The potential of ultra short echo time MRI in lung: diagnostic accuracy and image quality evaluation

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Abstract

Objective

To evaluate the diagnostic accuracy in the detection of pulmonary nodules and image quality of UTE-MRI imaging using ultra short echo time MRI (UTE-MRI).

Methods

A total of 48 patients in our hospital were collected and underwent CT unenhance scan and UTE-MRI scan. The image quality and number of nodules detected by CT were taken as the gold standard. Three diagnostic radiologists independently recorded the image quality (such as visibility and sharpness of normal anatomical structures) of CT and UTE and the number of pulmonary nodules detected. The diagnostic accuracy, subjective image quality and consistency between observations were statistically analyzed.

Results

Among 46 patients, 36 patients (78.2%) had pulmonary nodules on CT image, while 10 patients (21.7%) had no pulmonary nodules. A total of 48 lung nodules were detected, of which 3 were ground glass nodules. On UTE-MRI, a total of 46 lung nodules were detected. Compared with CT, the sensitivity of all MRI readers to detect lung lesions was 95.8%, and the three-observer agreement was nearly perfect (p < 0.001, Kendall W\textsuperscript{a} (Kender's Harmonious Coefficientt) = 0.913). The overall image quality score of the observers was high, ranging from good to excellent, and the consistency of UTE-MRI subjective image quality was good: Kendall W\textsuperscript{a} =0.877, P < 0.001, strong consistency; For tracheal display, the subsegment of bronchus could be displayed, and the wall of the tube was clearly displayed. The W\textsuperscript{a} value between observers was 0.804,P < 0.001, strong consistency. As for the display of blood vessels, subsegment blood vessels can also be displayed, with clear wall and uniform signal, Kendal W\textsuperscript{a} =0.823, P < 0.001, strong consistency.

Conclusion

Compared with CT, UTE-MRI can detect pulmonary nodules with a high detection rate, and the image quality is relatively good, and the consistency between observers is strong. The application of UTE-MRI may provide an alternative imaging method for the detection or follow-up of pulmonary nodules and the diagnosis of pneumonia under the condition of reducing ionizing radiation.

1. The Background

Although computed tomography (CT) is currently considered the preferred method for the detection of lung nodules, however, because MRI images are usually acquired slowly and repeatedly, breathing and cardiac movements have a greater impact on image quality, lung tissue has relatively little soft tissue or water component, and lung tissue and air have a poor pair comparison, This often results in a low signal-to-noise
ratio (SNR) in lung MRI, and the use of MRI is greatly limited. Lung magnetic resonance imaging, as an imaging tool for the diagnosis and characterization of lung lesions, has attracted extensive attention in recent years. Recent studies have shown that lung lesions can also be detected by MRI, because of its higher intrinsic soft tissue contrast, MRI provides even more information about the heterogeneity of lung nodules than CT. However, the role of MRI, such as diffusion weighted imaging (DWI), in the evaluation of nodules is still unclear, and some studies have shown conflicting results.

Ultra-short echo time MRI (UTE-MRI) is not easily disturbed by rapid T2* attenuation and respiratory motion, which has shown its utility in pulmonary applications. UTE technology is characterized by the TE time can be reduced to the microsecond level (32µs), and the signal is collected at the early stage of proton magnetic resonance signal attenuation. It is especially suitable for magnetic resonance imaging of organs with low proton content and heterogeneous magnetic field (such as lung tissue). Ohno et al. concluded that UTE-MRI can be used to display GGO, consolidation, etc., in high agreement with CT.

To our knowledge, the use of UTE-MRI sequences in MRI to detect pulmonary nodule detection rate and image quality assessment has been rarely studied, and its diagnostic performance and its impact on subjective image quality and interobserver consistency remain unclear. Therefore, the objective of our study was to evaluate the diagnostic accuracy, subjective image quality, and interobserver consistency of UTE-MRI imaging in the detection of lung nodules.

2. Materials And Methods

2.1. Inclusion criteria

The study was reviewed by the ethics committee of our hospital, and all patients signed informed consent. From November 2018 to October 2021, patients who underwent routine CT were selected for UTE-MRI examination within 24 hours. Some patients such as severe pneumonia, acute pulmonary edema, diffuse emphysema and other patients who could not tolerate MR Examination were excluded. In addition, patients under 18 years of age, pregnant women, and others not suitable for MRI, such as pacemaker implantation, claustrophobia, were also excluded.

2.2. CT examination

64-slice spiral CT scanner (uCT 760, United Images, China) was used for routine CT scan. Patients were asked to hold their breath after inhalation. All patients were in supine position with both upper limbs lifted and scanned from lung tip to lung floor. Scanning parameters are as follows: collimation width, 64x0.5mm, pitch 1.5, speed, 0.5s, tube voltage 120 kV, reference tube current, 110mAs (Automatic tube current technology), image matrix, 512x512. Images were reconstructed with layer thickness of 2.0 mm and layer spacing of 2.0 mm using 30% iterative reconstruction technique.

