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Chemical shift and diffusion-weighted magnetic resonance imaging of the anterior mediastinum in oncology: Current clinical applications in qualitative and quantitative assessment

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ABSTRACT

Recently, the use of magnetic resonance (MR) in clinical practice for the evaluation of the anterior mediastinum has considerably increased due to technological improvements and standardization of thoracic protocols. Currently, MR imaging is increasingly seen as a useful problem-solving modality, especially in equivocal cases at computed tomography, with the advantage of a higher contrast resolution and no radiation exposure. Chemical shift and diffusion-weighted MR are helpful in tissue characterization and present advantages over conventional MR imaging, first in providing quantitative data, without the need for the administration of contrast medium. By detecting microscopic fat in tissue, chemical shift imaging is useful for differentiating normal thymus and rebound hyperplasia from cancer tissue at diagnosis and after chemotherapy in oncologic patients, and for distinguishing lymphoid hyperplasia from thymoma in autoimmune diseases such as myasthenia gravis. Diffusion-weighted MR reflects diffusivity of water molecules within tissue and is increasingly used as a cancer biomarker, even in the thorax, for

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the detection and characterization of tumors, for their differentiation from benign conditions, and for monitoring treatment response. In this review, based on the current literature, technical considerations about image acquisition and data analysis of chemical shift and diffusion-weighted MR are discussed along with clinical applications in the field of benign and malignant disease of the anterior mediastinum.

1. Introduction

In the assessment of disease located in the anterior mediastinum, computed tomography (CT) is generally the first choice modality of diagnostic imaging, although in the last decade thoracic magnetic resonance (MR) has become a promising tool by using conventional T1- and T2-weighted spin echo sequences for evaluating the anatomical detail because of its better soft-tissue contrast compared with CT (Priola et al., 2006a; Nishino et al., 2006; Restrepo et al., 2005; Takahashi and Al-Janabi, 2010; Ackman and Wu, 2011). Furthermore, MR techniques previously shown to be successful elsewhere in the body, including chemical shift MR and diffusion-weighted MR, have recently been demonstrated to add diagnostic specificity to the characterization of thymic tissue and other mediastinal lesions, especially in the oncologic field (Ackman, 2014; Priola and Priola, 2014a; Priola et al., 2014). Indeed, in a recent survey among members of the Society of Thoracic Radiology, mediastinal MR has been the most frequent thoracic MR examination performed, generally for the evaluation of thymic lesions, although most of participants have reported limited experience in thoracic MR interpretation (Ackman et al., 2014). Chemical shift and diffusion-weighted MR have the advantage of providing quantitative data, in addition to morphological and qualitative assessment, compared with conventional nonvascular MR of the chest (Ackman, 2014; Priola and Priola, 2014a; Priola et al., 2014). In addition to the absence of radiation exposure, the substantial advantage of chemical shift and diffusion-weighted MR, over CT and conventional MR or dynamic studies with first gradient echo two-dimensional (2D) or three-dimensional (3D) sequences, is that they may provide useful information in patients with contraindications to the intravenous administration of contrast agents (Ackman and Wu, 2011). Lastly, chemical shift and diffusion-weighted sequences can be added to the standard MR protocol of the anterior mediastinum with focused imaging for thymus or lesion characterization without significantly increasing the overall acquisition time, which is less than 5 min for both sequences (Ackman, 2014).

Chemical shift MR is able to characterize the normal thymus and thymic hyperplasia by detecting microscopic fat interspersed within tissue, which are typical of such conditions (Takahashi et al., 2003; Inaoka et al., 2005). It has been proved useful in differentiating such benign entities from anterior mediastinal tumors (e.g., thymic tumors, lymphomas, metastatic lymph nodes from solid tumors) by using qualitative analysis of signal intensity variations and quantitative signal intensity ratios (i.e., chemical shift ratio—CSR and signal intensity index—SII) (Inaoka et al., 2007; Priola et al., 2015a).

Diffusion-weighted MR is helpful in the characterization of tumors on the basis of diffusion effects through the measurement of the apparent diffusion coefficient (ADC), which is used to assess the mobility of water molecules. Generally, malignant tumors have lower ADC values compared with benign lesions, most likely due to increased cell density leading to restriction of water molecules (Koh and Collins, 2007; Padhani et al., 2009, 2011; Koh et al., 2012). The ADC value has been reported as a reliable and valuable quantitative parameter for distinguishing benign from malignant lesions in different organs and has been used to assess treatment response after chemotherapy (Lichy et al., 2007; Gümüştaş et al., 2011; Nguyen et al., 2014; Blackledge et al., 2014; Priola et al., 2015c).

In this review, we present a comprehensive overview of the current clinical applications of chemical shift and diffusion-weighted MR imaging for the evaluation of the anterior mediastinum, along with technical considerations related to acquisition of images and analysis of qualitative and quantitative data. Finally, limitations and potential future perspectives for chemical shift and diffusion-weighted MR imaging of the chest are discussed.

2. Chemical-shift MR imaging

2.1. Technical background

2.1.1. Biophysical basis

Chemical shift imaging is the most sensitive MR technique for detecting microscopic fat in tissues and has been used clinically to diagnose adrenal adenomas and assess fatty liver (Park et al., 2007; Fujiyoshi et al., 2003; Halefoglu et al., 2012; Rinella et al., 2003; Hussain et al., 2005; Kang et al., 2012). The term chemical shift refers to the difference in precessional or resonance frequency between two proton MR signals, expressed in arbitrary units known as parts per million (ppm) of the resonance frequency of the static magnetic field B_0 (Hood et al., 1999). In clinical imaging, the chemical shift phenomenon is most evident between the hydrogen protons of lipid and those of water because of their large relative differences in magnetic shielding. The difference in precessional frequencies between lipid and water protons increases proportionally with the static magnetic field strength B_0, and is about 224 Hz at 1.5-T (i.e., the shift translates to approximately a 224-Hz separation between the resonant frequencies of fat and water protons) and 447 Hz at 3.0-T (Hood et al., 1999). Indeed, if a standard nonselective radiofrequency pulse is applied to a fat–water admixture, both proton species are excited, but the water signal precesses faster than the fat signal by about 3.5 ppm at 1.5-T and twice as fast at 3.0-T. This precessional frequency difference manifests itself as "artifacts", commonly known as "first kind" and "second kind" chemical shift effects, which allow microscopic fat detection and its quantification (Hood et al., 1999; Pokharel et al., 2013; Hughes Cassidy et al., 2009). Chemical shift of the first kind, or chemical shift spatial misregistration, occurs at interfaces between fat and water along the axis of the frequency-encoding direction. Frequency and phase components of MR signal resulting from a tissue are used to encode the spatial coordinates on the x- and y-axis of the 2D image. Because the frequency displacement cannot be differentiated from selected spatial frequency encoding, misregistration of the resultant signal occurs along the frequency-encoding direction (also known as readout axis) (Babcock et al., 1985) (Fig. 1). Relative to the water signal, if the MR magnet is tuned or centered to the frequency of water, at interfaces between fat and water, the signal from a voxel containing fat is displaced and mismapped to an adjacent voxel containing water, and this voxel appears bright, whereas the voxel that actually contains the fat is void because the fat signal has been mapped elsewhere. This misregistration results in alternating bright and dark bands in the frequency-encoding direction along the interface between two tissue types with dis-

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