Technical background of ASL in dementia
Training School in Toulouse/FR, Sept 30 – Oct 2, 2013

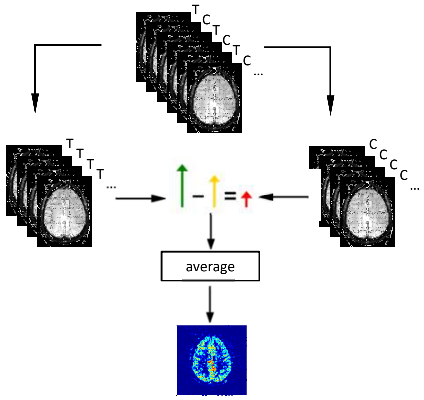
Wed October 2, 2013 – Image Processing

Pre-processing: motion correction, denoising, outlier detection

Alessandra Bertoldo

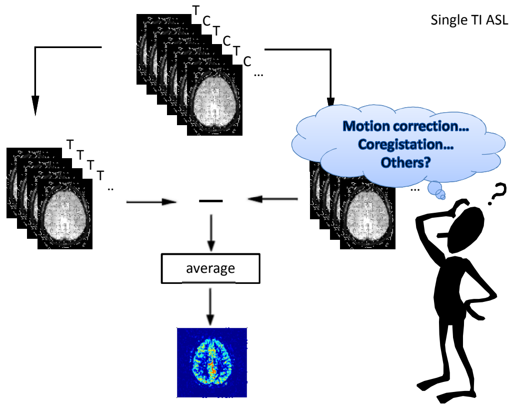
Pre-processing of ASL data

Single TI ASL

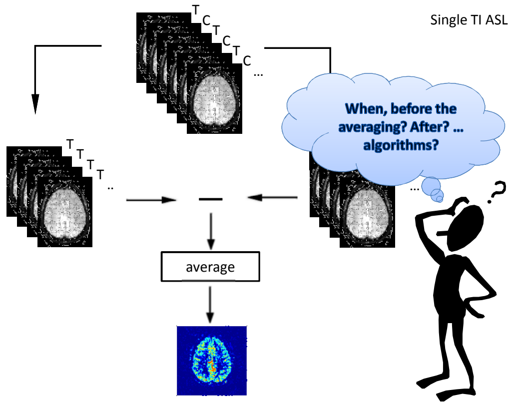


Pre-processing of ASL data

Single TI ASL



Pre-processing of ASL data



Pre-processing of ASL data: SUMMARY

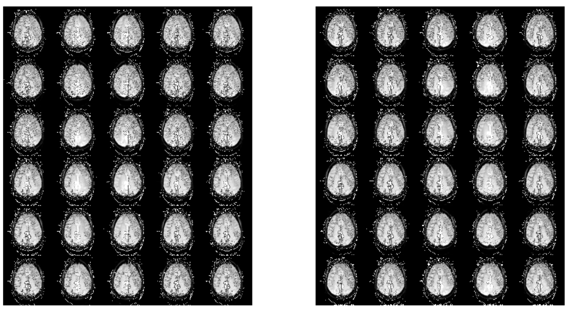
1) Outlier detection/ Intra-scan quality control
2) Motion correction
3) Image denoising-deblurring
4) Smoothing
5) Coregistration
6) EPI distortion correction