2.3. MRI examination

All patients underwent 3T routine magnetic resonance imaging (HD750, General Healthcare, USA) using a multichannel phased array body receiving coil. Supine position, advanced foot, calm regular breathing training,
axial, sagittal and coronal RT (respiratory gated) UTE scanning (TR 10 ms, TE 0.032 ms, 320×75, layer thickness 2.0 mm, no interlayer gap, flip Angle = 9°, without fat suppression, matrix 380 × 210, The scanning time was about 3 min 30 s in coronal and sagittal view, and about 7 min in axial view.

2.4. Data analysis

All datasets were analyzed independently by three different observers with 12 years (Wang), 4 years (Lin), and 5 years (Guo) experience in thoracic radiology. The patient's clinical history and radiographic indications were unaware to the observer. First, UTE-MRI images were individually analyzed in a random order. The reader is asked to record and label all visible lung nodules. In addition, the observer using 5 point rating scale subjective image quality assessment overall UTE-MRI image (5 = perfect, 4 = good, 3 = diagnostic, 2 = bad, 1 = unacceptable), vascular conditions (5 = perfect, sub-subsegments blood vessels, 4 = good, Subsegment blood vessels, 3 = diagnostic, Segment blood vessels, 2 = bad, Lobe vessels, More artifacts in each vessel, 1 = unacceptable, unable to distinguish lobar vessels), bronchial condition (5 = perfect, sub-subsegmental bronchus visible, 4 = good, subsegmental bronchus visible, 3 = acceptable, segmental bronchus visible, 2 = poor, lobar bronchus visible, 1 = unacceptable, unable to distinguish lobar bronchus). To determine the gold standard for the presence of pulmonary nodules, observers were asked to evaluate CT images after a 4-week interval to mitigate potential memory bias. The observer was unaware of the image features, previous reports, and the results of UTE-MRI image analysis. Third, observers were asked to record and label all visible lung nodules. In addition, observers were asked to measure the short diameters of all detected lung nodules. If all three observers labeled and measured the same lung nodule, the mean diameter of all measurements was used for further analysis. If not, the CT analysis of a 12-year observer was used as the gold standard, as was the MRI image.

2.5. Statistical analysis

Using software (SPSS version 27; IBM, Armonk, NY) performed the statistical analysis. Continuous variables are expressed as mean ± standard deviation (SD). The Kolmogorov-Smirnov test was used to assess the normality of the data distribution. Normally distributed data were analyzed by t-test. In the case of unequal variances, Wilcoxon rank sum test was used. P values P < 0.05 was considered statistically significant. The accuracy of each observer in detecting pulmonary nodules on UTE-MRI images, as compared with CT, was calculated if T < 1 was present, Fisher's exact test was used, p < 0.05 was considered statistically significant. Kendall's test was used for the consistency of lung nodule detection and image quality evaluation in the three readers, Kendall's Harmonious Coefficient ($W^a$) < 0.2 indicates a poor degree of consistency; Between 0.2 and 0.4 indicates a general degree of consistency. A value between 0.4 and 0.6 indicates a moderate degree of consistency. Between 0.6 and 0.8 indicates a strong degree of consistency; A value between 0.8 and 1.0 indicates a high degree of consistency.

3. Results

A total of 46 patients (27 men, 19 women; Mean age 54.5 ± 12.5 years) underwent CT and MRI scans after enrollment in the study. Fourteen patients presented with primary lung cancer (non-small cell lung cancer, n = 12; Small cell lung cancer, n = 2). Three cases were inflammatory nodules, and no pathological results were obtained for the other patients. The mean CT dose index (CTDIvol) was 7.97 ± 1.50 mGy, and the mean dose-length product was 344 ± 40.4 mGy-cm. On routine CT, pulmonary nodules were detected in 36 patients (78.2%)
and not in 10 patients (21.7%). A total of 48 lung nodules were detected. The mean nodule diameter was 8.69 ± 3.13 mm, ranging from 4.5 to 15.9 mm, of which 3 were ground glass nodules (Fig. 1). On UTE-MRI, 48 lung nodules were detected in 36 patients (Table 1). Compared with CT, the sensitivity of all MRI readers to detect lung lesions was 95.8%, and the three-observer agreement was nearly perfect (p < 0.001, Kendall W³ = 0.913), as shown in Table 1. Compared with the reference standard CT, two false-positive lesions were recorded by one observer and one false-positive lesion by two observers, with a mean diameter of 5.6 ± 0.5 mm and a range of 5.1 to 6.1 mm. The mean short diameter measured by UTE-MRI was about 8.70mm, which was smaller than that measured by CT (8.98mm), and there was a significant difference between them, p < 0.001, z-value = 4.365. The overall image quality score of the observers was high, ranging from good to perfect (Fig. 2), and the consistency of UTE-MRI subjective image quality was excellent: Kendall W³ = 0.877, P < 0.001, strong consistency; For the display of trachea, the subsegment of bronchus can be displayed, as shown in Fig. 3, and the wall of the tube is clearly displayed. As for the display of blood vessels, subsegment blood vessels can also be displayed (as shown in Fig. 4), with clear wall and uniform signal (Table 2).

