Lung Cancer Perfusion: Hybrid acquisition technique for 3D MRI to overcome breath hold limitations and minimize motion-related displacement.

C. Hintze[1], A. Stemmer[2], M. Bock[3], T. Kuder[1,3], F. Risse[3], J. Dinkel[1], M. Puderbach[1], C. Fink[4], H. U. Kauczor[1], and J. Biederer[1,5]

[1]Radiology, German Cancer Research Center, Heidelberg, Germany, [2]Medical Solutions, Siemens AG, Erlangen, Germany, [3]Medical Physics in Radiology, German Cancer Research Center, Heidelberg, Germany, [4]Clinical Radiology, University Hospital Mannheim, Mannheim, Germany, [5]Diagnostic Radiology, University Hospital Schleswig-Holstein Campus Kiel, Kiel, Germany

Introduction:

To record perfusion of lung cancer by imaging requires examination times exceeding breath hold capabilities of patients [1,2]. For full coverage of wash in a fast imaging method and for wash out a sufficient length of imaging in the range of minutes is necessary. The assessment of perfusion is disturbed by overall motion of the thorax and existing pathologies during breathing. The aim of this MR study was to evaluate a hybrid breath hold and navigator triggered technique in combination with a time-resolved 3D gradient echo pulse sequence (FLASH 3D) in imaging lung tumor perfusion to overcome the motion-related challenges.

Methods:

136 patients with suspected Lung cancer were enrolled prior to treatment (48 female/ 88 male, mean age 62, age range 19 – 82 years). 17 Patients received follow up examinations. A total of 157 examinations were performed. For imaging of tumor perfusion gadopentetate dimeglumine (Magnevist, Bayer Schering Pharma AG, Berlin, Germany) was administered with a dose of 0.07 mmol/kg body weight. Peripheral injection of the contrast media followed by a flush of 30 ml of normal saline solution was carried out at a rate of 5 ml/s using an automated injection system (Spectris Solaris MR Injector, Medrad Inc., Indianola, PA, USA). Tumor movement was measured with a coronal single slice multi frame steady state sequence during free breathing (TrueFISP; 60 acquisitions; TA: 19 s; TE/TR: 1.14/317.1 ms; FA: 67°).

Tumor perfusion was acquired by using a time-resolved FLASH 3D with a hybrid breath hold and navigator triggered acquisition technique. For the FLASH 3D the following image parameters were used: TE/TR: 0.76/2.32 ms; FA: 15°; bandwidth: 705 Hz/pixel; acceleration factor 2 using GRAPPA; reference k-space lines for calibration: 20; field of view (FOV): 400 x 333 mm; matrix: 192 x 160; slab thickness: 100 mm; 20 slices per slab, scan time per 3D data set: 2.25 s. Achieved voxel size was 2.1 x 2.1 x 5.0 mm. With the default settings 60 transversal data sets were acquired. The acquisition was performed in a hybrid technique with two phases. The first phase started in expiratory breath hold 3 s prior to contrast media injection. Typically 10 consecutive data sets were obtained. In the second phase the remaining 50 were measured whenever the patient had exhaled. While the reiteration time for the data sets in the first phase equals the scan time, the interval between measurements during the second phase is determined by the individual. Typically a 3D data set was obtained every 4 to 5 seconds. The respiratory triggering during the second phase was achieved by monitoring the patients diaphragm position with a 2D, low resolution real time gradient echo navigator sequence with low flip angle for Prospective Acquisition Correction (PACE). The navigator TR was set to 150 ms and the acceptance window for detection of diaphragm position was set to 2 mm.

Directly before the first phase in expiratory breath hold the mean diaphragmatic position is recorded in a learning phase of five breath cycles to prepare for its reacquisition after the breath hold phase. The first approach in instructing the patients for this examination simply called for a breath hold when necessary for the first phase. Upon noticing an occasional severe delay in the start of the acquisition of the first triggered data set, there was a change in the patient instruction. We deliberately provoked a shortage of breath directly before the start of navigator training with another breath hold to simulate the situation at the transition from phase one to two.

For data post processing a dedicated in-house-written analysis software based on the Interactive Data Language (IDL, Research Systems, Boulder, CO, USA) was used. After interactively browsing through the 60 measurements for displaced 3D data sets a manual motion correction was performed when necessary. In this case the displaced 3D data sets were put back in line again by applying a rigid registration in form of altering the slice position of a 3D block in full steps of slice thickness. The number of displaced 3D data sets and their individual correction in z-axis where recorded. Furthermore the individual time delay necessary for the first acquisition in the second, free breathing phase was recorded. The entire perfusion measurements were loaded into a 4D viewer of our analysis tool – for perfusion analysis.

