MR-simulation for radiotherapy treatment planning of head and neck cancer using 3T MAGNETOM Vida

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Abstract

Purpose
To explore the potential of the new 3T MAGNETOM Vida for magnetic resonance (MR)-based radiotherapy (RT) simulation and treatment planning in head and neck cancer (HNC) patients as well as for follow-up imaging during RT treatment.

Methods and materials
A set-up has been defined to position HNC patients in RT treatment position for MR examination using the MAGNETOM Vida system for anatomical and functional image data acquisition before and during RT. MR imaging was performed using a flexible 18-channel body coil (Body 18) to allow positioning of the patient using a thermoplastic mask for head and shoulder fixation as well as a flat table top. T1-weighted contrast-enhanced as well as T2-weighted images were acquired to assess anatomical information. Additionally, diffusion-weighted (DW) MR image sequences were used for assessing functional tissue information.

Results
Our first experience with the described setting showed that imaging with the MAGNETOM Vida system in RT treatment position using the flexible coil is possible. Anatomical and functional MR image data showed very high image quality. Furthermore, MR data could be easily fused to planning CTs of HNC patients and were used for more accurate target volume and organ at risk delineation.

Conclusion
MR imaging before and during RT in treatment position is possible in the MAGNETOM Vida system. With this set-up, high image quality can be achieved, which is essential for improved target volume delineation in MR-guided RT.

Introduction

Magnetic resonance (MR) guided radiotherapy (RT) approaches have gained a lot of attention in the last years [1]. MR offers high resolution imaging of anatomical and functional tissue properties. In contrast to computed tomography (CT), MR imaging provides high soft tissue contrast. Consequently, MR imaging data may be extremely valuable for target volume delineation in high precision RT and also for assessing anatomical and functional changes in the tumor region early during treatment [2, 3].

Figure 1:
Patient examination in radiotherapy specific position using a flat table top, a thermoplastic mask and a flexible body coil in the MAGNETOM Vida.

The new generation of MR scanners, such as the 3T MAGNETOM Vida, offer extremely fast and accurate imaging sequences to assess anatomical and functional characteristics of tumors and may thus be ideal tools for MR-based RT simulation and response assessment during treatment.

The aim of this project was to develop an imaging set-up on the MAGNETOM Vida system allowing for MR imaging of head and neck cancer (HNC) patients in RT treatment position, i.e. using a thermoplastic mask and a flat table top for integration into RT target delineation and treatment planning [4, 5].

Methods and materials

Imaging set-up

To allow MR imaging of HNC patients in RT treatment position using the MAGNETOM Vida system, a flat table top overlay (Qfix, Avondale, PA, USA) is positioned on top of the regular patient table. Patients are positioned on this flat table top using a thermoplastic mask (ITV, Innsbruck, Austria) which is fixed at the table top using an MR-compatible mask holder system.

For MR imaging, the flexible 18-channel body coil (Body 18) is positioned around the RT mask with a distance of approximately 2 cm (cf. Fig. 1) in addition to the integrated 72-channel spine coil.

Using this set-up, MR imaging is performed before the start of RT treatment and after approximately two weeks of treatment to analyse early treatment response.

Imaging protocol

The MR imaging protocol consists of the following sequences:

1. T2w anatomical MRI:
   A quiet T2w TSE anatomical sequence in transverse orientation is used for anatomical depiction of organ structures and oncologic findings using the following parameters: matrix 192 x 192, resolution 1.3 x 1.3 mm^2, slice thickness 4 mm, TE = 53 ms, TR = 8180 ms, STIR fat sat.
2. Diffusion-weighted imaging (DWI):
   DWI of the head/neck region is a challenge due to magnetic field inhomogeneities often resulting in image distortion, ghosting and signal loss which makes the use of DWI for RT planning difficult. The MAGNETOM Vida system offers technical solutions to overcome these limitations using readout-segmented (RESOLVE) echo-planar imaging (EPI) and slice specific shimming (SliceAdjust).

   DWI was thus performed using a RESOLVE sequence with SliceAdjust and eight different b-values (b = 0, 20, 40, 80, 120, 200, 500, 1000 s/mm^2) and the following parameters: matrix size 84 x 128, resolution 3 x 3 mm^2 (interpolated to 1.5 x 1.5 mm^2), slice thickness 5 mm, TE = 44 ms, TR = 10800 ms, with water-specific excitation.

   Subsequently, quantitative parameters are calculated including the apparent diffusion coefficient (ADC) but also perfusion parameters using multiple b-value images for intravoxel incoherent motion (IVIM) modelling. Thus detailed information about tissue perfusion and diffusion components can be obtained.
3. Dynamic contrast-enhanced imaging (DCE):
   DCE of the neck poses a challenge due to the necessity for high temporal resolution and the occurrence of involuntary pharyngeal and laryngeal motion. In order to overcome these challenges, the MAGNETOM Vida offers time-resolved radial imaging with compressed sensing reconstruction (GRASP). We implemented GRASP DCE of the neck region for quantitative analysis of tumor perfusion after injection of 0.1 mmol Gadobutrol/kg using the following parameters: matrix