<table>
<thead>
<tr>
<th>Observer</th>
<th>UTE detection(case)</th>
<th>mean diameter measured in UTE(mm)</th>
<th>CT detection(case)</th>
<th>mean diameter measured in CT(mm)</th>
<th>false positive in UTE(case)</th>
<th>Consistency of three observers in UTE images</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>48</td>
<td>8.70 + 3.07</td>
<td>48</td>
<td>8.98 + 3.02</td>
<td>2</td>
<td>p &lt; 0.001, Kendall W³ = 0.913</td>
</tr>
<tr>
<td>2</td>
<td>47</td>
<td>8.71 + 3.05</td>
<td>48</td>
<td>8.97 + 3.08</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>47</td>
<td>8.66 + 3.13</td>
<td>48</td>
<td>8.96 + 3.15</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

Table 2
Average scores and consistency of the three observers in UTE images.

<table>
<thead>
<tr>
<th></th>
<th>average score</th>
<th>Kendall W³</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall image quality</td>
<td>4.33 ± 0.51</td>
<td>0.877</td>
<td>P &lt; 0.001</td>
</tr>
<tr>
<td>Tracheal display</td>
<td>4.03 ± 0.54</td>
<td>0.804</td>
<td>P &lt; 0.001</td>
</tr>
<tr>
<td>Blood vessels display</td>
<td>4.34 ± 0.56</td>
<td>0.823</td>
<td>P &lt; 0.001</td>
</tr>
</tbody>
</table>

4. Discussion
With the improvement of CT utilization and resolution, more and more lung nodules with uncertain malignant tumors are detected. However, the differentiation of benign and malignant CT imaging features, as well as the
use of solid components to indicate malignant tumors and their prognosis are still controversial. Positron emission tomography (PET) containing F-18 fluorodeoxyglucose (18F-FDG) has not been shown to be valuable for the assessment of pulmonary nodules, especially ground-glass duration. There are significant radiation risks, and the possible need for further invasive procedures, postoperative complications, etc. In recent years, with 3.0 T MRI technology gradually mature and widely used, in the image SNR, contrast, chemical shift resolution and so on, magnetic susceptibility has more obvious improvement, including the emergence of faster image acquisition technology, can more clearly show normal anatomic structure, better check out diseased tissue, make it possible. The UTE sequence developed in recent years is mainly used to acquire the short T2 component, and its ultra-short TE value is used to rapidly acquire the MR signal of the short T2 component before it rapidly decays to zero. Because lung tissue contains a lot of gas, T2 time is very short, and signal acquisition is limited. UTE sequence just solves this kind of problem.

UTE-MRI is highly consistent with CT in displaying the characteristics of lung diseases (such as GGO, consolidation, nodule, fibrosis, et al.), and its image quality is similar to CT, which is considered to be of great value in evaluating various lung parenchyma diseases. Also, a study by Delacoste et al. shows that the image quality of UTE-MRI in quantifying the volume of pulmonary nodules is similar to that of CT.

The study found that UTE had a high detection ability for pulmonary nodules, almost close to CT, with a detection rate of 95.8%, and it could also detect some ground glass nodules. However, although UTE-MRI sequences allow for rapid acquisition time and diagnostic image quality, our results suggest that high-resolution CT is still necessary for accurate detection of small nodules less than 5mm in diameter, as well as ground-glass nodules, such as those detected by all observers in some cases. A 5mm lesion and a nodule that was missed on the magnetic resonance imaging. The main reasons are: First, the K-space center in MRI image acquisition is the low-frequency information, which mainly determines the image comparison; Second, the K-space is surrounded by high-frequency information that determines the edges and details of the image. For lung MRI, the use of radially or spirally sampled k-space to compensate for respiratory movements and very short T2* results in undersampling of the peripheral k-space, which results in blurred images. Third, some nodules are smaller, and the density is lower, showing ground glass composition. Fortunately, at least 95% of lung nodules are benign, most commonly granulomas or intrapulmonary lymph nodes. Smaller nodules are more likely to be benign, or histological features may not be clearly defined in most cases. Furthermore, according to recent guidelines, nodules < 5 mm are generally not included in screening programs. We also observed several false-positive nodules detected by UTE-MRI, mainly because our observers misinterpreted blood vessels as pulmonary nodules.