Individual tumor motion was determined in interactive analysis of the coronal TrueFISP.

Results:

In 4 cases the examination was aborted on request of the patient and no eligible perfusion images were acquired. In 4 patients the motion displacement exceeded the correctable distance due to heavy coughing. In 3 patients there was an error during contrast media injection. In total, 146 examinations provided 4D, T1-weighted perfusion measurements eligible for further assessment. Within which 60 cases a motion correction had to be performed. This typically involved just one acquisition in each examination (maximum 6 once). The mean correction in z-axis was equivalent to 1 slice or 5 mm. The maximal correction in z-axis was equivalent to 9 slices or 45 mm. In all 146 cases the direct measurement of tumor motion with the TrueFISP showed a mean displacement of 1,1 cm in z-axis and a maximum displacement of 5,5 cm. The time delay for the first detected expiration in all examinations after the first breath hold phase varied from 3,1 to 25,5 s. The median time delay was 7,0 s (SD 4,4 s).

There was no correlation between breath dependent tumor movement and motion artifacts during perfusion measurement. There was no correlation between time delay of the first measurement of the second phase and motion artifacts. There was no influence of the additional breath hold command prior to navigator training on the delay of the first acquisition or displacement of individual 3D data sets during the second phase (figure 1 and 2, right side with additional breath command).

In all 146 cases – after post processing when necessary – the final 4D data sets comprised of 60 contrast enhanced measurements of T1 weighted perfusion imaging of moving lung tumors with minimal remaining motion artifacts. All data sets covered the wash in with a high imaging frequency of 2.25 s / volume during the first imaging phase and provided coverage of wash out of up to 4 min at a slower and individual pace. In all cases further perfusion analysis was performed (figure 3).

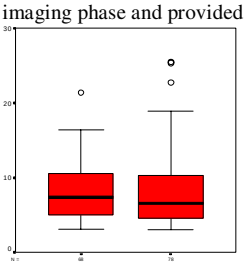

Figure 1. *Delay.*

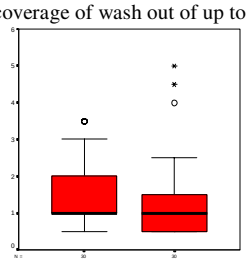

Figure 2. *Maximum displacement.*

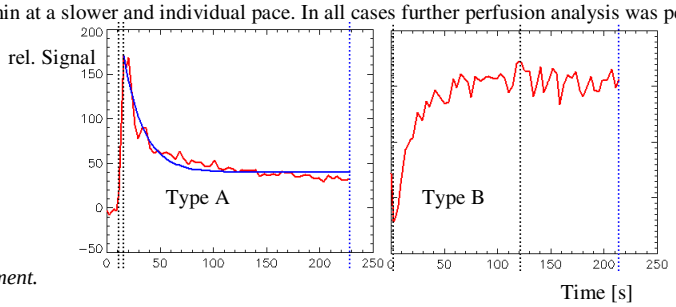

Figure 3. *Examples of curve types found in patients with lung tumors. Type A with distinct maximum and following wash-out phase. Type B with continuous wash-in.*

Discussion and Conclusion:

Adequate tumor perfusion measurements in lesions that have a breath cycle dependent movement have been successfully performed with a time resolved FLASH 3D sequence with a hybrid breath hold and 2D-PACE navigator triggered technique. The approach described allows for a fast imaging of rapid signal changes during wash in as well as prolonged imaging of the typically slower wash out for an almost unlimited amount of time. Even longer lasting imaging protocols are feasible, since it is no longer dependent on breath hold capabilities of the patient. Rigid registration can be used to deal with the remaining motion artifacts. The acquisition of 4D data allows for the use of an arterial input function in perfusion analysis since at least part of the Truncus pulmonalis is easily covered aside from the tumor to be examined. This method is ideally suited for prolonged and detailed perfusion imaging of pulmonary lesions since it deals with several topics at once: high initial time resolution, prolonged measurement and overcoming individual breath hold limitations, coverage of the whole lesion and simultaneously of an arterial input function.

References:

[1] Ohno Y et al. Radiology 2002;224(2):503-511. [2] Schaefer JF et al. Radiology 2004;232(2):544-553.