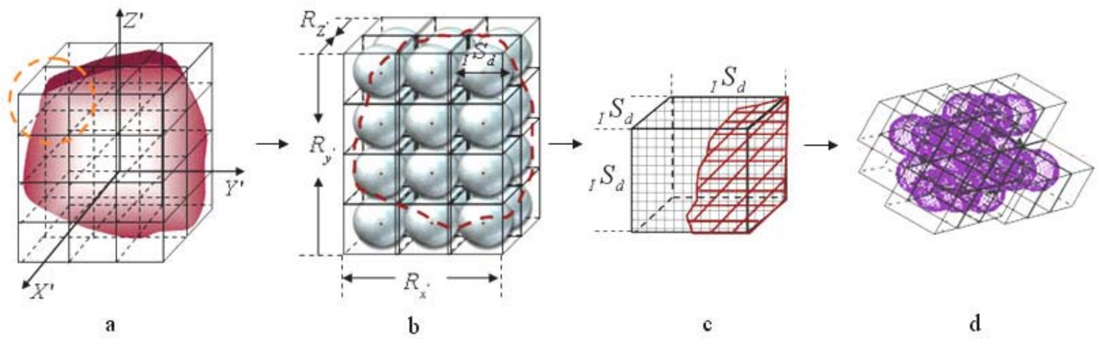


Fig. 2. Target approximation method based on cubic structures. (a) A rectangular parallelepiped was created from the characteristics of the tumor. (b) Multi-isocenters were packed into cubes. (c) A cube and tumor region consisted of voxel units. (d) 3-D arrangement representation of the target volume.

determined mainly using the following methods.

(1) A rectangular parallelepiped was used to create cubes surrounding the tumor volume.

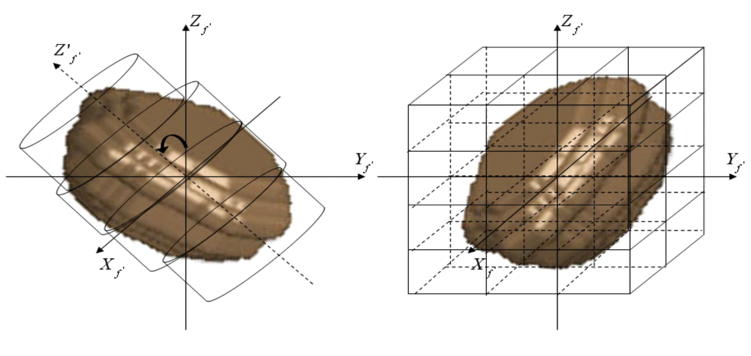
(2) For an array isotropy spheres, the rectangular parallelepiped is divided into cubic regions.

(3) The regions of the cube and tumor were composed of voxel units in three dimensional space, each cubes contained tumor fragments with different voxel counts. The voxel size was defined as 1×1×1 mm^3, and a voxel ratio was determined as the voxel counts in the tumor area by the voxel counts in the cube area. The optimal locations of the isocenters were determined to deliver a high dose in the tumor, while a low dose was delivered in the tissue outside tumor, was selected by a specific voxel ratio that was calculated automatically. Here, the multi-isocenter arrangement depends on the cubic structure and a voxel on space. The cubic structure does not allow a superposition of the spheres (Fig. 2).

3. Comparison of two techniques

The two methods of cube approximation based on the stochastic technique utilizing voxel units and a cylinder approximation based on the heuristic technique were compared with each other (Fig. 3). The target models applied two methods disunited from the asymmetrical and symmetrical target volumes. The asymmetrical target model was consisted of each 18, 20, 7 mm distances on the x, y, z-axis and 1,911 mm^3 volume. The symmetrical target model was constructed for each 18, 20, 18 mm distances on the x, y, z-axis and the 3,922 mm^3 volume. In the two target cases, the initial sphere diameter (${}_IS_d$) was applied to individually separated sizes as 5 mm and 8 mm relative to the target volume. In addition, the longest line of the asymmetrical and symmetrical was 19.92 mm and 21.68 mm respectively. In the cylinder piling based on the heuristic technique, the asymmetrical target with the 5 mm ${}_IS_d$ was surrounded by 4 cylinders, and the symmetrical target 8 mm ${}_IS_d$ was covered by 3 cylinders. Otherwise, the two targets were approximated as 20×20×10 mm^3 and 24×24×24 mm^3 rectangular parallelepipeds respectively. Finally, the spherical dose arrangement in an irregular shaped tumor was evaluated as a dose volume histogram (DVH), the volume of the prescription isodose surface divided by the target volume (ratio PITV) and maximum dose to prescription dose (ratio MDPD) referred by the Radiation Therapy Oncology Group (RTOG) stereotactic radiosurgery criteria.[2)] Moreover, the dose calculation algorithm as the spherical dose model reported by Suh *et al.* was applied.[3)] This model was derived from the reference head model and the single isocentric dose model. It utilizes four standard arcs about a single isocenter with equal arc spacing (e.g. 100 arc with 45 arc spacing). The spherical dose model has only two beam parameters, a radial distance (r) from the isocenter and a collimator diameter (C), 0.5 to 3.5 cm. Equation (1) shows the dose calculation when r is ≤C/2 and Equation (2) represents the dose calculation of an r of >C/2.

$$D = 1 -_1 S \ \exp\left[-S_2\times\left(\frac{C}{2}-r\right)-S_3\times\left(\frac{C}{2}-r^2\right)\right] \quad \cdots\cdots (1)$$



a　　b

Fig. 3. The illustration surrounding target by two techniques. The $Z'_{f'}$ is the longest line in target volume. (a) target approximation using cylinders. (b) target approximation applying a rectangular parallelepiped and cubes.

$$D = S_4(1 - S_1 - S_4) \cdot \exp\left[-S_5 \times \left(r - \frac{C}{2}\right)\right] \quad \cdots\cdots (2)$$

RESULTS

This study was compared the cubes with cylinders method for two targets, which is asymmetric with a 1,911 mm^3 target volume and symmetric with a 3,822 mm^3 target volume. The Cylinders approximation based on heuristic technique was accepted prior to. In the asymmetry target, the cylinder piling method was packed by 36 spheres (within four cylinders) with a 5 mm diameter. Simultaneously, the plan provided coverage of 57% of the isodose shell for the 100% target volume and 67% of the isodose shell for the 95% target volume. The cube piling method was arrayed using 19 spheres with a 5 mm and 10 mm diameter. The prescription isodose level was 68% to 100% of the target volume and 76% to 95% of the target volume. In the symmetry target, the cylinder piling method was packed by 12 spheres (within three cylinders) with an 8 mm diameter. The 100% target volume was covered with a 51% isodose level and the 95% target volume was encompassed by a 65% isodose surface to the maximum dose within the target. Likewise, the cube piling method was arrayed by 16 spheres with an 8 mm diameter. At the same time, this method provided 57% of the prescription isodose level to 100% of the target volume and the 67% isodose level to cover the 95% of the target volume. In the two methods, The MDPDs were ＜2.0, the PITVs using cylinder piling method were ＜2.6. The PITVs by the cubes piling method were ＜2.0. The average absorbed dose was ＞80% of the maximum dose in all cases.

CONCLUSION

In conclusion, these planning methods using target reconstruction and sphere packing were not fully satisfied due to the limits of the target reconstruction using the minimum beam parameters such as isocenter position, the number of isocenter, collimator sizes. However, the proposed protocol is a feasible approach for radiosurgery planning.

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