Strategies for Reducing Respiratory Motion Artifacts in Quantitative Renal Perfusion Imaging with Arterial Spin Labeling

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Introduction: Arterial Spin Labeling (ASL) is a potentially important technique for imaging renal function without the use of gadolinium-based contrast agents. Typically, many repetitions of the ASL measurement are required to attain sufficient SNR. Therefore, applying ASL in the abdomen carries the particular challenge of dealing with respiratory motion between successive image acquisitions. In body imaging, respiratory motion is typically managed by either acquiring data within a breath-hold or by gating acquisition to some point in the respiratory cycle. In ASL applications, use of background suppression reduces the corruption of the perfusion signal by physiological motion of the static tissues between acquisitions. A previous study of abdominal ASL employed navigators to compensate for respiratory motion but did not incorporate background suppression (1). We explore combinations of these strategies, including a novel *timed* breathing approach, for application to renal perfusion quantification with ASL. A preferred strategy for dealing with respiratory motion was established for clinical application of quantitative renal perfusion imaging. Imaging of volunteers was repeated in order to measure the test-retest repeatability of the various strategies. In addition, one strategy was repeated during one of the sessions in order to measure within-session repeatability.

Methods: BREATHING STRATEGIES – *Partial breath-hold:* several breath-holds were acquired and averaged together; each breath-hold encompassing 3-4 image acquisitions; *Timed breathing:* the subjects were asked to synchronize their breathing to the 6-s repetition time of the scanner in order that signal acquisition coincides with end expiration; *Free breathing:* completely free breathing was explored mimicking the case of a sedated or uncooperative patient. BACKGROUND SUPPRESSION – Each of the three breathing strategies was combined with heavy and moderate background suppression schemes (2). In addition, the timed breathing strategy was applied without background suppression. PROTOCOL – Five healthy volunteers were studied after obtaining written informed consent with IRB approval. The timed breathing with heavy background suppression strategy was repeated at the beginning and end of the hour-long session to estimate within session repeatability. Each volunteer was imaged twice, a week apart. ASL – Pseudo-continuous ASL (3) was used. The standard model for CASL (4) was used for perfusion quantification with tissue T_1 and M_0 reference images obtained during imaging. Sixteen ASL tag-control pairs were acquired for each combination of breathing strategy and background suppression. 2-D coronal images were acquired using an SSFSE sequence.

COMPARISON BETWEEN STRATEGIES – ROIs were drawn around the whole kidney and a mean value of absolute flow calculated. Test-retest repeatability was estimated from the difference between the mean perfusion at test and retest: the standard deviation of values from both kidneys of all subjects was found. Additionally, cortex and medulla were segmented according to measured tissue T_1 and the standard deviation of flow within the ROI found. Significant differences between strategies were then sought using Welch's t-test.

RETROSPECTIVE IMAGE SORTING – Imaging in a subsequent volunteer, respiratory bellows position was recorded immediately prior to each image acquisition and was used to eliminate images which were significantly out-of-position. The acceptance window for bellows position was 30% of the maximum bellows displacement between all images; the window was centered on the bellows position for the reference image. Ten ASL tag-control pairs were acquired for each strategy: deliberately breathing erratically, freely, and synchronized (timed) to the 6-s repetition of the image acquisition.

Results: The typical image quality and appearance of artifacts occurring for each background-suppression scheme in the quantitative perfusion images and in the perfusion-weighted difference images for heavy suppression are shown in Figure 1. Expressed as a percentage of mean flow, the test-retest repeatability within an imaging session for timed breathing with heavy background suppression was 4%. Test-retest repeatability between sessions a week apart was typically 10-20% for all strategies. For ROI standard deviation, only images without any background suppression showed a significant difference ($p < 0.01$ when compared to heavy background suppression), in particular, no significant differences were found between breath-held and free breathing acquisitions. Figure 2 demonstrates the improvement in image quality possible with retrospective sorting. Ten images out of 20 were rejected from the set of images acquired with free breathing, while 16 out of 20 were rejected from the set acquired with erratic breathing, and show the expected reduction in both blurring and SNR.

