Improved visualization of delayed contrast agent bolus onset in pulmonary perfusion MRI

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Introduction

Investigation of pulmonary perfusion by three-dimensional (3D) dynamic contrast-enhanced magnetic resonance imaging (DCE-MRI) was proposed recently for diseases such as pulmonary hypertension [1] or cystic fibrosis (CF) [2]. Subtraction images are mostly generated for clinical evaluation to facilitate the assessment of time-resolved three-dimensional pulmonary perfusion MR images [2,3]. In doing so, the temporal element is lost and the majority of data is not used for the diagnosis, although it might contain important information, particularly in diseases with inhomogeneous or delayed contrast agent bolus onset. The aim of this work is to demonstrate a simple analysis strategy for 3D DCE-MRI perfusion datasets in the lung without omitting the temporal information, thus enabling improved visualization of the results.

Material and Methods

A region of interest was drawn in the large pulmonary artery to define an arterial input function (AIF) and to determine the time point of the arterial peak enhancement $\tau_{arterial}$. Normalized signal-time-courses were calculated for each voxel of the 3D dataset as $S_n(t)=(S-S_0)/S_0$, where S_0 is the precontrast signal. Three parameters were determined for each pixel: (1) The normalized peak enhancement $S_{n,max}$ to detect regions of reduced perfusion (Fig. 1). (2) The time between $\tau_{arterial}$ and the tissue peak enhancement τ to visualize regions with delayed bolus onset. τ was calculated in relation to the $\tau_{arterial}$ to eliminate the impact of differences in the timing of contrast agent injection (Fig. 1). (3) The ratio $\Re = S_{n,max}/\tau$ was calculated to visualize reduced perfusion and delayed bolus onset in one parameter map.

Five datasets from patients with cystic fibrosis were chosen retrospectively from an ongoing study to investigate this approach. Images were acquired using a 1.5 T scanner (Magnetom SymphonyVision, Siemens Medical Solutions, Erlangen, Germany) with a 6-element body matrix coil combined with a 6-element spine array. Pulmonary perfusion was assessed by a dynamic 3D GRE sequence with GRAPPA and view-sharing within a single breath hold: TE/TR: 0.8 ms/1.9 ms; flip angle: 40°; receiver bandwidth: 1220 Hz/pixel; GRAPPA: acceleration factor 2, 20 reference lines; field of view: 350-500 × 184-206 mm²; matrix: 256 × 102-118; slab thickness: 176 mm; images per slab: 44; acquisition time per 3D volume: 1.6 s. Twenty consecutive datasets were acquired in coronal direction starting at the beginning of the contrast agent injection.

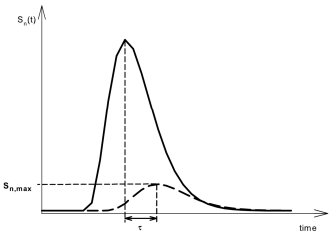

Figure 1. *Schematic diagram of the normalized arterial input function (solid line) and the lung tissue signal (dashed line). The normalized maximum signal $S_{n,max}$ and the time between the maximum of the AIF and $S_{n,max}$ τ is shown.*

Contrast agent injections were administered with an automatic power injector (Spectris Solaris EP MR Injection System, Medrad, Volkach, Germany) using a dose of 0.1 mmol/kg body weight gadopentetate diglumine (Magnevist, Schering, Berlin, Germany) at a flow rate of 3 ml/s followed by a saline flush of 30 ml at the same rate.

Results

In figures 2 and 3, the calculated parameter maps and the corresponding subtraction image of a slice is presented for two patients with cystic fibrosis. In figure 2, perfusion defects can be seen in the subtraction image in the upper right lobe and in a smaller rim in the upper and lower left lobe. The reduced perfusion in the upper lobes is confirmed by the $\Re$ map. In contrast, the $S_{n,max}$ map reveals almost normal perfusion. Considering τ, the upper most region has normal and the lower region delayed but non-reduced perfusion, which can't be seen on the subtraction images.

In figure 3, both lungs have perfusion defects. In the case of the left lung, the subtraction and the parameter maps match. A delayed onset can be seen in some regions. In the upper right lung, the subtraction image reveals reduced perfusion. In contrast, in the parameter maps, the lung apex has normal $S_{n,max}$ but a delayed bolus onset, whereas the lower portion shows no delay but reduced perfusion. Again, the $\Re$ map as a summary of $S_{n,max}$ and τ, reveals a larger region of impaired perfusion similar to the subtraction image.

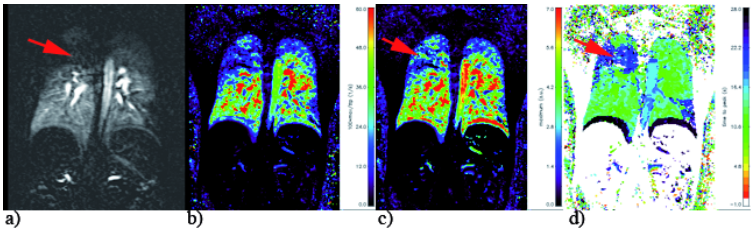

Figure 2. *a) Subtraction image and corresponding parameter maps b) $\Re$, c) $S_{n,max}$ and d) τ of a 44 years old male CF patient with delayed, non-reduced perfusion (arrows).*

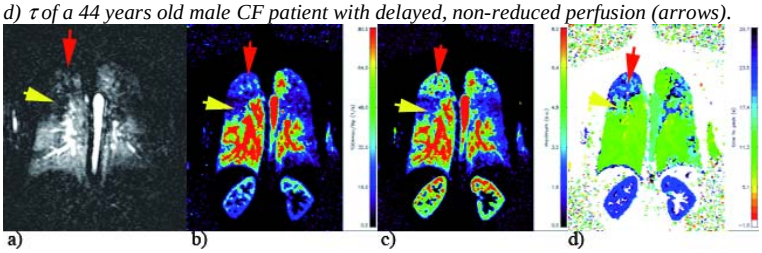

Figure 3. *a) Subtraction image and corresponding parameter maps b) $\Re$, c) $S_{n,max}$, and d) τ of a 9 years old female CF patient with reduced perfusion non-delayed (yellow arrows) and with delayed, non-reduced perfusion (red arrows).*

Discussion

Five different types of perfusion were found using the parameter maps. Thus, a classification based on these results is proposed: I) Normal perfusion. II) Delayed non-reduced perfusion detected with the parameter τ. III) Reduced non-delayed perfusion. IV) Reduced and delayed perfusion which might be referred to as perfusion failure. V) No perfusion. In contrast to the generation of subtraction images, an ROI is simply drawn in the large pulmonary artery. Pre-investigation of the data is therefore simpler and more efficient, since the artery is usually easy to identify, and the results more user-independent.

As demonstrated by the results, use of subtraction images alone might mask the real underlying perfusion conditions. While reduced perfusion (type III) was always detected by the subtraction images, delayed perfusion where it is not – or only slightly – reduced (type II), is also visualized as reduced perfusion. These different aspects of perfusion might have completely different consequences for the lung function or may have an impact on the treatment of patients with e.g. cystic fibrosis.

In conclusion, this analysis strategy allows for simple visualization of impaired perfusion in dynamic contrast-enhanced pulmonary perfusion MRI. Based on the results, perfusion was classified into five subgroups. The information of the dataset is reduced without discarding the temporal information but offering additional information compared to subtraction images. In addition, the analysis is user-independent and perfusion deficits are less likely to be masked compared to subtraction images.

References

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