学 位 論 文 の 要 旨

氏名　池田 新

学位論文名　Distortion of Magnetic Resonance Images and Treatment Planning for Stereotactic Radiosurgery

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著者名　Shin Ikeda, Masahiro Moriyama, Masaki Yokokawa
Atsuya Kawaguchi, Koji Uchida, Hajime Kitagaki
Nobue Uchida

論 文 内 容 の 要 旨

INTRODUCTION

Stereotactic radiosurgery (SRS) has recently become more widely used for metastatic brain tumors. Multidisciplinary therapy, such as the combination of whole brain irradiation with SRS or surgery, achieves superior results in terms of survival, neurocognitive function, and quality of life. Radiation oncologists commonly use computed tomography (CT), as it provides data on X-ray absorption. Magnetic resonance imaging (MRI) achieves greater soft tissue contrast and a more accurate depiction of tumors than does CT, but provides no information on X-ray absorption. Therefore, fused MRI/CT images are now used clinically. However, MRI have greater distortion due to nonlinearity of the gradient field, inhomogeneity of the magnetic field related to the eddy current, magnetic susceptibility, as well as other factors. To our knowledge, there have been no studies on how distortion in MRI images influences dose delivery in cases of SRS. Accordingly, we investigated the influence on localization of the distortion on MR images in a comparison with

CT scans relative to the special SRS frame, and the influence on radiation therapy planning, using a brain phantom.

MATERIALS AND METHODS

A brain phantom was created having T1 & T2 values similar to those of brain tissue, as previously described. A mixture of 3.0 % carrageenan gel, 60 μmol /kg gadodiamide hydrate, 1.0 % agarose gel, 0.24 % NaCl, 0.03 % NaN_3, and distilled water (2000 ml) was gradually heated while stirring until boiling and then poured into a pair of hemispherical molds (15 cm in diameter). Three "tumors" composed of butadiene resin were also prepared: one sphere approximately 3 cm in diameter and two spheres each approximately 2 cm in diameter. Three small titanium cylinders were used as markers. A three-axis laser pointer of the CT scanner was used to set the position of the phantom, and the scan reference point was marked by set-up markers that did not cause artifacts. The phantom was set up for MRI in the same manner. As automatic fusion is often not sufficiently accurate, the fusion was performed manually by five radiation oncologists to achieve the best possible outcome. If there were no distortion, the 3 axes and 3 landmarks would match precisely, as would the pair of 3-D images. However, distortion affects not only the tumor but also the phantom and markers on MR images, making impossible precise fusion of CT and MR data. We measured the greatest displacement of the phantom tumor on the fused images by counting pixels between the tumor contours of the compared MRI data and CT scans.

After fusing the CT and MR images in the radiation therapy planning system, we planned the photon beams for SRS based on MRI tumor contours. The prescribed dose was marginal 16 Gy delivered by 5 beam arcs with a circular collimator. We then compared some treatment parameters, including maximum dose, minimum dose, and homogeneity index, for treatments based only on CT with those based on fused CT/MRI with the greatest distortion.

RESULTS AND DISCUSSION

The CT scans and MR images were all of high quality. With MRI, tumor outlines were sharper and clearer than with CT. Tumor location and size on CT did not match well with those on MRI with manual tumor contouring. The maximum distortion of the larger tumor phantom outline was 3.3 mm on coronal MR images, and tumor volume was approximately 10% less than shown on CT scans. SRS planning with fused images derived from MR images achieved worse radiation dosimetry and treatment parameters than with those obtained by CT scan. The peripheral minimum dose decreased from 16.2 Gy for the MRI tumor contour to 10.6 Gy for the tumor CT contour. Dose volume histograms showed apparent deterioration of treatment quality for the CT tumor contour.

Spatial information and electron density data obtained from CT scans are essential for SRS, as the CT tumor contour helps to determine the true gross tumor target volume (GTV). However, evaluation of the GTV on plain CT scans is difficult due to poor tissue contrast, especially in the case of brain lesions even with contrast enhancement. MRI achieves better tissue contrast, especially with brain tumors; thus an MRI-depicted tumor contour is very helpful in determining the reference GTV. In generally, radiation oncologists use fused images utilizing both CT and MRI data for SRS planning in clinical practice though it is widely acknowledge that image distortion in MRI creates discrepancies in brain images. Linear distortion of MR images has been reported predominantly in the range of 2-3 mm. The present study shows that linear distortion of as much as 3.3 mm in MR coronal images can occur in peripheral regions of the brain. This result cannot be overlooked in light of the need for quality accuracy of SRS.

In SRS planning, 1-2mm is generally added to GTV as a margin for allowance for set-up error. Because minimum dose, prescription dose, and tumor volume are critical factors in SRS, these parameters must be defined accurately. It is possible the peripheral region of a brain tumor may lie outside the MRI-delineated contour and such distortion on the MR image may prevent local control and lead to more frequent recurrences or residual tumors due to inadequate coverage and dose levels in the course of SRS.

As the irradiated volume increases in SRS, so do the adverse effects, including brain necrosis and atrophy; therefore, the irradiated volume must be reduced to the greatest possible extent. In this phantom experiment, it was possible to distinguish the tumor outline on plain CT scans, and to identify discrepancies between CT and MRI-depicted tumor contours. Regardless of efforts to minimize the influence of distortion at the time of image acquisition, some distortion will remain on the MR image. The inability to determine or recognize the extent of such distortion in a clinical setting has been a significant problem for radiation oncologists. The nature and extent of any such influence in an actual clinical setting is a matter of speculation and future study.

CONCLUSION

This study showed that image distortion on MRI may significantly influence the outline of the target and estimated tumor volume, as well as the dosage delivered to the tumor.