Single TI ASL

Outlier Detection

TAG: 30 repetitions

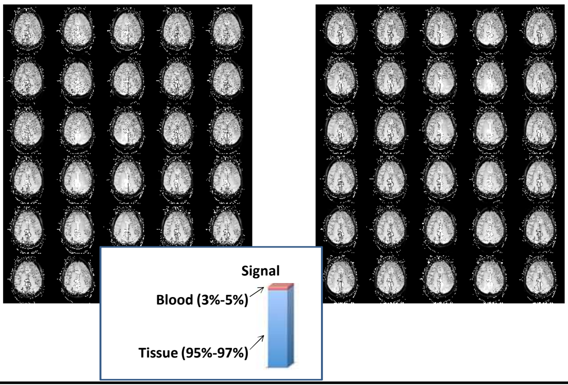
CONTROL: 30 repetitions



Outlier Detection

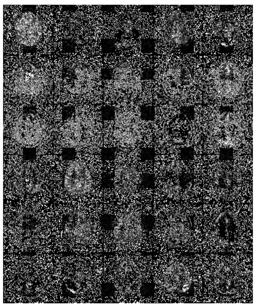
TAG: 30 repetitions

CONTROL: 30 repetitions



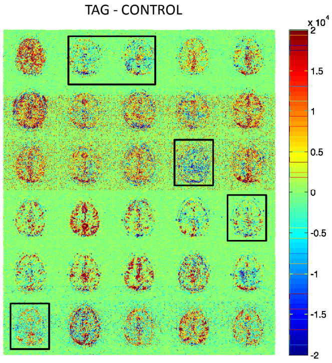
Outlier Detection

TAG - CONTROL

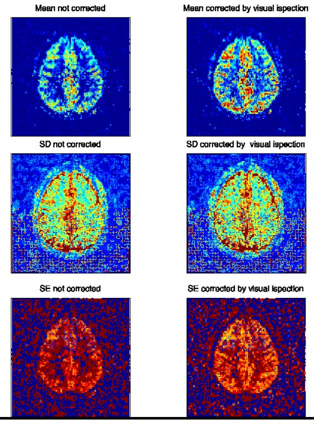


Outlier Detection

TAG - CONTROL

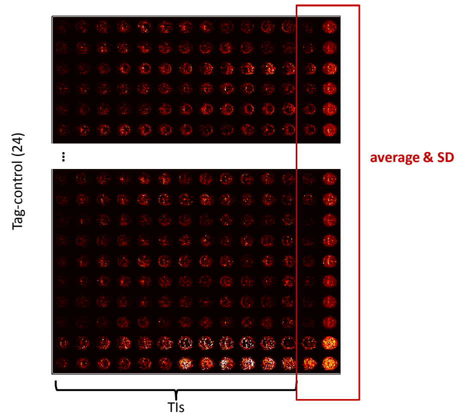


Outlier Detection

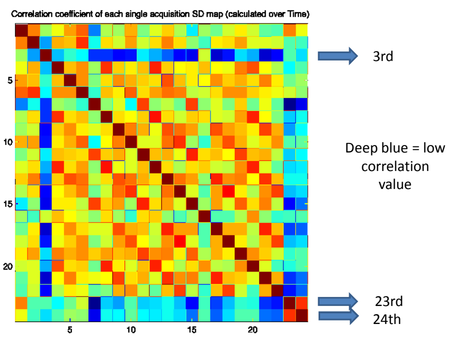


Coregistration: Multi TI

ASL QUASAR



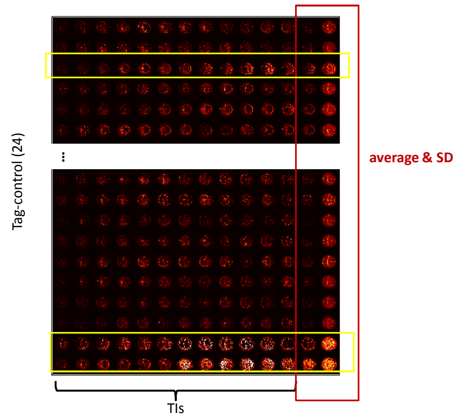
Coregistration: Multi TI



Map of the 2D correlation values between the 24 averages → Discard lower values

Coregistration: Multi TI

ASL QUASAR



Outlier Detection

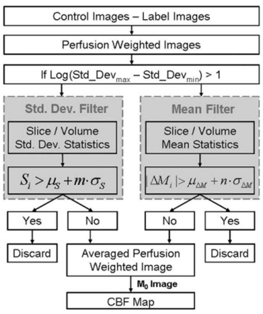
Currently only few attempts:

