MRI quantification of diffusion and perfusion in bone marrow by intravoxel incoherent motion (IVIM) and non-negative least square (NNLS) analysis.

Giulio Gambarota[1], Antoine Marchand[2], Eric Hitti[1], Frederik Monge[1], Regis Duvauferrier[2], Raphael Guillin[2], and Hervé Saint-Jalmes[1]
[1]*Université de Rennes 1, LTSI, Rennes, F-35000, France,* [2]*Department of Imaging, Rennes University Hospital, Rennes, F-35000, France*

Introduction

Measurements of the water apparent diffusion coefficient (ADC) and tissue perfusion in vertebral bone marrow are important in investigations of a number of pathologies [1]. In general, these measurements are challenging due to the large fat content of bone marrow [1]. Both ADC and perfusion can be determined using the intravoxel incoherent motion (IVIM) approach [2], which relies on a biexponential diffusion decay model. In this respect, the non-negative least square (NNLS) technique could be of interest for calculating perfusion, as it has been proven to be a robust technique in the analysis of multi-exponential signal decays [3].

The aim of this study was twofold: first, to assess the feasibility of measuring diffusion and perfusion in vertebral bone marrow using the IVIM approach, combined with fat suppression; secondly, to investigate the benefits of the non-negative least square (NNLS) technique for the analysis of IVIM data.

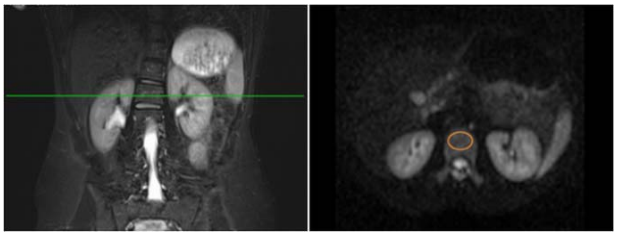

Figure 1. A coronal T2-weighted image (left) and an axial diffusion-weighted image (right) are shown. The elliptical region of interest centered on the first lumbar vertebra (L1) is illustrated on the diffusion-weighted image.

Methods

Fifteen healthy women were examined on a 1.5 T Siemens scanner. Diffusion-weighted echo-planar imaging was performed at five different b-values (0, 50, 100, 200, 600 s/mm^2) with a STIR module to suppress the lipid signal. To determine the perfusion fraction *f* and diffusion values D* (ADC) of the fast (slow) diffusion component, data analysis was performed with i) the Levenberg-Marquardt (LM) non-linear least squares algorithm, typically used in IVIM analysis [1], where the chosen fitting function is a biexponential function and ii) the NNLS technique.

Results

Typical MR images acquired on one volunteer are shown in Figure 1. The ROI for the analysis of the diffusion decay in the bone marrow is indicated on the axial image. The values of perfusion fraction *f*, as well as D* and ADC, are given in Table 1. The NNLS analysis revealed two diffusion components only in seven out of fifteen volunteers, i.e., not all decays displayed a biexponential behaviour, as assessed by the NNLS. An example of NNLS analysis, where the decay was biexponential, is shown in Figure 2.

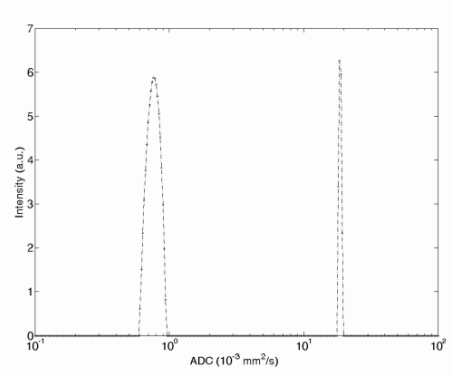

Figure 2. The NNLS spectrum of a fat-suppressed diffusion decay from vertebral bone marrow (L1). In this case, the NNLS spectrum exhibits two peaks at ~ 0.7x10^{-3} mm^2/s and ~ 20x10^{-3} mm^2/s, with a perfusion fraction of 14%.

Discussion

The value of water ADC in bone marrow found in this study is in good agreement with literature values [1]; on the other hand, no values of the perfusion fraction in bone marrow were reported in previous IVIM studies, where the LM non-linear least squares algorithm was used. In the current study, it is shown that the NNLS technique gives an important aid in the data analysis of IVIM signal decays. In fact, the NNLS provides an objective and reliable criterion to determine the number of decay components, in contrast to the LM algorithm where the biexponential model is imposed as a prior knowledge. Thus the use of NNLS is essential especially in cases where the signal-to-noise ratio is low or where motion artifacts and other factors might affect the data quality so that the signal decay might not necessarily display two diffusion components.

Table 1. IVIM results of obtained using the LM algorithm (bi-exponential curve fit, 'Bi-exp') and the non-negative least square (NNLS) analysis.

	Perfusion **%**	**ADC** (10^{-3} mm^2/s)	**D*** (10^{-3} mm^2/s)
Bi-Exp Fit	27 ± 17	0.45 ± 0.27	63 ± 145
NNLS	14 ± 6	0.60 ± 0.09	28 ± 9

Conclusion

The IVIM approach allows for measuring diffusion and perfusion in vertebral bone marrow. The NNLS technique, which allows identifying the number of diffusion components in a given decay, represent an essential analysis tool in the analysis of the IVIM data.

References [1] Yeung DK et al, J Magn Reson Imaging. 2004;19:222-228. [2] Le Bihan D et al, Radiology. 1986;161:401-407. [3] Whittall KP, Mackay AL. J Magn Reson. 1989;84:134-52.