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Original research article

Corticospinal tract-sparing intensity-modulated radiotherapy treatment planning

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ABSTRACT

Aim: To establish intensity-modulated radiotherapy (IMRT) planning procedures that spare the corticospinal tract by integrating diffusion tensor tractography into the treatment planning software.

Background: Organs at risk are generally contoured according to the outline of the organ as demonstrated by CT or MRI. But a part of the organ with specific function is difficult to protect, because such functional part of the organ cannot be delineated on CT or conventional sequence of MRI.

Methods: Diagnostic and treatment planning images of glioblastoma patients who had been treated by conventional 3-dimensional conformal radiotherapy were used for re-planning of IMRT. Three-dimensional fiber maps of the corticospinal tracts were created from the diffusion tensors obtained from the patients before the surgery, and were blended with the anatomical MR images (i.e. gadolinium-enhanced T1-weighted images or T2-weighted images). DICOM-formatted blended images were transferred and fused to the planning CT images. Then, IMRT plans were attempted.

Results: The corticospinal tracts could be contoured as organs at risk (OARs), because the blended images contained both anatomical information and fiber-tract maps. Other OARs were contoured in a way similar to that of ordinary IMRT planning. Gross tumor volumes, clinical target volumes, planning target volumes, and other OARs were contoured on the treatment planning software, and IMRT plans were made.

Conclusions: IMRT plans with diminished doses to the corticospinal tract were attained. This technique enabled us to spare specific neuron fibers as OARs which were formerly “invisible” and to reduce the probability of late morbidities.

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1. Background

Intensity-modulated radiotherapy (IMRT) is a technique that spares OARs while maintaining a high dose to the planning target volume. In order to avoid radiation dose to certain areas of the body in IMRT planning, these areas have to be contoured and defined as OARs on the treatment planning system. OARs are generally contoured according to the outline of the organ as demonstrated by CT or MRI. But a part of the organ with a specific function is difficult to protect, because the procedures to fuse functional images to radiotherapy planning CT images have not been fully formulated.

Recent advances in imaging technologies have enabled us to determine the brain areas of specific functions which are not visible in conventional CT or the conventional sequence of MRI. One of the newer imaging technologies includes diffusion tensor tractography. These images can depict the lineage of neuron fibers from the diffusion anisotropy of water in the neuronal axon. Using this method, the putative position of specific neuron fibers in the white matter, such as the corticospinal tract, optic radiation, arcuate fasciculus, can be known.[1–4] For patients with brain tumors who are undergoing neurosurgery, operative procedures have become safe, incorporating diffusion tensor tractography into the preoperative workup, since neurosurgeons are able to know the proximity of the tumor to the eloquent tract before surgery.[5,6] At our hospital, diffusion tensor tractography has also been fused to Gamma Knife treatment-planning MRIs, mainly for patients with arteriovenous malformation, with good clinical results.[3,4,7,8]

Treatment results of malignant glioma are not satisfactory, and various attempts to improve radiation delivery have been made to prolong the patients' survival. IMRT is one of the principal technologies applied for better dose distribution,[9] because the brain has many OARs visible on planning CT or on conventional MRI, such as the brainstem, optic pathways, eyeballs, and hippocampus. However, invisible parts, like specific neuron fibers, should be considered as OARs to reduce the morbidity rate, especially when a higher dose delivery is intended.

2. Aim

In this study, we tried to define the corticospinal tract as an OAR by fusing diffusion tensor tractography into the planning CT to diminish the dose to the corticospinal tract and use the result to conduct IMRT planning of patients with malignant glioma.

3. Materials and methods

3.1. *Patients and imaging studies*

High-grade glioma patients with pathological diagnosis confirmed by stereotactic biopsy who had been treated by 60 Gy of 3-dimensional conformal radiotherapy with concurrent and adjuvant temozolomide were selected. Their diagnostic images and treatment-planning images, respectively, were used for IMRT planning.

Diffusion tensor tractography was constructed as shown previously.[1,7] In brief, diffusion-weighted images were acquired at 1.5 T using a head coil with echo planar capability, by a single-shot spin echo-echo planar sequence (TR 6000 ms, TE 78 ms) before stereotactic biopsy. Diffusion tensors were then calculated and 3-dimensional fiber-tract maps were created using the free software dTV. The software was developed by the Image Computing and Analysis Laboratory at the Department of Radiology of the University of Tokyo Hospital, Japan, and is available online at http://www.ut-radiology.umin.jp/people/masutani/dTV.htm. A region of interest was manually drawn as seeds on an uninvolved region of the corticospinal tract that could be detected in the cerebral peduncle on the anatomical MR image (gadolinium-enhanced T1-weighted images or T2-weighted images), and another region of interest on the ipsilateral precentral gyrus as a target. Diffusion tensor tractography was reconstructed in 3-dimensional space from the seeds along the major eigenvector to trace axonal projections, and only the tracts reaching the target were displayed. Tracking was terminated when it reached a pixel with a fractional anisotropy lower than 0.18. Three-dimensional fiber-tract maps were made by marking the voxels running through the tract. The anatomical images and fiber-tract maps were blended, and the blended images were re-sliced and converted to the DICOM format by image processing software Dr. View (AJS Co. Ltd., Tokyo, Japan).

3.2. *Image fusion and treatment planning*

Treatment planning CT images were obtained with the head fixed by a thermo-plastic shell. Blended tractography images were fused to treatment planning CT images on a treatment planning system. The corticospinal tract that was displayed on the blended images was contoured manually on the treatment planning system and defined as an OAR. Gadolinium-enhanced T1-weighted images, T2-weighted images, or fluid-attenuated inversion recovery images were also fused to the planning CT in order to contour other OARs, gross tumor volumes, and clinical target volumes (CTVs). The eyeballs, lenses, optic pathways, and brainstem were contoured as OARs. CTV1 was defined as a perifocal edema with a 15-mm margin, and CTV2 was the tumor enhanced with gadolinium on MRI. PTV1 and PTV2 were defined as the corresponding CTVs plus 5-mm margins, and IMRT plans were made by the Pinnacle^3 treatment-planning system (Philips/ADAC, Milpitas, CA) to deliver 50 Gy to PTV1 and 65 Gy to PTV2 by the simultaneous integrated boost method in 25 fractions. Dose constraints are shown in Table 1. For comparison to the conventional IMRT plan, another IMRT plan was made under the same sets of dose constraints but without that for the corticospinal tract.

4. Results

Blended tractography images containing anatomical information and fiber-tract maps were constructed (Fig. 1). The