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Original contribution

Free-breathing ultrashort echo time lung magnetic resonance imaging using stack-of-spirals acquisition: A feasibility study in oncology patients

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ABSTRACT

Objectives: To investigate the diagnostic accuracy of lung magnetic resonance imaging (MRI) with a free-breathing three-dimensional ultrashort echo time spoiled gradient echo sequence using a stack-of-spirals acquisition (spiral 3D UTE) for pulmonary nodule detection at 3 T in oncology patients.

Methods: The institutional review board approved this retrospective study. Between June and September of 2017, 32 oncology patients underwent both free-breathing spiral 3D UTE of the lungs and thin-section chest computed tomography (CT) for pulmonary metastasis workups. Semiquantitative analyses of the visible pulmonary vessels, bronchi, mediastinum, and overall image quality on spiral 3D UTE were assessed by two reviewers; CT was used as the reference standard. The probability of nodule presence also was assessed.

Results: The mean acquisition duration of the spiral 3D UTE was 327 s (range, 300–465 s). The pulmonary vessels and bronchi were visible nearly consistently up to the sub-sub-segmental branch levels on spiral 3D UTE (96.9% [31/32] and 90.6% [29/32], respectively). > 90% of the spiral 3D UTE images had an acceptable or good mediastinal evaluation; > 80% had good or excellent overall image quality. Fifty nodules (6.1 ± 5.9 mm) were identified in 13 patients on CT; the overall nodule detection rate of spiral 3D UTE was 86% (43/50). All 20 nodules ≥ 5 mm in diameter were identified on spiral 3D UTE (100%).

Conclusions: Free-breathing spiral 3D UTE had high sensitivity for the detection of pulmonary nodules, a reasonable scan duration, and acceptable image quality, which may make it a potential alternative to CT for oncology patients.

1. Introduction

The applications of lung magnetic resonance imaging (MRI) have been limited by the low proton density and extremely rapid T2* decay of lung tissue and by physiological motions including respiration and cardiac pulsation of the thorax. On the contrary, computed tomography (CT) has excellent spatial resolution and image contrast and is the modality of choice for most pulmonary diseases. However, inevitable ionizing radiation exposure and its potential carcinogenic risks are major drawbacks of CT examinations, especially for oncology patients who are in need of repeated imaging workups for the evaluation of tumor recurrence or metastasis.

With recent improvements in MRI, new techniques such as an ultrashort echo time (UTE) have enabled the clinical application of lung MRI [1–8]. Considering the exceedingly short T2 and T2* values of the lungs, a short echo time is a critical factor in obtaining a diagnostic lung MRI examination [9,10]. Moreover, recent studies on a combination of a UTE and a radial acquisition technique, such as the pointwise encoding time reduction with radial acquisition (PETRA) sequence, have proven the feasibility of lung MRI for the evaluation of various pathologies including pulmonary masses or nodules, cystic fibrosis, and pulmonary embolisms [1–5,11].

The UTE sequence may begin a new era of pulmonary metastasis workups for oncology patients. However, well-known shortcomings of

Abbreviations: MRI, magnetic resonance imaging; CT, computed tomography; UTE, ultrashort echo time; PETRA, pointwise encoding time reduction with radial acquisition; 3D, three-dimensional; spiral 3D UTE, three-dimensional ultrashort echo time spoiled gradient echo sequence using stack-of-spirals acquisition; VIBE, volumetric interpolated breath-hold examination; TE, echo time; PPV, positive predictive value; NPV, negative predictive value

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lung MRI remain, particularly long scan durations due to inefficient k-space coverage [1,3,11]. To overcome this, we focused on a three-dimensional (3D) stack-of-spirals acquisition, which provides high readout efficiency [12–14]. We hypothesized that high-resolution lung MRI with a free-breathing 3D UTE spoiled gradient echo sequence using a stack-of-spirals acquisition (spiral 3D UTE) might visualize pulmonary nodules in oncology patients in a reasonable scan duration. Thus, the purpose of this study was to investigate the feasibility of spiral 3D UTE at 3 T in oncology patients for metastasis evaluation.

2. Material and methods

2.1. Study population

The study was retrospective in design; all images were acquired prior to the initiation of the study. Our institutional review board approved this retrospective study. All participants provided informed consent for MRI scans before image acquisition.

Since June 2017, our institution has included a spiral 3D UTE sequence in our body MRI protocol to evaluate pulmonary metastasis in oncology patients. Between June and September of 2017, 151 oncology patients at our institution underwent gadolinium enhanced body MRI, including liver, pancreas, rectum, or kidney/adrenal MRI, to evaluate primary tumors or hepatic metastasis. Exclusion criteria were (a) severe image distortion (n = 2) and (b) an interval of > 30 days between thin-section chest CT and spiral 3D UTE MRI (n = 117). Eventually, 32 patients who underwent both a spiral 3D UTE examination of the lungs and thin-section chest CT were included (22 men and 10 women; mean age, 62.2 years; range, 30–79 years). The mean duration between chest CT and MRI was 22.4 days (range, 0–30 days). The patients' baseline characteristics are summarized in Table 1.

