Silent Pseudo-Continuous Arterial Spin Labeling

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INTRODUCTION:

Pseudo-continuous arterial spin labeling (pCASL) is a frequently used method to measure blood perfusion in a completely non-invasive way. Conventional pCASL labeling employs trapezoidal gradient waveforms and requires high gradient strengths in combination with high slew rates for sufficient labeling of flowing blood spins. [1] This results in mechanical vibrations and a high acoustic noise level which is experienced as uncomfortable by patients as well as by technicians, and which may be a cause of compromised image quality in a certain number of pCASL measurements.

In this study, possibilities are presented on how to reduce the acoustic noise level and the mechanical strain of a pCASL sequence, either by optimizing the labeling interval duration or by applying an altered gradient waveform or both.

MATERIALS and METHODS:

In a preparatory experiment, the acoustic transfer function of the z-gradient coil was determined by recording the acoustic noise level of the MR scanner with a conventional microphone when applying alternating gradients of varying frequencies ranging from 100 Hz to 3000 Hz. Analysis of the acoustic noise level measurement yielded a transfer function that enables to translate a gradient pattern with a specific frequency spectrum into acoustic noise levels. This transfer function allows estimating at which frequencies acoustic noise amplification or reduction is to be expected. [2]

The original pCASL sequence consists of a train of short RF pulses in conjunction with synchronously pulsed gradients, which are separated by an interval of 1.0 ms. [1]

Two different approaches to reduce the acoustic noise were investigated in this study: 1.) Changing the labeling interval, and thus shifting the frequency of the gradients to a more favorable part of the transfer function, and 2.) changing the waveform of the gradient. Both approaches, as well as their combination, were compared to the original pCASL labeling scheme. For the first approach, the labeling interval was increased from 1 ms to 1.08 ms. For the second approach, a sinusoidal gradient waveform was applied instead of trapezoidal gradients using the same maximum and mean gradient strength as well as labeling interval and flip angle of the RF pulses as in the original sequence (Fig. 1).

In order to verify the proposed labeling schemes, the major brain feeding arteries were labeled in 5 healthy subjects using both, the original pCASL approach and the sinusoidal pCASL waveform, with and without extended labeling interval duration. The acoustic noise level was recorded and the labeling efficiency was calculated by normalizing the signal intensity of the modified pCASL approaches with respect to the signal intensity of the original pCASL sequence. All measurements were performed on a clinical Philips 1.5T Achieva scanner using the following parameters: field of view 220x220 mm, voxel size of 2.7x2.7x6 mm, gradient echo planar read-out. Labeling duration 1.65 s, post labeling delay 1.525 s with background suppression, 18 slices and 20 averages of label and control images. Scan time was approximately 2:40 min per measurement.

RESULTS:

Figure 2 shows the transfer function of the z-gradient coil that presents a complicated shape with strong variations and sharp local minima and maxima. One local minimum appears at about 925 Hz, which corresponds to a labeling interval of 1.08 ms between two consecutive RF pulses. The frequency spectrum of the original pCASL gradient pattern with 1.0 ms labeling interval has its highest amplitude at 1 kHz, the fundamental frequency corresponding to the labeling interval, but also contains significant amplitudes at the harmonics of the fundamental frequency at 2kHz, 3 kHz, etc. (Fig. 3). Increasing the labeling interval to 1.08 ms shifts the whole spectrum to 925 Hz and its harmonics, where the main amplitude causes less acoustic noise compared with an interval of 1.0 ms. The acoustical noise is reduced by about 40% (Fig. 4) while the labeling efficiency is still about 91% compared with the original pCASL sequence (Fig. 5). The frequency spectrum of the sinusoidal gradient pattern contains only a single frequency at 1 kHz with no harmonics and with considerably lower amplitude compared with the original pCASL sequence (Fig. 3). This is directly reflected in acoustic noise, which is decreased by 80% with a labeling efficiency of 92% compared with original pCASL; increasing the labeling interval even further decreases acoustical noise amplitudes. However, labeling efficiency is significantly decreased to only 83% compared to original pCASL with trapezoidal gradient pattern and a labeling interval of 1.0 ms (Figs. 4, 5).

