Prospective Motion Correction of Arterial Spin Labelling Demonstrated with Patient-Informed Motion

Ulrich Lindberg[1], Malte Laustsen[2], Thomas Ulrich[3], Alba Castrillo Perote[2], Gérard Crelier[3], Henrik Bo Wiberg Larsson[1], and Thomas Gaass[2]
[1]Department of Clinical Physiology and Nuclear Medicine, Copenhagen University Hospital - Rigshospitalet, Copenhagen, Denmark, [2]TracInnovations A/S, Ballerup, Denmark, [3]Gyrotools LLC, Zurich, Switzerland

Synopsis

Motivation: Arterial Spin Labelling is a promising non-invasive technique for cerebral perfusion measurement, but its sensitivity to patient motion limits its clinical application. This research explores prospective motion correction (PMC) to enhance ASL's reliability in motion-prone patient groups.

Goal(s): To evaluate whether PMC using the Tracoline device improves the quality of Perfusion Weighted Imaging (PWI) in ASL scans affected by motion.

Approach: ASL scans were conducted with PMC enabled, using head motion data from Tracoline to adjust the scan geometry in real-time during image acquisition.

Results: PMC significantly reduced motion artefacts, improving PWI quality and similarity to ground truth scans without motion.

Impact: This study demonstrates that prospective motion correction significantly enhances ASL image quality, making it more clinically viable for motion-prone patients. The findings encourage further exploration of real-time correction methods, potentially expanding ASL's diagnostic applicability across diverse patient groups.

Introduction

Arterial Spin Labelling (ASL) offers a non-invasive approach for measuring cerebral perfusion making it an ideal method for patient groups who do not tolerate contrast agent-based methods e.g. children, healthy controls. However, ASL's inherent characteristics—specifically its low signal-to-noise ratio and reliance on subtraction techniques—make it highly susceptible to motion artefacts. Prospective motion correction (PMC) presents a potential solution by enabling real-time scan geometry adjustments [1,2,3]. This study investigates the impact of PMC using an external tracking device on the quality of Perfusion Weighted Imaging in ASL, with the goal of enhancing ASL's clinical applicability.

Methods

Rigid-body head motion was recorded with a markerless motion tracking system (Tracoline TCL 3.2, TracInnovations, Ballerup, Denmark) [4, 5], providing head pose updates every 33 ms in six degrees of freedom.
Head motion updates were transmitted from the tracking system to the scanner spectrometer via an ethernet connection. The scan geometry was updated immediately prior to each slice readout, resulting in intra-volume motion correction. Head rotations were corrected by rotating the gradient waveforms. Shifts were corrected by adjusting the RF frequency and adding phase offsets to the raw MR signal. The motion correction functionality was fully integrated into the scanner software (through a research patch) and required no user interaction beyond enabling or disabling it.
Five healthy subjects (2 females) mean age 32±6 years, were included. During data acquisition, volunteers used an optical feedback system displayed on an in-room screen, which showed a cross replaying a randomly selected head motion trajectory from a database of pre-recorded patient motion, using the same optical tracking system. A second cross indicated the volunteer's current head position, allowing them to accurately reproduce the motion pattern.
Data was acquired on a 3 Tesla Philips Achieva dStream scanner (Philips Healthcare, The Netherlands) equipped with a 32-channel receive head-coil. A 2D pcASL sequence was acquired with standard Philips product sequence parameters, without background suppression (Table 1).
Four identical ASL scans were acquired; one ground truth without motion; one without motion with prospective motion correction; one with motion without correction; one with same motion with prospective motion correction. Data was registered to a T1w high-resolution scan, through a saturation recovery look-locker based T1 mapping sequence [6], and spatial coefficient of variation (CoV) [7] was calculated for a grey matter region of interest (fig 1. red overlay) calculated on the T1w images (fsl_anat). Results from PMC were compared to volume alignment on uncorrected motion scans using fsl_mcflirt [8]. To quantify the amount of motion in each scan a motion score [9] representing 6-DOF head motion as the maximum surface displacement of a 64mm diameter sphere was calculated on changes in head position in 1s intervals and averaged over the scan duration.

