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Research article

Pulmonary nodule detection in oncological patients – Value of respiratory-triggered, periodically rotated overlapping parallel T2-weighted imaging evaluated with PET/CT-MR

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ABSTRACT

Purpose: To prospectively evaluate the detection and conspicuity of pulmonary nodules in an oncological population, using a tri-modality PET/CT-MR protocol including a respiration-gated T2-PROPELLER sequence for possible integration into a simultaneous PET/MR protocol.

Methods: 149 patients referred for staging of malignancy were prospectively enrolled in this single-center study. Imaging was performed on a tri-modality PET/CT-MR setup and was comprised of PET/CT and 3T-MR imaging with 3D dual-echo GRE pulse sequence (Dixon) and an axial respiration-gated T2-weighted PROPELLER (T2-P) sequence. Images were assessed for presence, conspicuity, size and interpretation of the pulmonary parenchymal nodules. McNemar's test was used to evaluate paired differences in nodule detection rates between MR and CT from PET/CT. The correlation of pulmonary nodule size in CT and MR imaging was assessed using Pearson correlation coefficient.

Results: 299 pulmonary nodules were detected on PET/CT. The detectability was significantly higher on T2-P (60%, $p < 0.01$) compared to T1-weighted Dixon-type sequences (16.1-37.8%). T2-P had a significantly higher detection rate among FDG-positive (92.4%) and among confirmed malignant nodules (75.9%) compared to T1-Dixon. Nodules < 10 mm were detected less often by MR sequences than by CT ($p < 0.01$). However, nodules > 10 mm were detected equally well with T2-P (92.2%) and CT ($p > 0.05$). In a per-patient analysis, there was no significant change in the clinical interpretation of the nodules detected with T2-P and CT.

Conclusion: Despite the overall lower detection rate compared with CT, the free-breathing respiratory gating T2-w sequence showed higher detectability in all evaluated categories compared to breath-hold T1–weighted MR sequences. Specifically, the T2-P was found to be not statistically different from CT in FDG-positive nodules, in detection of nodules > 10 mm and concerning conspicuity of pulmonary nodules. Overall, the additional time investment into T2-P seems to be justified since clinical relevant assessment of pulmonary lung nodules can mostly be done by T2-P in a whole body PET/MR staging of oncologic patients.

1. Introduction

Simultaneous positron emission tomography/magnetic resonance (PET/MR) imaging was introduced into clinical routine and research about 4–5 years ago and has been widely studied in many different scenarios [1]. Its intrinsic superior soft tissue contrast is one of the most important reasons for MR superiority compared to computed tomography (CT) imaging within PET/CT. However, this argument does not apply for lung imaging where CT has certain advantages (e.g. lung nodule detection). Since oncological imaging is the most common clinical application of PET/CT, lung nodule detection and interpretation in an oncological population is important when comparing PET/CT

Abbrevations: CT, computed tomography; ICC, intraclass correlation coefficient; MRI, magnetic resonance imaging; PROPELLER, periodically rotated overlapping parallel lines with enhanced reconstruction

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and PET/MR.

Since the clinical introduction of MR, chest imaging has been one of the most challenging topics, as summarized in a recent review article [2]. Beginning in the early 1990s, studies were already trying to evaluate MR imaging of the chest in different scenarios, such as lesion detection, evaluation of the mediastinum and pleural pathologies [3]. Although MR imaging of the chest is limited by low proton density and fast transverse magnetization decay of the lung parenchyma, based on recent technical improvements current MR-imaging is improving and is now partly considered clinically useful and a robust complementary tool in the assessment of chest pathologies [2,4].

In current simultaneous PET/MR imaging, T1-weighted Dixon-type MR pulse sequences are used to generate the attenuation correction for PET (MRAC) [5]. The use of higher resolution T1-Dixon for PET-positive lung nodules was already assessed in several studies with reasonable results [6]. Additionally, studies evaluating the lung parenchyma demonstrated good results with turbo spin-echo (TSE) T2-weighted (T2-w) pulse sequences, detecting pulmonary infectious lesions, however, with somewhat long acquisition times [7]. Cieszanowski et al. [8] compared different T1-w and T2-w sequences for lung nodule detection, and demonstrated that T1-w imaging was partly more accurate than T2-w imaging. However, no gated sequences were tested. On the other hand, respiration-gated MR pulse sequences demonstrated improved image quality, by minimizing physiological motion artifacts [9] and thereby increasing the detectability of metastatic lung nodules.

As one of the most widely used hybrid imaging examinations, PET/CT is known to have a high accuracy concerning the evaluation of lung nodules. Despite the above mentioned efforts and results, one of the concerns with regard to substituting the CT component of PET/CT with the MR component of PET/MR is the lower accuracy or even inability of MR imaging for lung nodule detection [10–12].

Thus, the aim of our study was to prospectively evaluate the detection, conspicuity and interpretation of pulmonary nodules in oncological patients using a tri-modality PET/CT-MR protocol including a respiration-gated T2-weighted-PROPELLER (Periodically Rotated Overlapping ParallEL Lines with Enhanced Reconstruction) sequence, and to find out whether it is worth the investment concerning imaging time for possible integration into a simultaneous PET/MR-protocol.