1. Tan H., Maldjian J.A., Pollock J.M., Burdette J.H., Yang L.Y., Deibler A.R., Kraft R.A. *«A fast, effective filtering method for improving clinical pulsed arterial spin labeling MRI»* *Journal of Magnetic Resonance Imaging* 29, 1134–1139 (2009) ➔ PASL
2. Maumet C., Maurel P., Ferré J.C., Barillotan C. «*Robust Cerebral Blood Flow Map Estimation in Arterial Spin Labeling*» *Lecture Notes in Computer Science* 7509, 215-224 (2012) ➔ PICORE Q2TIPS + simulated data

Outlier Detection

"A mean and standard deviation-based filter was implemented to remove outliers in the set of perfusion-weighted images (control – label) before being averaged.... the filtering procedure was performed on both a volume-by-volume basis and a slice-by-slice basis" (Tan et al., 2009)

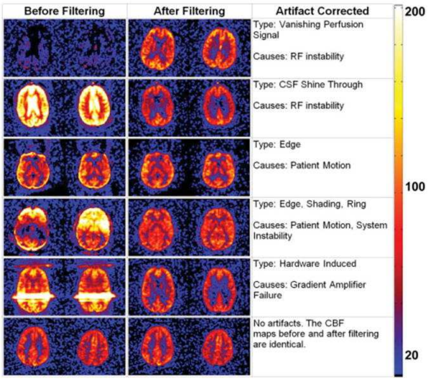
m=1.5



n=2.5

Tan et al., J Magn Reson Imaging. 2009 May; 29(5): 1134–1139.

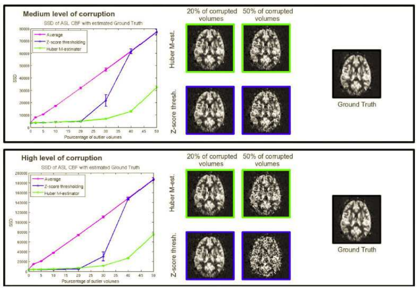
Outlier Detection



Tan et al., J Magn Reson Imaging. 2009 May; 29(5): 1134–1139.

Outlier Detection

Maumet et al. proposed to quantify CBF values by using the Huber's Maximum likelihood-type-estimator since it is less influenced by outliers than other estimators



<<In all configuration Huber's M-estimators is either better or as good as z-thresholding to estimate robust CBF maps. In the presence of outliers, Huber's M-estimator is always more accurate than the sample average>>

Maumet et al., Lecture Notes in Computer Science 7509, 215-224 (2012)

Motion correction

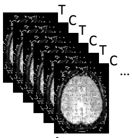
Motion correction

Head motion results in severe image artifacts especially in ASL since it requires identical positioning of label and control images

Currently it is possible to retrieve only few contributions to solve this issue

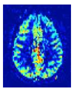
- **hardware**: e.g. systems tracking the movement
- **software**: e.g. algorithms for motion correction

Motion correction: basic strategy



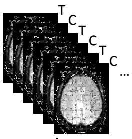
e.g. FSL mc-flirt
-all tag & ctrl
-meanvol

Common Reference



- Before averaging, motion correction is performed through 3D rigid body registration of the images.
- Often six-parameter based rigid body transformation is used. It minimizes the distance between each volume and the reference volume (for instance, the first image of the ASL series)

Motion correction: basic strategy



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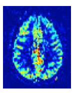


BUT:

differences can be interpreted as motion but generated by the change of the ASL perfusion signal between ctrl & tag (zig-zagged spin labeling paradigm)

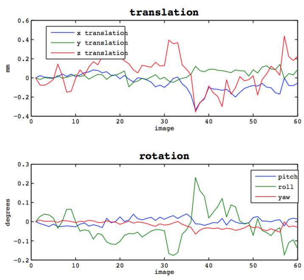
Motion correction

Wang Z. «*Improving cerebral blood flow quantification for arterial spin labeled perfusion MRI by removing residual motion artifacts and global signal fluctuations*»
Magn Reson Imaging 30:1409-1520 (2012)

