Perfusion MRI with Radial Sampling: Arterial Input Function and Tissue Enhancement Curve Assessment

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Introduction

The accuracy of quantitative analysis of tissue perfusion derived from dynamic contrast enhanced T1-weighted MRI critically depends on the knowledge of the arterial input function (AIF) and tissue enhancement curves. The true AIF is equivalent to the functions describing changes in contrast agent (CA) concentration in the arterial blood with time. The CA concentration cannot be directly measured in perfusion MRI studies. As result, the AIF is typically estimated from the mean signal intensity of the blood in a region of interest assuming a linear relationship between CA caused change in blood signal intensity and CA concentration. In many practical cases, such an assumption is not valid due to high concentration of CA and/or long saturation recovery time of the applied pulse sequence.

To improve the accuracy of the AIF estimate, two methods have been proposed [1,2]. The first method uses two scans (with low and high CA concentrations). The low bolus scan is only used to estimate the AIF of the high bolus scan. In the second technique, the AIF is found from an additionally acquired low-resolution image with a much shorter saturation recovery time. Both techniques allow more reliable AIF assessment than the conventional approach. However, both have a number of drawbacks. The main problems with the dual-bolus techniques are: increased imaging time and complexity, and the AIF of the high bolus scan can be accurately derived from the AIF of the low bolus scan only if the patient's physiological parameters are the same during both scans. In the second method, the limited time interval available for acquisition of diagnostic slices is additionally reduced to accommodate the low-resolution image scan.

Theory and Methods

Turbo-FLASH pulse sequence with saturation recovery magnetization preparation is usually used for dynamic contrast enhanced T1-weighted imaging. Effective saturation recovery time (eSRT) of the pulse sequence is defined by the time delay between the saturation pulse and the time when the central part of k-space is acquired. In a perfusion study, the choice of eSRT is a compromise between the accuracy in AIF estimate and the SNR of tissue enhancement curves. With shortening eSRT, the accuracy of the AIF estimate improves but tissue signal decreases and vice versa. A T1-weighted pulse sequence with Cartesian sampling has only one eSRT. However, when radial sampling is used, each readout (projection) passes through the center of k-space making it possible to reconstruct a set of images with various eSRT by using different subsets of k-space projections. Images reconstructed from subsets with short eSRTs can be used to more accurately estimate the AIF because the nonlinearity between CA caused change in blood signal intensity and CA concentration is significantly or completely suppressed for the images. More reliable tissue enhancement curves can be found from the images with longer eSRTs due to increased tissue signal. Furthermore, a dynamic T1 map and the corresponding CA concentration map can be recovered from a set of images with various eSRTs.

To test the proposed concept, myocardium perfusion studies were performed on a 3T Trio MR system (Siemens Medical Solutions, Erlangen, Germany) using a turbo-FLASH pulse sequence with saturation recovery magnetization preparation (TR/TE=1.9/1.18 ms, time interval between saturation pulse and the first excitation pulse: TI=28 ms, flip angle=12^o, 96 projections with 128 readout points, FOV=260 mm, 8 mm slice thickness). A contrast agent bolus of 0.06 mmol/kg of Gd-DTPA was used. The data sampling scheme was implemented in such a way that each subset of 24 time-adjacent projections covers 180 degrees. A set of images with various eSRT were reconstructed from the corresponding subsets of 24 projections by complex filtered backprojection. To suppress streaking artifacts, the high frequency components of all available 96 projections were included in each image reconstruction. The reconstructed images were post-processed to remove the noise bias.

Results

The AIF and tissue enhancement curves found from the images reconstructed using a complete set and four subsets of available projections are shown in Fig. 1. The curves corresponding to longer eSRTs have higher values. To test the accuracy of the estimates, the curves were scaled to have the similar values for time > 65 sec. From the scaled versions (Fig. 2), it is obvious that the linear relationship between change in signal intensity and CA concentration is valid for the myocardium (all scaled tissue enhancement curves closely coincide), but the relationship is violated for blood signal (AIF estimates) in high CA concentration regions. The deviation from the linearity is more substantial for the AIF estimates found from the images with longer eSRTs as expected.

