Radiotherapy

A 3D T1-weighted gradient-echo sequence for routine use in 3D radiosurgical treatment planning of brain metastases: first clinical results

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Abstract. The authors report on a 3D sequence for MRI of the brain and its application in radiosurgical treatment planning of 35 brain metastases. The measuring sequence, called magnetization-prepared rapid gradient echo (MPRAGE), was compared with 2D T1-weighted spin-echo (SE) sequences following intravenous contrast medium application in 19 patients with brain metastases. The average diameter of all lesions was similar in both sequences, with 16.8 and 17.0 mm for SE and MPRAGE, respectively. Target point definition was equal in 29 metastases, and in 6 cases superior on MPRAGE, due to better gray-white matter contrast and increased contrast enhancement. In cases of bleeding metastases there was improved depiction of internal structures in 3D MRI. Postprocessing of 3D MPRAGE data created multiplanar reconstruction along any chosen plane with isotropic spatial resolution, which helped to improve radiosurgical isodose distribution in 4 cases when compared to 2D SE. However, sensitivity of 3D MPRAGE to detect small lesions (<3 mm) was decreased in one patient with more than 30 metastases. We conclude that 3D gradient-echo (GE) imaging might be of great value for radiosurgical treatment planning, but does not replace 2D SE with its current parameters.

Key words: Radiosurgery - MPRAGE - Spin echo - Metastases

Introduction

Brain metastases are a major problem in neuro-oncology, with a rate of 43% of all intracranial tumors [1]. For multiple or inoperable metastases radiotherapy is an accepted treatment modality with radiosurgical techniques being employed at a linear accelerator facil-

ity [2] combined with stereotactic localization methods [3].

To avoid or minimize the side effects of radiosurgery, precise localization and definition of target volume is an indispensable prerequisite. For the delineation and localization of tumors and organs at risk CT is the standard imaging modality [5]. By virtue of good soft tissue contrast and multiplanar image format MR has become an important alternative to CT as a technique for assessing the necessary image data [6]. In order to plan irradiation treatment the sole use of MR-based data is generally feasible [7]. However, in radiosurgery film dosimetric phantom measurements have shown that tissue inhomogeneities do not significantly influence the shape of relative dose distribution of deeply positioned lesions of the brain [2, 7]. Therefore, dose calculation of radiosurgery can be based only on 3D geometric conformation of the patient’s head using MRI data at the sole data input base [7].

Generally T1- and T2-weighted SE sequences are employed for standard imaging in radiosurgery. The 3D GE imaging offers important advantages to SE sequences with regard to spatial resolution, slice profile, contrast variability, imaging time, specific absorption rate (SAR), and reduced vascular flow artifacts. This study was performed to evaluate the ability of a T1-weighted 3D GE imaging sequence (MPRAGE) [4] to serve as a practical alternative to routinely enhanced 2D SE as a sole base for radiosurgical treatment planning of brain metastases.

Materials and methods

Patients

A total of 19 patients with suspected intracranial metasta-

ses originating from different primary tumors (Table 1) were referred to the German Cancer Research Center (dkfz) for single high-dose radiosurgery. Histologic results of the primary lesions were available in all
Table 1. Primary tumors of 19 patients with brain metastases

<table>
<thead>
<tr>
<th>Type</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Malignant melanoma</td>
<td>10</td>
</tr>
<tr>
<td>Bronchial carcinoma</td>
<td>6</td>
</tr>
<tr>
<td>Breast carcinoma</td>
<td>2</td>
</tr>
<tr>
<td>Pancreas carcinoma</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 2. Location of 35 brain metastases in 19 patients

<table>
<thead>
<tr>
<th>Location</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cortex: interface gray/white matter</td>
<td>26</td>
</tr>
<tr>
<td>Cerebellar hemispheres</td>
<td>4</td>
</tr>
<tr>
<td>Corona radiata</td>
<td>3</td>
</tr>
<tr>
<td>Basal ganglia</td>
<td>2</td>
</tr>
</tbody>
</table>

