MEASURING THE INFLUENCE OF VESSEL GEOMETRY ON PCASL LABELING EFFICIENCY

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TARGET AUDIENCE: Clinicians and researcher interested in efficient planning of the pseudo-continuous arterial spin labeling (ASL).

PURPOSE: The labeling efficiency of pseudo-continuous ASL[1] (pCASL) and its inter- and intra-subject reproducibility is a crucial point for reliable cerebral-blood-flow (CBF) measurements with ASL. Potential causes of varying labelling efficiency are, for example, B_0 field inhomogeneity[2], blood velocity[3], or labeling-plane positioning[3]. The common recommendation is to position the labeling plane on a straight part of the vessel and perpendicular to them[6]. However, it is not always possible to avoid tortuous parts of the vessels if angiography is not available. Here, we study the effect of vessel geometry on the labeling efficiency both trough simulations and experiments.

METHODS: **Simulations:** Labeling efficiency was calculated for three cases of vessels geometry using numerical simulations as described by Wu[4]. Blood velocities between 1 and 40 cm/s were investigated and laminar flow was assumed. First, efficiency was calculated for a plane perpendicular to a straight vessel and angulated at 12.5°, 22.5°, or 45°. Second, a simple bend of the vessel was assumed with a length of the horizontal section of 0, 5, or 10 mm and the labeling plane positioned on the center of it and 2, 6, or 12 mm below (see Fig. 1a). Third, the bend was rotated 0°, 12.5°, 22.5°, or 45° so that the labeling plane intersected the vessel three times (Fig. 1b). **Acquisitions:** Five healthy young volunteers (age 31.8±3.9 y) were scanned at 3T using an eight-channel head-coil. A 3D TFE T_1-weighted sequence and five pCASL sequences (pCASL1-pCASL5) with different position of the labeling plane were acquired. The T_1-weighted sequence had voxel size 1×1×1 mm^3. The common parameters of the pCASL sequence were: TR/TE = 3765/11 ms, FOV = 220×220 mm^2, pixel size = 2.75×2.75×6 mm^3, 17 slices (0.6 mm gap), flip angle = 90°, 20 averages, background suppression with 2 pulses, 2D multi-slice EPI readout, labeling with a Hanning RF-pulse with duration 0.5 ms, tip angle 18°, and inter-pulse pause 0.5 ms, labeling time/post-labeling delay 1525/1650 ms. A reference image was acquired 5000 ms after saturation. For pCASL1, the labeling plane was set parallel with the imaged slices and the gap was set in a way that the labeling plane intersected vertebral arteries (VA) at the level of siphon. The labeling plane was placed as parallel to the horizontal section of the VAs as possible (Fig. 1c). For pCASL2,3, the labeling plane was positioned 6 and 12 mm lower, respectively, than in pCASL1 (Fig. 1c). In pCASL4, 5 the labeling plane was positioned as in pCASL3 and rotated in the sagittal plane -30° and 30° with the center of rotation in the internal carotid arteries (ICA), see Fig. 1c. **Preprocessing:** The dynamics of all sequences were aligned with the first dynamics of pCASL1, thus co-registering the sequences and compensating for motion within each sequence. The T_1-weighted image was aligned to the mean control image and segmented to obtain partial volume fractions for gray matter (GM). CBF was quantified according to the ASL white-paper[6]. Mean CBF (GM > 70%) in the vascular territories corresponding to the anterior cerebral artery (ACA), posterior cerebral artery (PCA), middle cerebral artery (MCA), and vertebral artery (VA) were computed for each sequence and subject. For pCASL1,2,4,5, the relative difference of the mean CBF for each region was calculated relative to pCASL3 which was considered optimal as it contained no twists or angulations.

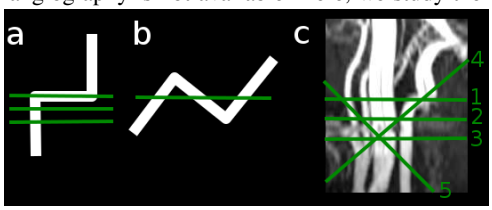

Figure 1. a) A bend in the vessel with the labeling plane positioned at the horizontal section or below. b) The shape from a) with angulated labeling plane. c) Planning of the labeling plane position for pCASL1-5.

