Perfusion MRI of the Lung

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Perfusion is the amount of arterial blood delivered in a certain time period to a tissue or an organ (mL×min-1×100 g-1). The arterial blood reaches the lung by its vasculature and more distally by its capillaries in the alveolar walls. At this microscopic level, complex mechanisms regulate the matching of local ventilation (V) to perfusion (Q). Since the extent and distribution of the pulmonary blood flow play an essential role in the V/Q matching, and the V/Q matching is important for an efficient alveolar-capillary gas exchange, variations of regional pulmonary blood flow can influence the degree of lung function. Therefore, imaging modalities that assess the regional pulmonary blood flow have the potential to add to the understanding of the functional alteration in lung disease.

Existing imaging modalities such as scintigraphy, PET, SPECT, CT, and MRI offer different technical approaches for the assessment of lung perfusion. The MRI technique for imaging lung perfusion was initially developed at the beginning of the 90's (1). At that time, the perfusion MRI examinations were technically hampered by the same issues that were commonly encountered while performing MRI scans of the lung parenchyma (2). Indeed, the intrinsic low proton density and fast signal decay of the lung, as well as signal loss due to physiological motion (cardiac pulsation and respiration) were generally considered as insurmountable limitations to all possible applications of lung MRI (2). However, dedicated MRI techniques that use breath-holding, respiratory and cardiac gating procedures, and short repetition and echo times have unequivocally shown the clinical feasibility of lung MRI. More recent technical advances in the field of MRI have allowed for the development of innovative systems with improved magnet and hardware design, and more powerful gradients. These systems are typically equipped with new pulse sequence techniques that fully exploit the capability of multichannel coils by using efficient k-space sampling schemes with parallel imaging. These technical improvements have significantly reduced the sensitivity of MRI to the artifacts inherently produced by the lung, and have established a common ground for developing advanced and more robust approaches for imaging lung perfusion with MRI.

Compared to other modalities, MRI currently offers numerous advantages for imaging lung perfusion. First, as a noninvasive and radiation-free modality, MRI is particularly advantageous for assessing lung perfusion in young patients and in conditions where repeated examinations are required (i.e., precise assessment of perfusion changes in various positions or in different respiratory maneuvers, evaluation of the course of disease, monitoring of the therapeutic response through quantitative imaging). Second, current contrast-enhanced MR techniques that image perfusion during the first pass of intravascular contrast through the pulmonary circulation are robust, and sufficiently validated for clinical use (3-6). These contrast-enhanced techniques provide a map of the distribution of the pulmonary blood flow of the entire lung, at considerably high temporal and spatial resolution, with a level of functional detail that cannot be obtained by any other single imaging modality (7-12). Third, non-contrast-enhanced MR techniques for imaging of lung perfusion using spin labeling of blood (13-15) or the

recently proposed Fourier Decomposition analysis (16) are actively being developed. Considering the pace of the technological progress in this field, it is likely that MRI will become a validated reference method for clinical imaging of lung perfusion when contrast injection is contraindicated (i.e., renal failure). Forth, quantitative analyses of time-resolved contrast-enhanced and non-contrast-enhanced MR perfusion examinations have been demonstrated, and it has been shown that quantification of lung perfusion by MRI can be used to objectively estimate the functional changes in lung disease (5,7,17,18). Fifth, the feasibility of a qualitative and quantitative assessment of lung perfusion using different MR systems and field strengths has also been shown (19,20), which contributes to the overall clinical applicability of perfusion MRI. Sixth, imaging of lung perfusion can be integrated in a comprehensive MR examination that includes measurements of ventilation and respiratory mechanics, of flow and distensibility of pulmonary arteries, as well as of volumes and function of the right heart. This integration emphasizes the capability of MRI to provide advanced insights into the physiological and pathophysiological aspects of many pulmonary and cardiopulmonary diseases.

Current clinical applications of perfusion MRI include the assessment of regional pulmonary blood flow in patients with vascular diseases, such as pulmonary embolism, pulmonary hypertension, pulmonary arteriovenous malformations, and congenital cardiovascular diseases (21). Additionally, perfusion MRI of the lung has been successfully performed for the assessment of functional aspects related to regional pulmonary blood flow in patients with nonvascular diseases, such as tumors, chronic obstructive lung disease, and cystic fibrosis (21). For most of these diseases, the clinical benefit of a qualitative evaluation of pulmonary blood flow by MRI has been demonstrated, and the agreement of this approach with alternative imaging modalities such as perfusion scintigraphy has been also shown. In parallel, quantitative methods for assessing lung perfusion by MRI have shown the potential to contribute greatly to the preoperative evaluation and treatment planning, particularly in patients with lung cancer. Current research therefore confirms the potential of perfusion MRI of being used as a first or second line modality for imaging regional pulmonary blood flow in daily clinical routine.

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