2.2. MRI protocols and the spiral 3D UTE sequence

All subjects underwent MRI of the liver (n = 22), biliary system and pancreas (n = 2), rectum (n = 7), or kidney and adrenal glands (n = 1) on a 3-T MRI system (MAGNETOM Skyra, Siemens Healthcare, Erlangen, Germany) with a 30-channel anterior body coil in combination with an 18-channel spine coil. All MRI examinations were performed with intravenous contrast administration, including gadoxetate disodium (Primovist, Bayer Schering Pharma, Berlin, Germany) for liver and biliary-pancreas MRI examinations and gadoterate meglumine (Dotarem, Guerbet, Roissy CdG, Cedex, France) for rectum and kidney/adrenal MRI examinations (Table 1). The UTE protocol was included as the last scan of each body MRI; patients were placed in the supine position with their arms raised to avoid fold-in artifacts. Most sequences were acquired with a delay of > 5 min after contrast injection.

Table 1
Patient characteristics and body MRIs.

Characteristics (n = 32)	
Age (years)[a]	62.2 ± 11.96 (range, 30–79)
Sex, male:female	22:10
Primary malignancy	
Hepatobiliary carcinoma	13
Stomach carcinoma	1
Colorectal carcinoma	13
Pancreas carcinoma	1
Breast carcinoma	1
Non-small cell lung carcinoma	1
Renal cell carcinoma	1
Adrenal cortical carcinoma	1
Body MRI	
Liver MRI[b]	22
Biliary-pancreas MRI[b]	2
Rectum MRI[c]	7
Kidney/adrenal MRI[c]	1

Note. Unless otherwise indicated, data are number of patients.
[a] Data are mean ± standard deviation.
[b] Enhanced MRI with gadoxetate disodium.
[c] Enhanced MRI with gadoterate meglumine.

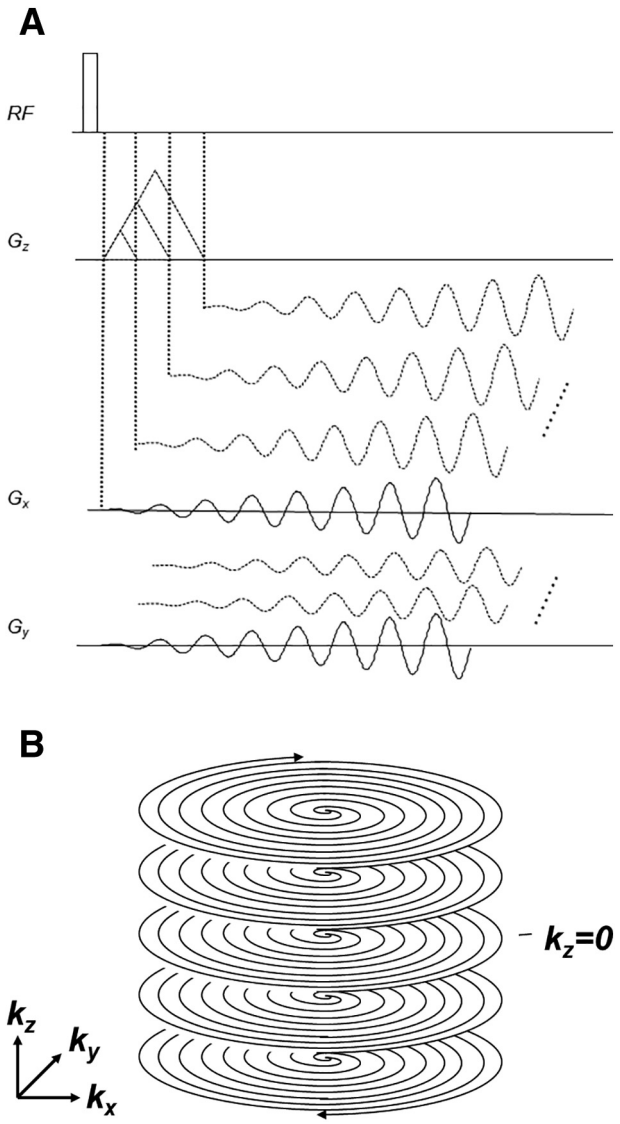

Fig. 1. (A) Sequence diagram of spiral 3D UTE with variable echo times. (B) Diagram of the stack-of-spirals trajectory.

UTE imaging was performed in a coronal orientation using a prototypical 3D spiral volumetric interpolated breath-hold examination (VIBE) sequence. The parameters of the free-breathing spiral 3D UTE sequence were as follows: repetition time, 3.12 ms; echo time, 0.05 ms; field-of-view, 480 × 480 mm^2; and voxel size, 1.5 × 1.5 × 1.5 mm^3. The spiral sampling-related parameters were as follows: number of spirals used for in-plane encoding, 367; duration of the spiral readout, 1160 μs; and pseudo golden-ratio (137.5°) view reordering. A non-uniform Fourier transform was used for image reconstruction. To further improve robustness to breathing motion, prospective respiratory gating without navigator positioning was used and the specified coil element closest to the diaphragm edge was selected for navigator signal processing. The total acquisition duration was 5–8 min (mean, 327 s; range, 300–465 s) depending on the patient's breathing pattern.

The spiral 3D UTE sequence uses a stack-of-spirals trajectory with an adaptive echo time (TE) (Fig. 1) [13]. In-plane spiral sampling reduces the minimum time necessary to cover k-space compared with a 3D radial trajectory [13,14]. Cartesian sampling is performed for