Pseudo Random Amplitude Modulation: A High Efficiency Method to Measure Flow and Perfusion

T. R. Brown[1], N. C. Shapley[2], H. Tang[3]

[1]Radiology & Biomedical Engineering, Columbia University, New York, NY, United States, [2]Chemical Engineering, Columbia University, New York, NY, United States, [3]Imaging, Merck Research Laboratories, Rahway, NJ, United States

Introduction Arterial spin labeling (ASL) techniques, in which two images are compared, one with the arterial spins inverted and the other not, have been very successful at measuring cerebral blood flow (CBF) non-invasively (1). However, to calculate an absolute CBF the transit times between the labeling and imaging planes must be known. They are either assumed or measured by acquiring data at various time between the end of the labeling pulse and the image acquisition which is costly in time (2). We propose here to use pseudo random sequences (PRS) (3) to modulate the magnetization of inflowing spins so that the resultant transit times can be deconvolved from the acquired images in a single unified acquisition. We have demonstrated the technique on a flow phantom.

Methods Images were acquired on a 89 mm vertical bore 9.4T Bruker Biospin imager. A gradient echo sequence with a variable selective 180^o pulse inserted immediately before the imaging block was used. The 180^o pulse, which inverted a 20 mm wide region, was either on or off depending on the value of the element in a 63 element long PRS. The imaged slice was in the middle of this region and was 1 mm thick. Imaging parameters were FOV 20 mm, TR 50, 100 and 200 ms, matrix 64x64, flip angle 45^o. A total of 63x64 transients were acquired, cycling through the PRS once for each k-space line. The flow phantom consisted of a 1.27cm id Tygon tube containing water running through the RF coil of 3cm id. A computer-controlled pump (Masterflex L/S) circulated the water in a closed loop. Flows were varied from 50 to 200 mL/min.

Theory The magnetization that arrives at the imaged slice will be a sum of the different travel times (due to the different velocities) from the edge of the inversion slab to the slice location. At every TR the spins that have crossed into the inversion region experience either a 180^o pulse or not as determined by the elements of the PRS. How many of these they will experience will depend on how long it takes them to travel to the slice location. For each travel time the spins will be modulated differently by the effects of the PSR. If we ignore the effects of relaxation since the transit times are much less than the T_1 then the equation relating the measured images and the flow distribution is

$$I_i = \sum_{j=0}^{N-1} I_0 (-1)^{\sum_{k=i}^{i-j} S_k} f_j \qquad [1]$$

where I_i is the image observed at the ith element in the PRS, f_j is the spins that have taken j TR periods to move from the edge of the inversion slab to the slice location and S_k is the kth element of the PSR (either 0 or 1). This is a matrix equation for f which can be solved by calculating and inverting the expression involving the PSR.

Results At the flow rates used, flow was non turbulent and parabolic. The sequential transit time images of the flow distribution *f* after inversion are shown in Fig. 1 for TR = 50ms (a), and TR = 100 ms (b), for a flow of 200mL/min. Several different flow rates and TR were also investigated. Fig. 2(a) shows similar images of *f* for TR = 100ms for a flow of 100mL/min, from which a pixel-wise velocity map was calculated (fig. 2(b)) and the velocity profile at the center of tube (fig. 2(c)) was derived from the curve fitting of the plots. The theoretical maximum velocity in the center of the phantom is 2.63 cm/s corresponding to a transit time of 380 ms. In all cases the observed transit time pattern was consistent with the theoretical velocities.

Discussion Figures 1 and 2 show the reconstructed transit time images at two different TR's, and two different flows at the same TR. As can be seen, not only is the appearance of the signal at the center of the tube in the transit time images at the theoretical expected time, but the images also clearly reflect the expected parabolic shape. These results demonstrate the ability of pseudo random amplitude modulation (PRAM) to recover all the transit time distributions in a unified way. The method has a number of advantages. It has a duty cycle of approximately 50%. There is no need for separate control and labeled images. Instead the entire sequence is used to calculate the entire time course of the labeled spins moving from the labeling plane to the imaged plane. We are now implementing the method on a human scanner.

Conclusion We have shown pseudo random amplitude modulation can acquire an entire set of transit time (flow) images from a flow phantom in a single unified study. We expect that the technique will have considerable use in arterial spin labeling studies *in vivo*.

References 1. Golay X, Hendrikse J, Lim TC., Top Magn Reson Imaging. (2004), **15**:10-27.; 2. Barbier EL, Silva AC, Kim HJ, Williams DS, Koretsky AP., Magn Reson Med. (1999), **41**:299-308.; 3. Knuth, DE, The Art of Computer Programming, Vol. 2. (1998), 3rd ed., Addison-Wesley, Boston.

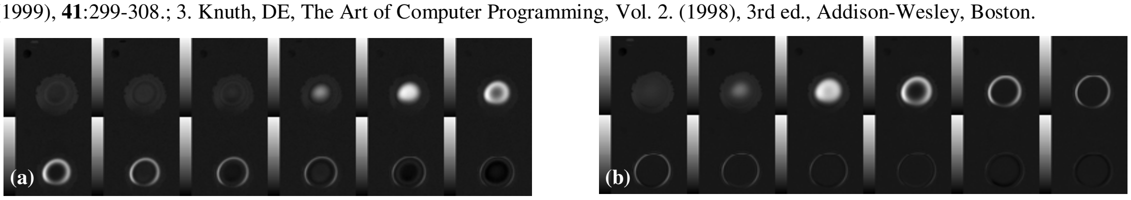
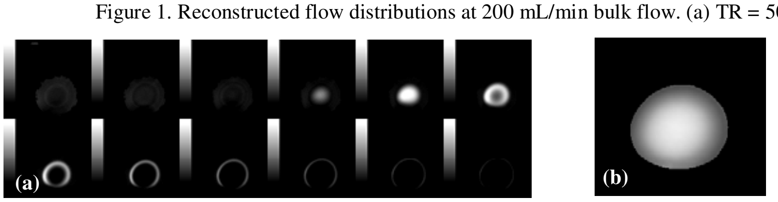


Figure 1. Reconstructed flow distributions at 200 mL/min bulk flow. (a) TR = 50 ms; (b) TR = 100 ms.



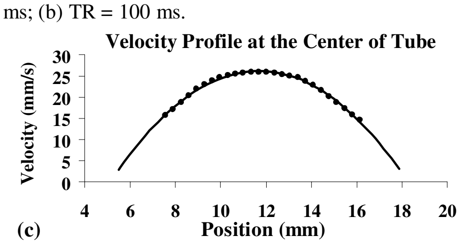


Figure 2. Reconstructed flow distributions at 100 mL/min bulk flow. (a) TR = 100 ms; (b) calculated velocity map; (c) velocity profile at the center of tube.