Note: Diffuse spread of more than 50 metastases in 1 patient

patients. The series included 10 males and 9 females (age range 24–63 years; mean age 46 years). The different locations of the intracerebral metastases are summarized in Table 2. The details of the clinical symptoms in 19 patients presenting with intracerebral metastases are shown in Table 3. In all cases a neurosurgeon evaluated the metastases to be unresectable. A single metastasis was found in 10 patients, 2 in 5 patients, and 3, 4, and 8 metastases were detected in another three patients, respectively. In one case more than 50 metastases were found. Single high-dose irradiation was performed in 17 patients. In one patient with 8 metastases it was decided to irradiate only metastases that were most likely to cause clinical symptoms in the near future. The patient presenting more than 50 metastases received whole-brain irradiation.

Imaging and radiation techniques

A 1.5 T MRI system was used (Magnetom SP, Siemens AG, Erlangen, Germany). After performance of an initial transversal T1-weighted sequence Gd-DTPA (0.1 mmol/kg/body weight) was administered as a slow IV injection. Consecutively, MPRAGE was performed with heavily T1-weighted imaging parameters (TR 10 ms, TE 4 ms, TI 300 ms, flip angle 10°, 128 partitions at a slab thickness of 256 mm [yielding in 2-mm section thickness], field of view [FOV] 200–260, and matrix 256 × 256). The MPRAGE version with these sequence parameters and centric-phase-encoding order lasted 6 min, 46 s. To avoid wrap-in effects imaging of the whole head was necessary. Thereafter, 2 ml Gd-DTPA were injected and a standard T1-weighted SE sequence followed (TR 600 ms, TE 15 ms, two acquisitions with 4 mm section thickness, and matrix 256 × 256). Overall image acquisition time for 2D SE imaging was 11 min, 52 s.

During the diagnostic and therapeutic procedure the patient’s head was immobilized in an individually fitting light cast head mask. A targeting device, visualized in the tomograms, was attached to determine the stereotactic target point coordinates [8]. By employing this system and several computer programs developed at the German Cancer Research Center, the information about size, shape, and localization of the target volume can be transformed between the imaging system and different imaging systems [8]. A computer program allows precise calculation of target point coordination and definition of target volume, collimator size, and isodose distribution [8]. The planning target is defined by a radiation oncologist. A detailed description of the stereotactic system and its accuracy is given elsewhere [9].

Correction of spatial distortion in MRI

Implementation of MRI for stereotactic localizations requires accurate spatial information. Depending on the individual imaging system eddy currents of the pulsed gradients, excited in the cryo shield during the imaging system, may introduce geometric distortions in all three dimensions. These errors in position can be evaluated by means of two phantoms localized within the stereotactic guidance system: a 2D phantom displaying “pin-cushion” distortion in the x–y plane and a 3D phantom displaying displacement, warp, and tilt of the image plane itself. The image-plane distortion is corrected (diminishing displacements to the size of a pixel) by calculation based on modeling the distortion as a fourth order 2D polynomial, where errors in the z coordinate and tilt of the image planes may be corrected by adjustment of the gradient shimming currents. Patient-induced distortion due to susceptibility variations is a general problem and cannot be corrected by phantom measurements and polynomial mapping. Phantoms, measurements, and correction methods, as well as geometric and anatomic verification, are described in detail elsewhere [8].

The geometric accuracy was tested by assessing the stereotactic coordinates of a point source with and without correction and comparing these with those measured manually. For this purpose a cross plastic tube (1 mm inner diameter) filled with Gd-DTPA solution was placed in the stereotactic guidance system. The cross was aligned in the z direction and the stereotactic coordinates of its cross-point was measured (MPRAGE sequence) from axial images. After geometric correction the image-based evaluated stereotactic coordinates of the cross-point coincide within 1 mm with regard to the manually measured exact stereotactic coordinates, whereas discrepancies of approximately 2 mm appeared without correction of geometric distortion. After correction the accuracy of the geometric information was limited only by the pixel resolution of the image (1 mm). A more detailed description is provided elsewhere [9].

Results

All 19 patients had 6 weeks postirradiation MR scans taken for follow-up. Chronic and temporary treatment discomfort included alopecia (4 cases), skull erythema