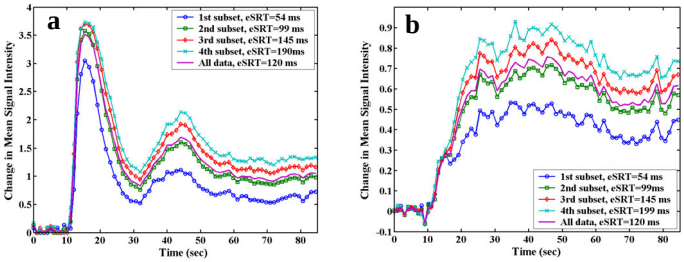

Figure 1. The AIF estimates (**a**) and tissue enhancement curves (**b**).

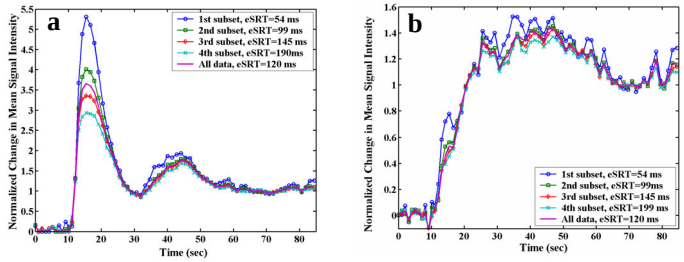

Figure 2. The scaled AIFs (**a**) and tissue enhancement curves (**b**).

Typically, CA concentration in the blood and tissues cannot be reliably recovered from MR images with one eSRT. In the case of radial sampling, a set of images with different eSRT can be reconstructed making CA concentration calculation applicable. Figure 3a demonstrates the CA concentration curve for arterial blood (the true AIF) and the myocardium derived using the curves shown in Fig. 1 and the analytical expression describing both the magnetization evolution for turbo-FLASH sequence with saturation recovery preparation and the effects of the image reconstruction scheme employed. Conversion to CA concentration was done assuming that relaxivity of Gd-DTPA is equal to 4 l/(mmol·sec), T1 of the arterial blood is 1.5 sec, and T1 of the myocardium is 1.1 sec. The scaled versions of the CA concentration curve for the blood and the AIF estimates shown in Fig. 3b demonstrate that the AIF estimate with eSRT=54 ms is the closest to the CA concentration curve. However, it also underestimates the CA concentration peak.

Discussion

A set of images with different eSRTs can be reconstructed from perfusion MRI dataset acquired using radial sampling. The most accurate estimate of the AIF can be found from the images with the shortest eSRT. Conversion of the AIF and tissue enhancement curves to CA concentration representation is possible when a set of the images with different eSRTs is available.

Acknowledgments

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References

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[2] Gatehouse PD, et al, JMRI 2004;20:39-45.

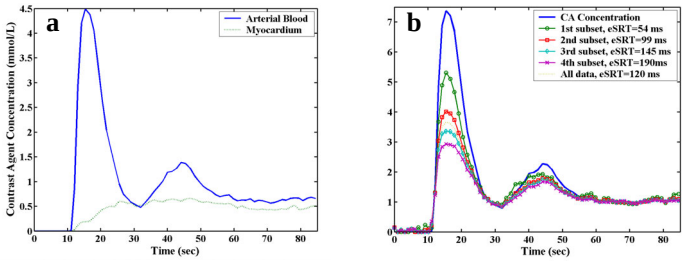

Figure 3. (**a**) The CA concentration curve for the blood and the myocardium. (**b**) Comparison between the scaled CA concentration curve and the scaled AIF estimates. The scaling was done to have similar values for time > 65 sec.