1) all ASL images, tag+ctrl ➔ standard strategy (six-parameter based rigid body trasformation)

2) the zig-zagged label-control patterns ➔

Motion correction



Motion correction

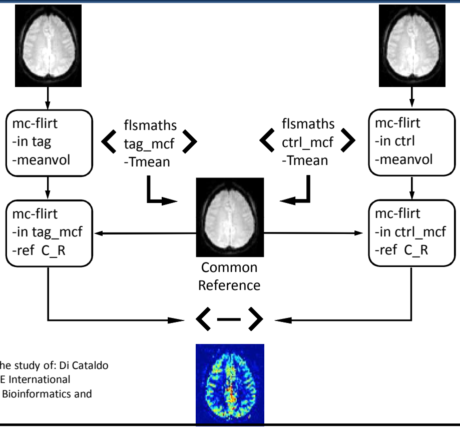
Wang Z. «*Improving cerebral blood flow quantification for arterial spin labeled perfusion MRI by removing residual motion artifacts and global signal fluctuations*»
Magn Reson Imaging 30:1409-1520 (2012)

1) all ASL images, tag+ctrl ➔ standard strategy (six-parameter based rigid body trasformation)

2) the zig-zagged label-control patterns ➔ regressed out from those motion time courses through simple regressions. Denoting label by – 1 and control by 1, the zig-zagged label-control paradigm is a binary numerical series consisting of oscillating -1 and 1.

3) Third, the cleaned motion parameters ➔ then used for real motion correction (SPM ASLtbx)

Motion correction



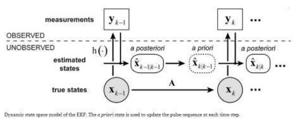
Suggested by the study of: Di Cataldo et al., 2011 IEEE International Conference on Bioinformatics and Biomedicine

Motion correction: software

White N., Roddey C., Shankaranarayanan A., Han E., Rettmann D., Santos J., Kuperman J. , Dale A. «*PROMO – Real-time Prospective Motion Correction in MRI using Image-based Tracking*»
Magn Reson Med. 2010 January; 63(1): 91–105 (2010)

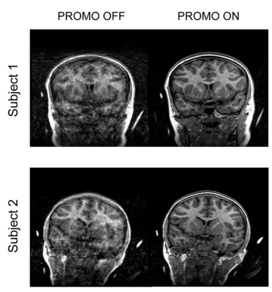
PROspective Motion (PROMO) is a navigator based module developed to be inserted into various MR pulse sequences for real-time 3D motion estimation and correction.

The PROMO approach utilizes three orthogonal 2D spiral navigator acquisitions (SP-Navs) along with a flexible image-based tracking method based on the Extended Kalman Filter algorithm for real-time motion measurement.



PROMO has been integrated into PCASL

Motion correction: software

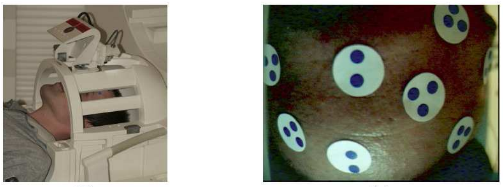


two healthy young males

Motion correction: hardware

Hoßbach M., Gregori J., Wesarg S., Günther M. «*Head Motion Compensation for Arterial Spin Labeling Using Optical Motion Tracking*»
Lecture Notes in Computer Science 7761: 1-8 (2013)

A real-time head motion tracking system is evaluated using MR-compatible cameras attached to the head coil, tracking blue dot markers on the forehead



(a) (b)

Fig. 1. (a) MR compatible cameras attached to the camera holder, which is attached to the MRI head coil. (b) Image of a volunteer as seen by one of the in-bore tracking cameras. Blue dots on paper stickers are used for tracking.