The results of this study found that the average diameter of lung nodules measured using UTE images was smaller than that measured on CT images, and there was a large difference in the measurement results. The main reason may be the shown at nodule margins, UTE-MRI is weaker than CT images, or some nodules are central solid, with ground glass at the edges, and the ground glass parts at the edges are less dense and not clearly displayed (as shown in Fig. 5).

In addition, we assessed the subjective image quality rated by three observers. We found that the average UTE MRI score was diagnostic to perfect (3–5 points), mainly good, and weaker than CT images. One possible
explanation may be that observers are more familiar with the gray scale contrast of CT images and the imaging features of lung nodules than MRI. Of course, CT is superior to MRI in terms of higher temporal and spatial resolution. Despite this, the study found only minor differences in overall image quality and detection performance for nodules larger than 5mm.

The subsegmental bronchi and blood vessels can be observed on UTE-MRI images. Although the overall score of trachea display is lower than that of blood vessels, it is mainly because the trachea contains more air and the interference is more serious. However, it has extensive application value for most lung conditions, such as patients with pulmonary edema, bronchitis and other diseases. With the functional imaging of pulmonary MR, it has great potential in evaluating pulmonary function in the future.

Furthermore, interobserver evaluations of UTE-MRI and CT image compactness were nearly perfect, indicating that the image quality of the two modes was objectively good and diagnostic, regardless of observer experience.

Finally, the optimal magnetic field strength for MR lung imaging. Although researchers such as Chassanionon et al. compared UTE images of the lungs of 1.5 T and 3 T, the results showed that the 1.5T image quality was higher than that of 3T. However, due to the need for higher spatial resolution to improve the precision and accuracy of nodule detection, more and more studies are being conducted at 3 T.

Therefore, UTE-MRI may be used in the future as a partial replacement for CT, especially in infants who are not eligible for radiation, or in patients who require MRI but require additional lung CT to follow up pulmonary nodules, or PET-MRI. Patients with known pulmonary nodules larger than 5mm may be followed up with MRI or alternatively with CT to reduce radiation dose.

Of course, there are some limitations to our study. First, we did not compare MRI sequences with other MRI sequences, which have been previously reported to be highly sensitive and specific in detecting lung lesions. We used CT as the gold standard, and the study focused on UTE sequence assessment. Second, the number of cases was relatively small, and there was no subtype analysis of lung nodules (e.g., solid and subsolid lung nodules), although our study included some ground-glass nodules. Third, multiple detected lung nodules had no pathological results. Our study mainly observed image quality and nodule detection rate, which had nothing to do with pathological results. In the future, more cases will be added and further studies will be conducted to compare with pathology to determine whether UTE-E MRI can indeed prevent or replace repeated chest CT in patients at higher risk.

In conclusion, compared with CT, UTE-MRI can detect pulmonary nodules with a high detection rate, and the image quality is relatively good, and the consistency between observers is strong. The application of UTE-MRI may provide an alternative imaging method for the detection or follow-up of pulmonary nodules and the diagnosis of pneumonia under the condition of reducing ionizing radiation.

**Declarations**

**Ethics approval and consent to participate**
This study was conducted in accordance with the Declaration of Helsinki (as revised in 2013) and approved by the ethics committee of Fudan University Zhongshan Hospital Xiamen Branch.

All patients signed an informed consent form prior to the examination.

**Consent for publication**

Not applicable.

**Availability of data and materials**

The raw data cannot be made freely available because of privacy restrictions but the datasets used and/or analysed during the current study available from the corresponding author on reasonable request (zhuliuhong@163.com).

**Competing interests**

The authors declare that they have no competing interests.

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**Authors’ contributions**

Funan Wang and Xiaoxia Li contributed equally to this work. (I) Conception and design: F Wang, L Zhu; (II) Provision of study materials or patients: C Lin, Xiaoxia Li; (III) Collection and assembly of data: F Wang, C Lin, Guoqiang Huang; (IV) Data analysis and interpretation: L Zhu; (V) Manuscript writing: All authors; (VI) Final approval of manuscript: All authors.

**Acknowledgements**

Not applicable.

**References**


12. .47–57.


Figures
Figure 1

clearly shows the shape of ground glass nodules.
Figure 2

Sagittal view, CT and UTE images were of good overall quality, and the interlobar fissure was clearly shown.
Figure 3

Display of small vessels, clearly showing subsegmental vessels.

Figure 4

shows a subsegmental bronchus with a lumen of about 2mm.

Figure 5

Subsolid nodules. UTE-MRI showed less ground glass than CT images.