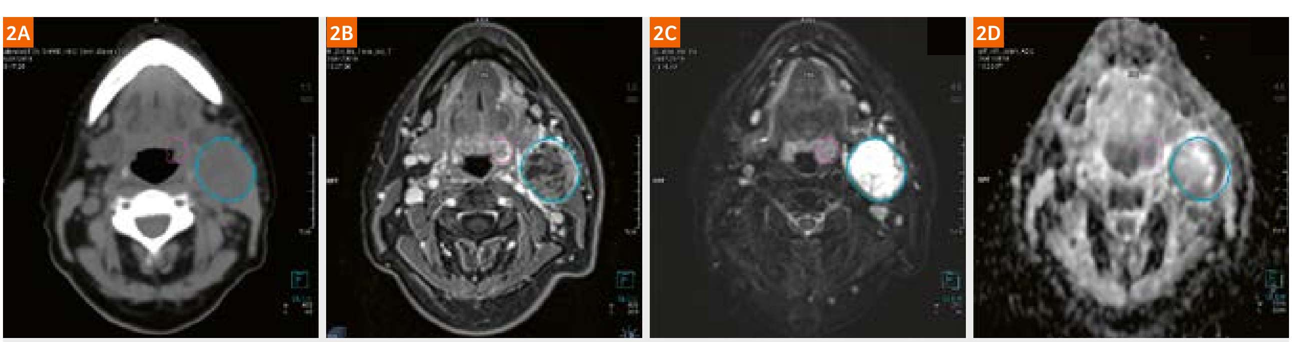

Figure 2:
CT and MR images for RT simulation in a patient with HNC. The primary tumor region is contoured in pink, a large lymph node metastasis in blue. Image data are shown in the following sequence: **(2A)** planning CT, **(2B)** T1w MR post contrast, **(2C)** T2w MR image (STIR) and **(2D)** ADC map.

size 224 x 224, resolution 1.1 x 1.1 mm^2, slice thickness 3 mm, TR = 4.14 ms, TE = 1.86 ms with spectral fat saturation. Dynamic frames were reconstructed with a time resolution of 4.3 s.

4. T1w post contrast:
After DCE, a highly resolved isotropic T1-weighted contrast-enhanced VIBE sequence is performed for detailed anatomical depiction of the structures of interest using the following parameters: matrix size 270 x 320, resolution 1 x 1 x 1 mm^3, TR 6.56 ms, TEs 2.46 and 3.72 ms, with Dixon fat sat.

Axial, coronal and sagittal reformations are automatically performed within the *syngo* RT image suite.

Target volume delineation for radiotherapy treatment planning
After successful image acquisition, MR imaging data were transferred to the RT treatment planning system or a dedicated contouring system (RT image suite, Siemens Healthcare, Erlangen, Germany). Here, the MR data was registered to the RT planning computed tomography (CT) scan and used for target volume and organ at risk (OAR) delineation.

Results

First experience on five patients with this set-up showed MR images of high, diagnostic quality. In particular, we observed high image quality and anatomical accuracy of DWI using the RESOLVE sequence with slice adjust and of DCE using GRASP. An image example is provided in Figure 2.

Patients tolerated imaging in RT treatment position well, as the net imaging time for the RT simulation sequences was approximately 20 minutes. MR imaging data for each patient was transferred to the RT treatment planning system (Oncentra Masterplan, Elekta AB, Sweden) as well as to the *syngo*.via application RT image Suite for registration to the planning CT and tumor as well as OAR contouring. Rigid as well as deformable image registration with the planning CT worked very well due to the same patient positioning with flat table top and thermoplastic mask. Figure 2 presents an example of a patient examined with the 3T MAGNETOM Vida system for RT simulation.

In addition to anatomical information assessed from T1w and T2w MR sequences we aim for measuring functional properties of tumors using DW-MR imaging. IVIM data with eight different b-values were of very high quality in the first patients. Hence, quantitative ADC maps as well as information on perfusion and diffusion from a bi-exponential fit could be acquired.

Discussion

With the proposed set-up, consisting of a thermoplastic mask, a flat table top and a flexible body coil high quality anatomical and functional MR imaging in RT treatment position is possible for patients with HNC. Thus, this set-up constitutes an optimal tool for pre-treatment RT simulation in order to gain accuracy in target volume delineation as well as for the assessment of functional information in terms of ADC or IVIM data. Advanced MR sequence techniques such as RESOLVE DWI with slice adjust and GRASP together with the available hardware of the Vida System provide the necessary qualitative and quantitative image quality for precise RT planning.

Moreover, additional follow-up data can be acquired early during RT where this set-up may be beneficial to quantify radiation induced functional changes on a regional or even voxel level. Such quantitative and geometrically accurate data might be used in the future as a basis for individualized RT treatment interventions as e.g. dose painting.

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References

1 Lagendijk JJW, Raaymakers BW, Van den Berg CAT, Moerland MA, Philippens ME, van Vulpen M. MR guidance in radiotherapy. Phys Med Biol 2014;59:R349-69.
2 Van der Heide UA, Houweling AC, Groenendaal G, Beets-Tran RGH, Lambin P. Functional MRI for radiotherapy dose painting. Magn Reson Imaging 2012;30:1216-23.
3 Baumann M, Krause M, Overgaard J, et al. Radiation oncology in the era of precision medicine. Nat Rev Cancer 2016;16:234-9.
4 Hanvey S, McJury M, Tho LM, et al. The influence of MRI scan position with oropharyngeal cancer undergoing radical radiotherapy. Radiat Oncol 2013;8:129.
5 Fortunati V, Verhaart RF, Verdujin GM, et al. MRI integration into treatment planning of head and neck tumors: Can patient immobilization be avoided? Radiother Oncol 2015;115:191-4.