Motion correction: hardware

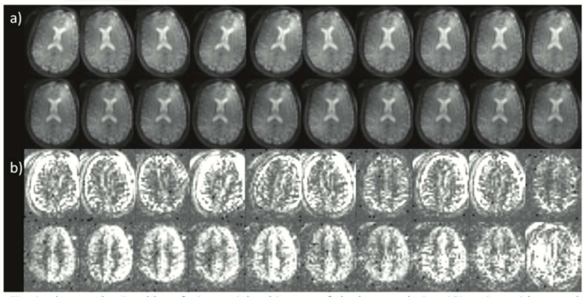


Fig. 1: a) non-selective, b) perfusion weighted images of the low-resolution ASL series, without and with real time motion correction. When head motion occurs between non-selective and slice-selective acquisition (not shown), perfusion difference images become unusable. Signal can be recovered using motion correction (lower row).

Denoising – Method 1

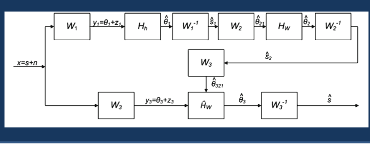
Signal-to-noise (SNR) ratio is a critical issue in ASL data (especially PASL QUIPSS II or Q2TIPS)
Possible solutions:

- Average of a high number of volumes (40-100)
- Increase the magnetic field strength
- Improve the coil efficiency
- Employ a denoising algorithm in the post-processing

Gaussian Smoothing
Image convolved with a Gaussian Function (blur of the pixel)
Voxel size = 3.75 x 3.75 x 6.3 mm^3
Filter = two-dimensional gaussian kernel FWHM = 8 mm and FWHM = 5.6 mm

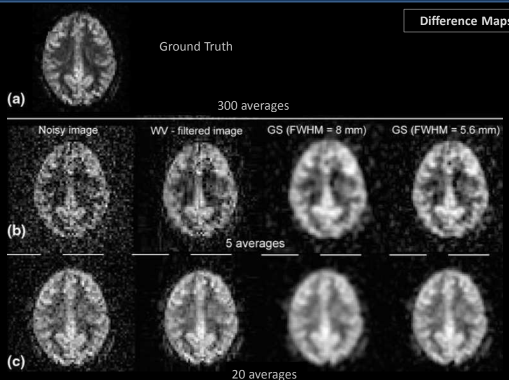
Wavelet Denoising

W = wavelet-transform matrix
X = measured image
S = true object signal
N = noise (gaussian)
Y = wavelet coefficient



Bibic A et al., "Denoising of ASL data: wavelet domain filtering compared with gaussian smoothing", MAGMA 2010, 23:125-137

Denoising – Method 1



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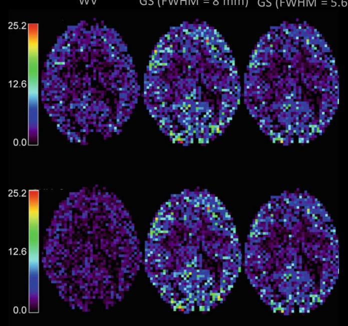
Denoising – Method 1



Bibic A et al., "Denoising of ASL data: wavelet domain filtering compared with gaussian smoothing", MAGMA 2010, 23:125-137

Denoising – Method 2

Ground Truth

Difference map obtained from the average of 64 control/label pairs

3D GRASE pCASL acquisition, single PLD

Wiener Filter

$$b = \mu + \frac{\sigma^2 - v^2}{\sigma^2}(C - \mu)$$

μ, σ^2 = Mean and variance within a 3x3 kernel centered in each pixel
C = pixel value
v^2 = noise variance
b = filtered pixel

AD Filter

$$K = 1.4826 \cdot MAD(\nabla I)$$

MAD = Median Absolute Deviation
∇I = image intensity gradient
K = scale parameter

Gaussian Filter

$$M = S \otimes G$$

S = original image
G = gaussian kernel
(sd = 0.5 voxel, kernel size = 3x3)
M = resulting image