2. Methods

2.1. Patient population

In this prospective study, a total of 149 adult patients were enrolled (84 men, 65 women; mean age 63 yr/range 28–88 yr). From December 2012 to April 2014, all patients referred for a clinical 18F-FDG PET/CT for staging/follow-up of various oncologic diseases underwent an additional scientific chest-MRI. Patients were included if pulmonary nodules were detected on the “low-dose” CT of the PET/CT. Exclusion criteria were unwillingness to participate in the study or contraindications to MRI. This study was approved by the local ethics cantonal committee and written informed consent was obtained from all patients prior to the study examination. This study received financial support by an institutional grant from GE Healthcare. Only non-GE employees were control of inclusion of data and information that might present a conflict of interest for those authors who are employees of GE Healthcare.

2.2. Imaging protocol

Sequential PET/CT and a non-enhanced MRI of the chest were acquired on a tri-modality PET/CT-MRI system (time-of-flight (TOF) Discovery PET/CT 690, 3 Tesla Discovery MR750w, both GE Healthcare, Waukesha, WI, USA). A dedicated MR and CT compatible shuttle transfer mechanism connecting the MR and PET/CT systems allowed scanning without repositioning of the patient as described in previous studies [13–16].

Table 1
Acquisition parameters of MR imaging pulse sequences.

	T1-DIXON	T2-Propeller
Repetition time/echo time, ms*	4.3/1.6	~10000/100
Slice thickness, mm	4.0	4.5
Gap, %	0	2
Matrix	288 × 224	288 × 288
Field of view, mm	50	40
Bandwidth, kHz	142.86	62.5
Voxel size, mm^3	1.7 × 2.2 × 2.0	1.4 × 1.4 × 4.5
Flip angle, °	12	NA
Acquisition time, min:sec	00:14	~5 min[a]

[a] Acquisition time of the T2-Propeller depends on the breathing pattern of the patient.

Patients fasted for at least 4 h prior to 18F-Fluorodeoxyglucose (FDG) injection of a standard dose of 3–3.5 MBq/kg body weight. After an uptake time of 30 min, patients were positioned on the shuttle table in the MR scanner. MR was acquired during the FDG uptake time, so that the patients did not had to stay longer in our department compared to a standard PET/CT examination. MR was acquired with 32-channel radiofrequency (RF) coils (GEM 32-channel torso coil, posterior and anterior array combined, GE Healthcare). An axially acquired T1-weighted 3D dual-echo GRE sequence (LAVA-Flex; GE Healthcare) covering the same FOV as the PET/CT was acquired first. All stations were acquired during breath-hold. Then, a whole-body coronall T2-weighted fast recovery fast spin-echo (FRFSE) sequence was acquired. Additionally, for dedicated lung imaging, an axial T2-weighted sequence with motion correction (PROPELLER, GE Healthcare) was acquired using respiratory gating. The MRI protocol is detailed in (Table 1). For our study, the T1 w sequence (LAVA-Flex in breath-hold) and the respiration-gated T2 w (PROPELLER) were assessed. After completion of the MR acquisition, coils were removed and the patients were transferred to the PET/CT scanner. The PET/CT acquisition followed the standard clinical procedure in our institution as published before [15].

2.3. Image analysis

Images were analyzed by 2 readers independently (1 board certified radiologist with 4 years of substantial nuclear medicine experience and 1 dual board certified radiologist/nuclear medicine physician). Readers were informed that all patients came for staging/restaging of an oncological disease. Different image datasets of each patient (CT from PET/CT, T2-PROPELLER, breath-hold T1-w Dixon (with all 4 reconstructions: water only (WO), fat only (FO), in-phase (IP) and out-of-phase (OP)) were evaluated in random order (except for CT − see below) with an interval of at least six weeks between each evaluation (meaning evaluation of CT vs. MR data sets). All four reconstructions of the Dixon-type sequence were evaluated since pulmonary lesions may have different tissue compositions. Thus, such lesions might be evaluated differently depending on the reconstruction, however, all are available from one single acquisition. Furthermore, in clinical routine readers are obligated to evaluate all available data to achieve a final conclusion, too. The entire rating procedure was performed on a standard imaging workstation (Advantage Workstation, Version 4.5, GE Healthcare, Milwaukee, WI, USA). First, the CT of the PET/CT was evaluated for the presence of pulmonary nodules, the localization of the nodules was noted. After the CT-evalution, the MR-datasets were evaluated for presence of pulmonary nodules, too, Then, a 4-point conspicuity score was given for every MR dataset (respiration-gated T2-PROPELLER, T1-w Dixon with all four reconstructions//1: 0–25% of the nodule contour visible; 2: 25–50% visible; 3: 50–75% visible and 4: 75–100% visible). Additionally, the detected lesions were clinically interpreted on MR and on CT with the following interpretation: primary tumor, metastatic nodule or unspecific. The changes in interpretation from CT to MR datasets were compared as well. Clinical interpretations