Discussion: The test-retest repeatability between sessions includes variability due to slice-placement for imaging and labeling as well as physiological variability in flow, and thus was lower than the in-session repeatability. The between-session repeatability represents a level reasonably achievable in a longitudinal patient study. Moderate and heavy background suppression, utilizing two and four inversion pulses, show reductions in perfusion signal compared to signal without background suppression of 16% and 23%. However, visual inspection of images indicates the superior robustness of heavy background suppression that is not apparent in ROI measurements. The novel timed breathing approach produces comparable image quality to breath-held acquisitions when the subject is able to cooperate. Retrospective sorting enables images without gross motion related artifact to be obtained with free breathing at the expense of lower SNR associated with image rejection. The acceptance criterion may be adjusted to trade off loss in SNR for reduced image degradation due to motion.

Conclusion: High quality quantification of renal perfusion is obtainable using ASL and with good repeatability. Image quality is optimized using background suppression and with breath-hold or timed breathing strategies in cooperative subjects. In a clinical setting the ability to implement retrospective image sorting will make ASL in the abdomen robust to free breathing.

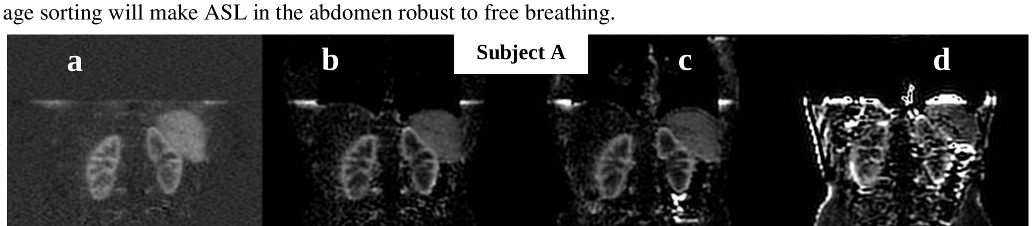
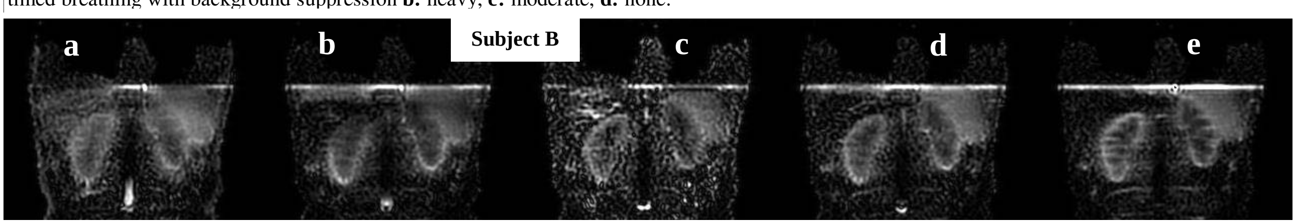


Figure 1: (*above*) **a:** Perfusion difference for image (b); quantitative perfusion maps for timed breathing with background suppression **b:** heavy, **c:** moderate, **d:** none.

Figure 2: (*below*) In a second subject: Quantitative perfusion maps with **a:** erratic, **b:** free breathing, and after retrospective sorting of **c:** erratic, **d:** free breathing; and **e:** with only timed breathing.
[Note slightly blurred appearance of images in Fig. 2 which were acquired with centric phase ordering; linear phase ordering was used for images in Fig.1.]



References: 1. Gach, Proc. ISMRM 2005, #2990. 2. Garcia, MRM 2005;54:366-372. 3. Garcia, Proc. ISMRM 2005, #37. 4. Buxton, MRM 1998;40:383-396.