Kinetic Study of Bone Marrow Perfusion Using Arterial Spin Labeling

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Introduction: Dynamic contrast-enhanced MRI (DCE-MRI) studies have shown how bone perfusion is altered in some bone diseases, such as osteoporosis (1) and osteoarthritis (2). Kinetic modeling study of bone perfusion in osteoarthritis (2) showed how quantitative analysis increases our understanding of the pathophysiological processes behind the altered perfusion. However, contrast injection in DCE-MRI is necessarily invasive and also might be nephrotoxic. As a non-invasive technique, arterial spine labeling (ASL) has shown great potential in perfusion study of abdominal organs (3). This pilot study was designed to explore the feasibility of kinetic modeling of ASL signal on bone marrow of vertebrae.

Methods: A turbo field echo (TFE) based acquisition with STAR labeling (TFE-STAR) was implemented and applied on lumbar spine of a female volunteer with a 3T Philips Achieva MRI scanner. The imaged slice (FOV=32cm) was located axially at the vertebrae L3 (Fig.1) with an 8mm thickness. The labeling region was located 20mm, 30mm, 40mm, and 50mm superior to the imaged slice with a 130mm thickness, i.e. the same experiment was repeated with different transit delay for the labeled blood arriving to the imaging plane. Thirty cycles were repeated to average signal and increase signal-to-noise ratio (SNR).

An existing kinetic model (Eq.1) (4) was applied on the ASL signal analysis.

$$\Delta M(t)=\begin{cases}2M_{ob}f(t-\Delta t)\alpha\exp(-t/T_{1b})q_p(t) & \Delta t<t<\tau+\Delta t\\ 2M_{ob}f\tau\alpha\exp(-t/T_{1b})q_p(t) & \tau+\Delta t<t\end{cases} \quad \text{(Eq.1)}$$

where $\Delta M(t)$ is magnetization difference carried into the voxel by arterial blood; f is blood flow; M_{ob} is equilibrium magnetization of arterial blood; α is RF labeling efficiency; Δt is transit delay for labeled blood arriving within imaging plane; τ is time for labeled blood to pass through labeling thickness; T_{1b} is longitudinal relaxation time of arterial blood; $q_p(t)$ includes all other factors.

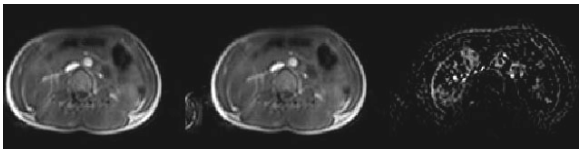

Fig.1. Averaged phase-one label, control, and differential images acquired by STAR-TFE

According to our experiment protocol, we simplified $q_p(t)$=1 and α=1. The signal intensity after labeling was normalized by that of control image, i.e. $(S(t)-S_{control}/S_{control})$, so that M_{ob} equaled to 1. We selected optimal values for T_{1b} and τ from multiple fitting results, obtaining T_{1b}=1sec and τ=0.9sec. After substituted these parameters into Eq.1, the blood flow parameter f and Δt were estimated by curve fitting.

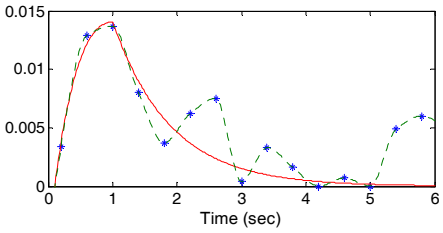

Fig.2. Curve fitting of the ASL intensity signal by kinetic model at 20mm labeling distance.

Results: Blood flow parameter f was obtained for the four labeling locations (Table 1). Fig.2 shows a normalized signal with curve fitting result at the labeling location with 20mm distance.

Table 1 Kinetic model results for different labeling locations

Labeling location	20mm	30mm	40mm	50mm
Δt (sec)	0.1	1.3	2.9	3.4
f (ml/ml.s)	0.019	0.06	0.21	0.45

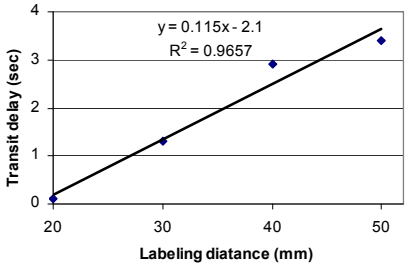

Fig.3. Linear relationship between Δt and labeling distance

Discussion: This is a pilot study to investigate the possibility of quantitatively evaluating bone marrow perfusion by kinetic model using a non-invasive MRI method. Wash-in and wash-out phases of the ASL signal were observed. Kinetic modeling showed good promise at allowing quantitative analysis of the ASL signal. One important physiology parameter that could be provided by this method is blood flow velocity. A strong linear correlation (r=0.98, p=0.000) between Δt and labeling distance was observed (Fig.3). Based on this, we may deduce the contrast transit velocity in bone marrow as 0.91cm/sec, which is smaller than blood flow in arteries and should be a lumped value including the effects of blood flow in artery and contrast perfusion with fluid into bone marrow. Another important parameter is f. In a previous study, f was defined as the cerebral blood flow with unit ml/min·ml (4), while in current study, we choose to regard f as perfusion within bone marrow. Although the perfusion values could not be verified by current knowledge, the result for labeling location 20mm is compatible with previous study (4) which was also based on ASL MRI. However, the perfusion estimation is clearly influenced by Δt. One explanation could be that the model used (Eq.1) was initially designed for cerebral perfusion (4), which may not be fully applicable to bone marrow. Another reason is that some assumptions in the applied model do not hold true in bone marrow. For parameters, such as T_{1b}, a smaller value than previous study was observed, which may reflect fat content in the bone marrow. Our future research will concentrate on optimizing ASL sequence design and signal processing to maximize SNR as well as developing a new kinetic model more fully reflective of bone marrow perfusion.

In conclusion, ASL analysis using a kinetic model is promising with regard to quantification of bone marrow perfusion. This will be improved further by improving ASL signal and appropriateness of model.

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