Results

Figure 1 shows ASL perfusion maps for Subject 1 for ground truth still scans (still), uncorrected motion scans (UC), motion scans corrected using optical tracking (PMC), and motion scans corrected using volume alignment (RMC). Significant degradation of the ASL signal is observed in the UC scans. Enabling PMC leads both to images with less visual motion artifacts and to higher similarity to still scans than conventional methods using RMC.
Figure 2 shows the CoV within each group. PMC achieves a clearly better CoV when compared to UC and RMC.
Figure 3 shows both instructed and performed head motion curves for UC and PMC scans for Subject 2. Table 2 lists mean motion score [9] and mean-squared-error (MSE) between instructed and performed head rotations for each scan. A high degree of reproducibility was observed between the two motion scans (UC/RMC and PMC). Similarly, the still scans shows lower motion-score and good compliance.

Discussion

Conventional image-based rigid volume alignment improves quality of ASL perfusion maps during motion (Figure 1) but leaves intra-volume motion uncorrected. In addition, performance is limited by signal differences in volumes with/without labelling and limited structural information when background suppression is utilized.
Prior studies exploring PMC [1,2,3] and external tracking [1] in ASL have been limited to one FOV-update during volume acquisition. We demonstrate that per-slice PMC and external tracking improves likeness of perfusion maps during head motion to maps acquired without motion, illustrated visually (Figure 1) and with CoV score in grey matter ROI (Figure 2).
The motion-feedback system allowed subjects to recreate involuntary head motion data recorded on patients, making findings more accurately represent performance in a clinical setting compared to controlled head nodding in one axis, as were performed in [1,2,3].

Conclusion

This study demonstrates that prospective motion correction significantly enhances ASL image quality, making it more clinically viable for motion-prone patients.

Acknowledgements

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Figures

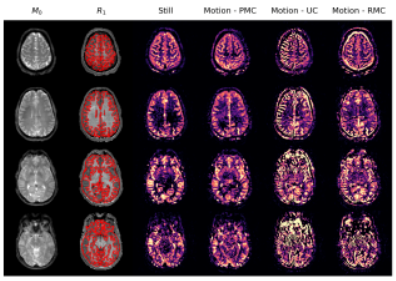

Figure 1: ASL perfusion maps for Subject 1 for ground truth still scans (still), motion scans corrected using optical tracking (Motion-PMC), uncorrected motion scans (Motion-UC), and motion scans corrected using post-processing volume alignment (Motion-RMC). Also depicted are a M0 map and a R1 map with grey-matter ROIs indicated by the red outline.

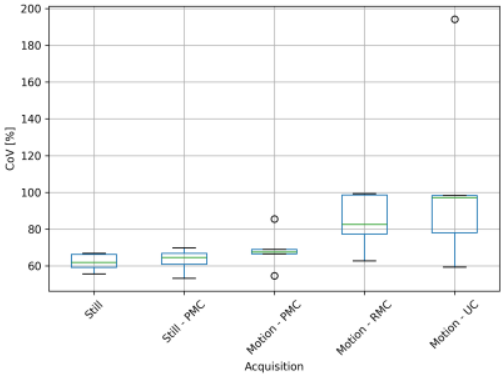

Figure 2:Spatial coefficient of variation (CoV) [3] for all subjects calculated for a grey matter ROI (fig 1. red outline) in ground truth still scans (Still), still scans corrected using optical tracking (Still-PMC), motion scans corrected using optical tracking (Motion-PMC), motion scans corrected using volume alignment (Motion-RMC), and uncorrected motion scans (Motion-UC). All ASL scans are co-registered to T1w structural scans of the same subject before calculation of CoV using FSL FLIRT.