DISCUSSION:

Detailed characterization of the transfer function of the gradient coil allows estimating noise amplification and attenuation with respect to different frequencies present in the gradient spectrum. The transfer function is specific for the used gradient coil and for other scanner hardware. Changing the labeling interval will result in a shift of the frequency spectrum of the pCASL gradient pattern. In case of original pCASL, an increased labeling interval of 1.08 ms results in less amplification of the most prominent frequency, which is directly reflected in less acoustical noise (Fig. 4). However, other harmonic frequencies of the pCASL spectrum, which also contribute to the total acoustical noise, may experience stronger amplification. Using a sinusoidal gradient waveform with only a single frequency avoids this problem and allows for an easy optimization of the labeling interval duration. The proposed sinusoidal gradient waveform reduces acoustical noise during labeling very efficiently. This is a result of only one frequency with lower amplitude present in the frequency spectrum of the sequence (Fig. 3).

However, all approaches result in a decrease of labeling efficiency. In case of an increased labeling interval, also less energy was deposited because the flip angle was kept constant. Adjusting the flip angles such that the total RF power deposition is the same compared to a 1.0 ms labeling interval may counteract the loss in labeling efficiency and result in comparable labeling efficiencies. For the case of using a sinusoidal gradient waveform, using a different RF pulse shape optimized for this gradient waveform could improve the labeling efficiency.

Apart from increasing patient comfort, less acoustic noise means also less mechanical stress to the MR hardware which will increase the lifetime of a scanner and decrease the service costs of specific components.

CONCLUSION:

The acoustic noise level of a pCASL sequence can be dramatically reduced by applying a sinusoidal gradient pattern for the labeling sequence at the expense of a slightly reduced labeling efficiency. Further reduction of acoustic noise is possible by adapting the labeling interval such that the frequency spectrum of the gradient pattern coincides with a local minimum of the transfer function. The loss of labeling efficiency might be overcome by optimizing RF pulse parameters with respect to the gradient waveform.

REFERENCES:

1. Dai et al, MRM 2008;60:1488-1497
2. Hedeen et al, MRM 1997;37:7-10

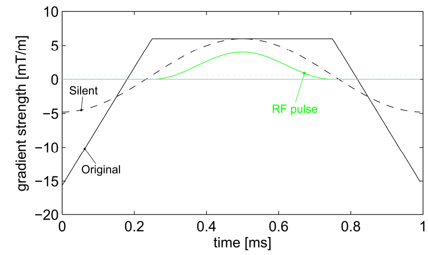

Fig 1: One labeling interval of the original pCASL gradient pattern (solid black line) and of the modified pCASL waveform (dashed). Additionally, the RF pulse amplitude is shown (green).

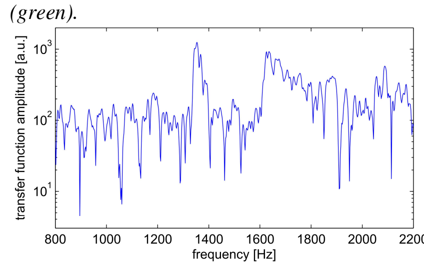

Fig 2: Transfer function of the z-gradient coil derived from an acoustic noise spectrum measurement.

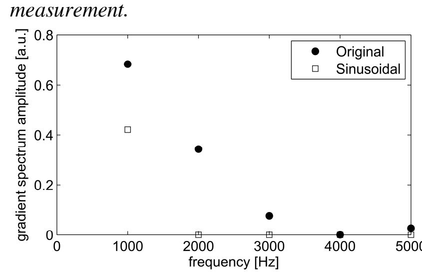

Fig 3: Frequency spectrum of the gradient wave-forms of the original pCASL and of the sinusoidal pCASL sequence.

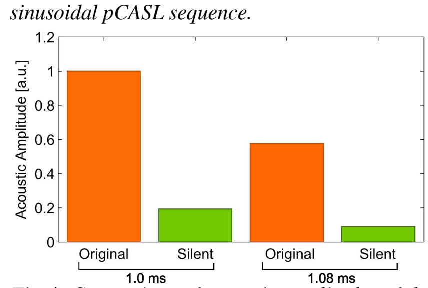

Fig 4: Comparison of acoustic amplitudes of the original pCASL and of the sinusoidal pCASL sequence with and without increased labeling interval.

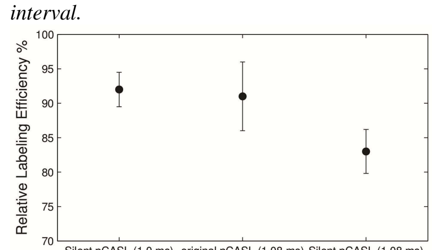

Fig 5: Comparison of labeling efficiencies of the original pCASL and of the sinusoidal pCASL sequence with and without increased labeling interval.