Theoretical and practical investigation of acoustic noise level reduction in pseudo-continuous Arterial Spin Labeling

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Purpose. Arterial Spin Labeling (ASL) is a non-invasive imaging technique for quantifying blood perfusion in tissue. Pseudo-continuous ASL[1] has recently emerged as the method of choice. It offers higher signal-to-noise ratio (SNR) than pulsed ASL and does so without the need for specialised hardware required by continuous ASL (dedicated RF amplifiers or local RF coils). However, concern has been raised about acoustic noise levels experienced by patients undergoing pCASL scans, leading to patient discomfort. This is especially a concern in imaging unsedated infants or elderly patients, where exposure to long lasting acoustic noise can increase patient unseat in the scanner. This study investigates the Sound Pressure Level (SPL) produced by the pCASL sequence and how it can be reduced without significantly changing the inversion efficiency.

Methods. The main source of acoustic noise in the pCASL labeling module is a long train (1.5-2s) of rapidly changing gradient waveforms (Figure 1) repeated many times over a 4-6 minute scan. It has been previously shown[2], that the noise spectrum of gradient can be predicted by the gradient wave spectrum if the system acoustic resonances are known:

$$p(t) = \int_0^{\infty} h(\tau)g(t-\tau)d\tau \text{ or } P(f) = H(f) \cdot G(f) \text{ in the frequency domain}$$

where $p(t), P(f)$ is the system output, $g(t), G(f)$ is the input (gradient waveform), $h(t), H(f)$ is called the transfer function; it can be calculated as the complex ratio of output response to an input excitation spectrum.

pCASL produces a spectrum with its fundamental peak at the frequency 1/(RF spacing) and series of harmonics at multiples of the peak frequency. Acoustic noise can be reduced by manipulating the RF spacing and RF duration to target minima in the system response. To verify this, the FFT of gradient shapes was calculated to study the gradient system response to different timing 'strategies' summarised in Table 1 (10 RF spacing values were considered starting from 1 ms every 0.1 or from 1.5ms every 0.15 ms; RF duration was either fixed or increased proportionally to RF spacing. Average amplitude of RF pulse over RF spacing was unchanged; the amplitude of positive gradient lobe was always 0.6 G/cm and that amplitude of negative lobe was matched so that Gpos/Gmean was equal to 10, 20 or 15, depending on the 'strategy'). Bloch equation simulations were performed to analyse changes in labeling efficiency resulting from changes in RF spacing and/or RF pulse duration. Real system response was measured with a Bruel and Kjaer 2260 integrating sound level meter on a 3T Philips scanner for chosen timing 'strategies'. A healthy volunteer underwent a series of pCASL perfusion scans to evaluate the labeling efficiency of these chosen 'strategies'.

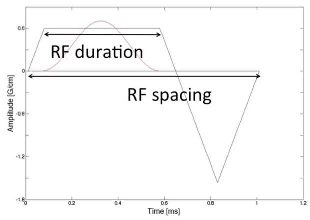

Figure 1. Single pCASL gradient shape

Results. Analysis of system response spectra indicated that reduction of up to 15dB in total SPL is possible compared to the default scanner setting, which was later verified for strategy 3 and 6 (lowest calculated SPL levels and best reduction) by direct measurements of SPL of pCASL labeling (Figure 2). A reduction of 6dB compared to the default scanner setting was achieved. Bloch equation simulation showed (Table 1), that by choosing high Gpos/Gmean or/and adjusting the RF duration, the labeling efficiency was preserved. Mean perfusion signal of 8 brain slices of volunteer together with STD, shown in Figure 3, suggest that there is no loss of labeling efficiency for the chosen strategies compared to default setting.

Discussion. A small adjustment of RF spacing and RF duration can reduce the acoustic noise experienced by the patient undergoing pCASL scan by 6dB down to the levels to EPI readout module. The difference in calculated vs measured SPL levels can be explained by the lack of a transfer function specific to our scanner and by the fact that the measurements were performed at the location of the patient's ear in the presence of a phantom.

Conclusion. It has been shown that acoustic noise level and therefore patients' comfort during scanning can be increased by adjusting timing values of pCASL gradient waveform without compromising labeling efficiency. Adjustment of the timing in the sequence does not require programming new gradient shapes and therefore can be easily implemented. However, further improvements could be expected from the use of smoother gradient forms.

'Stra-tegy'	FA°	RF spacing [ms]	RF duration [µs]	Gpos/ Gave	Labeling efficiency Min	Max
1	18-36	1-2	500	10	0.53	0.89
2	18-36	1-2	500 -1000	10	0.89	0.89
3	18-36	1-2	500	20	0.89	0.9
4	18-36	1-2	500 -1000	20	0.9	0.91
5	30-39	1.5-1.95	500	15	0.85	0.9
6	30-39	1.5-195	500-650	15	0.89	0.9

Table1. pCASL Design parameters (FA - flip angle of RF pulse,Gpos - amplitude of positive gradient, Gave - average gradient amplitude calculated from positive and negative gradients amplitude and RF spacing)

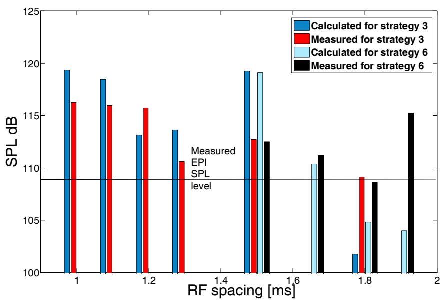

Figure 2. Measured SPL of pCASL labeling module and EPI readout module

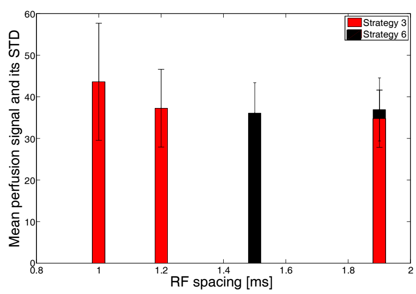

Figure 3. Mean perfusion signal

References: 1.Weiying Dai. Continuous Flow-Driven Inversion for Arterial Spin Labeling Using Pulsed Radio Frequency and Gradient Fields. *MRM 60:1488–1497 (2008).* 2. Hedeen RA, Edelstein WA. Characterization and prediction of gradient acoustic noise in MR imagers. *MRM 1997;37:7–10.*