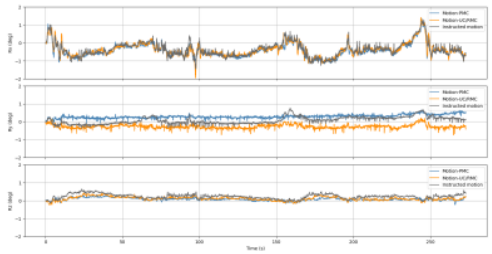

Figure 3: Head motion Euler angles (Rx, Ry, Rz) for subject 2 showing instructed motion (black), performed motion during uncorrected motion scan (Motion-UC/PMC, orange) and motion during scan corrected using optical tracking (Motion PMC, blue).

	T1w	*ASL*	*T1 mapping*
Acquisition Matrix	240x240	88x88	88x88
Reconstructed Matrix	512x512	128x128	128x128
No. Slices	170	16	16
Field-Of-View [mm3]	240x240x170	240x240x95	240x240x95
Echo Time [ms]	2.97	13	13
Repetition Time [ms]	6.63	4550	520
SENSE (CS: Compressed SENSE)	CS: 1.87	2.3	2.3
Flip Angle [deg.]	8	90	30
Labelling Duration [ms]	-	1800	-
Post-Labelling Delay [ms]	-	1800	-
Slice Read-out Time [ms]	-	53	32
Label dist. from centre of FOV [mm]	-	90	-
No. Look-Locker phases			16

Table 1: Sequence parameters for the applied T1w structural sequence, ASL sequence and T1 mapping sequence.

	Still	**Still - PMC**	**Motion - UC**	**Motion - PMC**
Subject 1				
Motion Score [mm]	0.20	-	0.55	0.66
MSE to instructed [deg]	0.01,0.01,0.01	-	4.59,3.05,2.02	6.52,1.67,1.63
MSE to Motion - UC [deg]	-	-	-	0.76,0.42,1.92
Subject 2				
Motion Score [mm]	0.42	0.40	0.41	0.32
MSE to instructed [deg]	0.53,0.13,0.03	0.11,0.01,0.01	0.01,0.15,0.02	0.02,0.07,0.03
MSE to Motion - UC [deg]		-	-	0.02,0.33,0.01
Subject 3				
Motion Score [mm]	0.24	0.19	0.45	0.40
MSE to instructed [deg]	0.03,0.23,0.01	0.01,0.02,0.01	0.09,0.98,0.03	0.20,0.57,0.09
MSE to Motion - UC [deg]	-	-	-	0.16,0.18,0.07
Subject 4				
Motion Score [mm]	0.16	0.19	0.67	0.64
MSE to instructed [deg]	0.01,0.04,0.00	0.01,0.04,0.01	0.45,0.15,0.10	0.30,0.11,0.05
MSE to Motion - UC [deg]	-	-	-	0.35,0.07,0.11
Subject 5				
Motion Score [mm]	0.14	0.13	0.60	0.52
MSE to instructed [deg]	0.01,0.07,0.00	0.01,0.04,0.00	0.12,0.10,0.01	0.10,0.18,0.01
MSE to Motion - UC [deg]	-	-	-	0.10,0.03,0.01
Mean				
Motion Score [mm]	0.23	0.23	0.53	0.51
MSE to instructed [deg]	0.11,0.09,0.01	0.03,0.02,0.00	0.17,0.34,0.04*	0.16,0.23,0.05*
MSE to Motion - UC [deg]				0.16,0.15,0.05*

Subject 1 was excluded from entries marked with * due to current position not being displayed correctly.

Mean motion score and MSE between instructed and performed head rotation Euler angles (Rx, Ry, Rz) for each scan. The motion score is calculated for windows of 1s duration and averaged for the whole scan. A high degree of reproducibility is observed between the two motion scans (UC/RMC and PMC). Subject 1 was excluded from mean MSE-values marked with (*) since their position in the scanner was not displayed during scanning.