Wavelet Filter: Harr wavelet

$$thr = \sqrt{2\log(y)} \times v$$

v = noise variance
y = number of pixels
thr = optimal threshold (soft and hard)

ICA filter

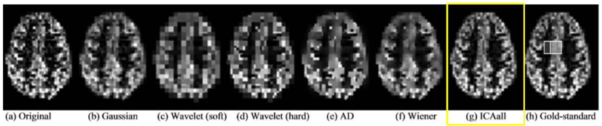
$$C(x,t) = \sum_{j=1}^{M} a_j(x) \cdot S_j(t) + noise$$

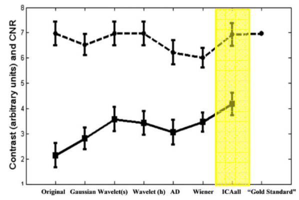
a = independent signal components
S = weigth coefficients
C = total signal

Wells JA et al., "Reduction of Errors in ASL Cerebral Perfusion and Arterial Transit Time Maps Using Image De-Noising", MRM 2010,64: 715-724

Denoising – Method 2

Difference Maps





CNR = contrast to noise ratio in the two ROIs
Contrast = mean signal ROI_1 – mean signal ROI_2

Wells JA et al., "Reduction of Errors in ASL Cerebral Perfusion and Arterial Transit Time Maps Using Image De-Noising", MRM 2010,64: 715-724

SMOOTHING

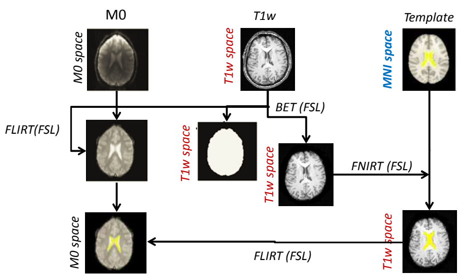
Denoising of arterial spin labeling data can be done also using smoothing.
Two different levels:

1) Smoothing the raw ASL images (usually by a conventional Gaussian filter)
2) Smoothing after CBF calculation and spatial normalization (usually by a conventional Gaussian filter)

Partial volume effect

Signal to noise ratio

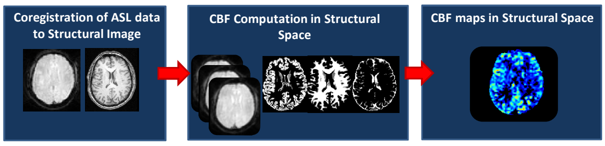
Coregistration



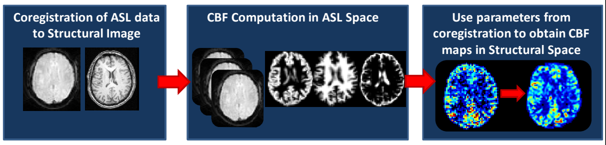
Adapted from: Thomas W Okell, Michael A Chappell, Michael E Kelly and Peter Jezzard, Journal of Cerebral Blood Flow & Metabolism 2013; doi: 10.1038/jcbfm.2013.129

Coregistration

Method 1



Method 2



Coregistration

Considerations

- ***M_{0b}***: if we use an external calibration scan and a voxelwise approach for M_{0t} estimation, it is necessary to coregister also this image to the Structural image. This increases the possibility of bias in the CBF estimations.
- ***2D readout***: in this case, the acquisition time (inversion time TI or post-label delay PLD) for each slice needs to be corrected for the slice acquisition time, i.e.

$$TI_i = TI + (i-1)*slice_{scan\_time}$$

This correction results to be not completely precise if you use Method 1.

EPI distortion correction

Addressed for fMRI and DTI studies but still open issue in ASL

1) The most successful approach to minimizing EPI distortions makes use of acquired magnetic "field maps" that can be used for subsequent dewarping of the associated EPI images (a capability that is included in the FSL and SPM software packages)
2) DTI → TORTOISE software package based on the use of SD maps of the DTI quantities of interest for datasets with different phase-encoding directions