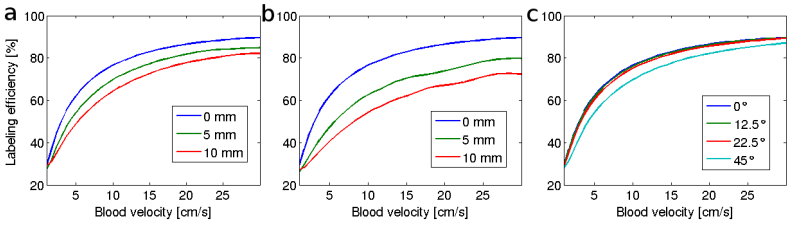

Figure 2. Labeling efficiencies for a simple bend with horizontal stretch length 0, 5 and 10 mm (Fig. 1a) with labeling plane placed directly on the horizontal stretch (b) or 2 mm below (a). c) Labeling efficiency for plane angulation.

pCASL	ACA	MCA	PCA	VA
1	2.6 ± 7.4	0.6 ± 9.9	-5.0 ± 4.4	-14.7 ± 5.3**
2	-3.1 ± 5.6	-1.6 ± 6.2	-3.3 ± 5.0	-7.4 ± 9.1
4	1.7 ± 8.7	0.3 ± 4.7	-8.4 ± 5.5*	-16.9 ± 12.1*
5	3.3 ± 6.1	3.0 ± 6.7	-0.3 ± 6.3	-4.5 ± 4.9

Table 1. Mean relative CBF difference from the pCASL3 for different vascular territories. The values marked (*) were significantly different from zero with p<0.05, and values marked (**) with p<0.01.

RESULTS: According to the numerical simulations, the decrease in labeling efficiency due to plane angulation is under 5% for most blood velocities and angle up to 30°, but it can go up to 10% for 45° angulation (Fig. 2c). For a bend in the vessel (Fig. 1a) of length 10 mm, the labeling efficiency can be decreased 20-25% (Fig. 2b). With increasing distance of the labeling plane, the decrease is only about 10% at 2mm (Fig. 2a), under 3% at 6mm and under 1% at 12 mm distance. For multiple intersections (Fig. 1b), the labeling efficiency decreased 25-30% regardless of the examined angle. The mean relative difference from sequence pCASL3 for different vascular territories is displayed in Tab. 2.

DISCUSSION: The experiments confirmed that labeling plane shift (pCASL1,2 in Tab. 1) or angulation up to 30° on ICA (pCASL4,5) produced less than 4% change of CBF in the ACA and MCA regions. Positioning the labeling plane on a section of VA parallel with it (pCASL1) caused 5.0% and 14.7% CBF decrease in PCA and VA regions respectively, although only in VA the change was significant. By increasing the distance from the bend (pCASL2), the CBF decrease became lower and not significant. Significant decrease of CBF of 8.4% and 16.9% in both PCA and VA regions, respectively, was achieved by positioning the labeling plane in a way to intersect VA at siphon multiple times. More significant decrease was expected from the simulations. The reason can be, that the actual vessel geometry was different from the worst modeled case. More measurements need to be done to find out why the decrease was lower in PCA than in VA. There are several limitations in this study. The magnetization transfer effects on the label were not taken into account[5]. Laminar flow profile was assumed, however the vessel thickness with regards to gradient fields was neglected for simplicity. By angulating the labeling plane, it is possible that it can intersect the imaged volume and thus directly or by magnetization transfer effects lower the measured perfusion signal. To minimize influence of this, the pixels where minimal-maximal intensity difference for all sequences was more than 10% were excluded from the analysis.

CONCLUSION: Reasonable angulation of the labeling plane causes only insignificant changes in labeling efficiency and measured CBF. On the other hand, twist and loops of the vessels as well as multiple crossing of the vessels by a labeling plane can cause significant changes of up to 25% and possibly even more, although this has been experimentally demonstrated only in VA region and not in PCA region.

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