Adaptive Sequential Design for Optimal Scheduling of Continuous ASL Data Acquisition

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Introduction: It has been demonstrated that Optimal Sampling Schedule (OSS) theory [1] can be used as an objective strategy for choosing a TI sampling scheme in pulsed arterial spin labelling (PASL) experiments, yielding an improvement in parameter estimation precision [2]. However, this requires *a priori* estimates of the likely value of the fitted parameters. Adaptive Sequential Design (ASD) addresses this issue by incorporating the OSS strategy into an adaptive process which iteratively updates the parameter estimates and adjusts the sampling schedule accordingly as data are acquired. Simulation work on an ASD-CASL protocol demonstrated that an optimized sampling strategy approach can be tuned in real time to incorporate pathological/abnormal parameter information, thereby improving parameter estimation precision [3]. Here we implemented the ASD concept with real-time feedback on a Siemens MR scanner. Good parameter estimations were achieved on-line in normal volunteers.

Algorithm: The OSS strategy for PASL experimental design, based on a D-optimality criterion, has been described previously in [2]. PASL OSS design takes physiologically plausible Gaussian distributions of cerebral blood flow (CBF) values and Δt values (the transit time between the labelling plane and the imaging voxel), as *a priori* parameter estimates, which are used to generate an optimized TI sampling schedule. In the present work, rather than making *a priori* assumptions about the underlying parameter distributions, we use an ASD strategy that iteratively analyzes the real-time data from the scanner, and instructs the scanner to acquire data using an updated and refined protocol. Within each iteration perfusion-weighted data are acquired using the current schedule. The standard ASL model [4] is then fitted to all currently acquired data voxelwise in order to obtain updated parameter estimates. These estimated parameter distributions are then used as sample distributions to generate the updated OSS. Before commencing the next iteration, the current schedule is updated to the new OSS. The iterative procedure ceases when the time limit for the scan is reached, or when a pre-determined tolerance is achieved. In this work, OSS design for optimization of CBF estimation was applied to continuous ASL (CASL) data. This procedure, when applied to a single voxel, finds the optimal Post Labelling Delay (PLD) to be equal to the underlying Δt value for that voxel. The updated PLD values which are optimal for all voxels within a grey-matter mask can then be calculated by partitioning the area under the distribution function of all estimated Δt values into N equal parts.

Methods: 6 healthy volunteers (1 female, 5 male, age 25-28) were scanned using a Siemens 3T TIM Trio system fitted with a single-channel T/R head coil. 12 axial slices (4×4×5mm voxel size) were acquired. A CASL-EPI sequence was used, with TR/TE = 4310/13ms. The labelling duration was 2.0 seconds (20×100ms RF pulses) and the post labelling delay was varied according to the optimised schedule. On-line image analysis was coded within the Siemens real-time image calculation environment (ICE). A grey-matter mask was generated by thresholding the difference images after the first iteration, and was used throughout the experiment. An initial schedule of 10 PLDs evenly distributed between 0 and 1.5s was used. At the end of each iteration, the scanning pauses briefly while the ICE program accesses all the currently acquired ASL difference data voxelwise within the grey matter mask and calculates the Δt values. Based on the distribution of all estimated Δt values, the new optimised schedule was generated and returned to the scanner. The scanning then continued with the updated OSS for the next iteration. The ICE calculation and feedback time after each iteration took 1-5s. 10 iterations were used, giving a total experiment time of ~13mins.

Results and Discussion: Preliminary results are shown in Figure 1. In the lower panel, the initial evenly distributed schedule is shown in black and the final optimized schedules of all 6 subjects are shown in different colours. The upper panel shows the distribution of all on-line estimated Δt values within the grey matter mask of one subject, based on which the final OSS is generated (red). The aim of this study was to prove that the concept of ASD-ASL strategy with real-time feedback is feasible. The self-evolving program is capable of giving good parameter estimates on-line. The results show that a reasonable parameter distribution can be obtained in real time, based on which the optimized schedule can be generated. Compared to the initial evenly distributed schedule, the final optimized schedules use more densely spaced PLDs around the peak in the Δt distribution.

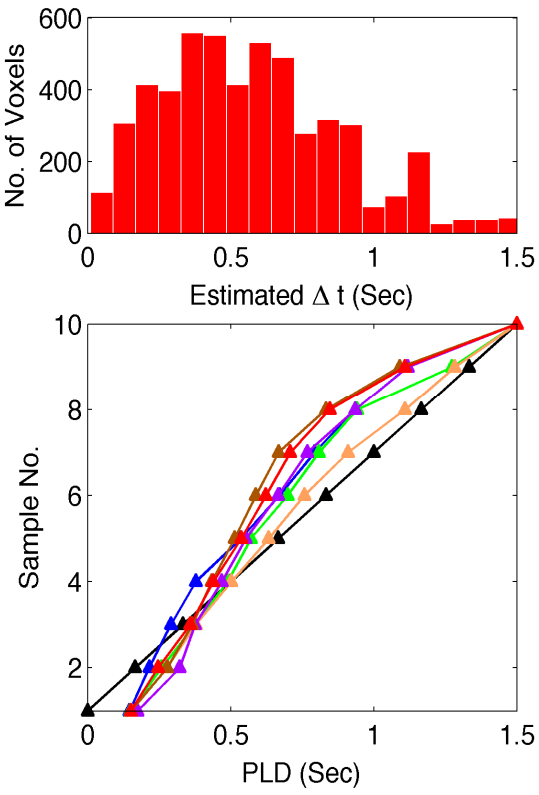

Fig. 1: Upper: distribution of on-line estimated Δt values (upper panel) for one subject. Lower: initial (black) and final (coloured lines) sampling schedules of six subjects.

Conclusion: An ASD-ASL strategy optimally utilizes the ability to dynamically interpret and act on experimental data and analysis information. It is capable of adapting itself to optimize data acquisition based on estimation of the underlying parameter values, thereby improving the precision of parameter fits. We expect this adaptive approach, which can be tuned in real time, to be capable of incorporating pathological/abnormal parameter information, offering the greatest advantage when applied to patient populations.

Acknowledgement: We thank Dr J.J Wang of the University of Pennsylvania for providing the CASL labelling pulse sequence module.

References: [1] DiStefano, Am. J. Physiol. 1982 24:531-534; [2] J. Xie et al, MRM. 2008 59:826-834; [3] J. Xie et al, HBM 2008, No.339; [4] Buxton et al, MRM 1998 40:383-396;