Arterial Spin Labelling in Dementia
Training school in Verona/IT, July 4-6, 2013

Acquisition

ASL BASICS II

M. A. Fernández-Seara, Ph. D.

Neuroimaging Laboratory
Center for Applied Medical Research
University of Navarra
Pamplona, Spain

Outline

- Arterial spin labeled perfusion MRI: basic theory
- ASL data acquisition: the ASL pulse sequence
  - Labeling strategies: CASL, PASL and PCASL
  - Arterial transit time effects on ASL
  - Multi TI/PLD acquisitions
  - Readout options
  - Background suppression
  - Bipolar gradients for intravascular signal suppression
  - ASL protocol

ASL Basics II

Learning Objectives

- To understand the pros and cons of various image acquisition approaches
- To understand the general differences between 2D and 3D approaches
- To understand the effect of background suppression
- To be able to choose the appropiate imaging sequence, depending on the application
- To be able to prepare an ASL protocol

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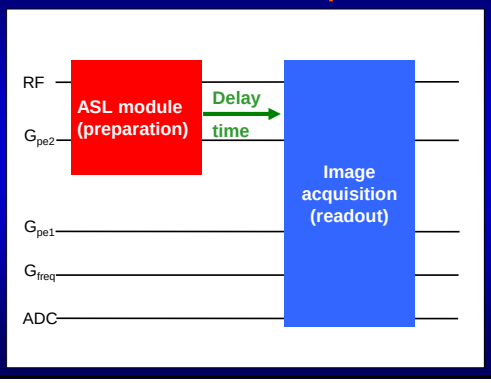
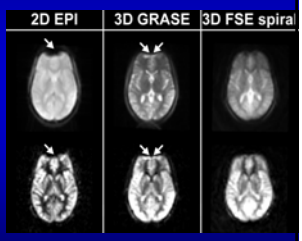
  - Arterial transit time effects on ASL
  - Multi TI/PLD acquisitions
  - ➢ **Readout options**

The ASL Pulse Sequence

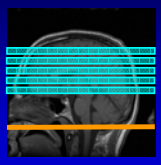


Imaging Readout

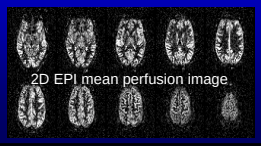
- In general, the ASL preparation and imaging readout are independent
- High SNR, low sensitivity to motion
- T2* weighting not necessary or desirable
- Single shot
  - –Motion correction
  - –Perfusion time series (fMRI or fcMRI)
  - –Lower resolution
- Multi shot
  - –Higher resolution
- Most frequently used: 2D EPI, 3D GRASE, 3D FSE-spiral

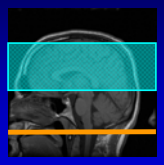


2D versus 3D



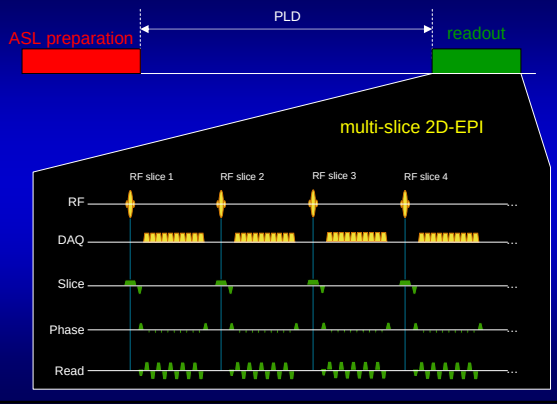
- Sequential slice acquisition (ascending order)
- Slice dependent PLD
- Slice dependent perfusion SNR





- Volume excitation
- No slice dependence of perfusion SNR
- Higher SNR efficiency
- Facilitates the use of BS
- Most 3D ASL sequences based on FSE readouts
- Blurring in the slice direction

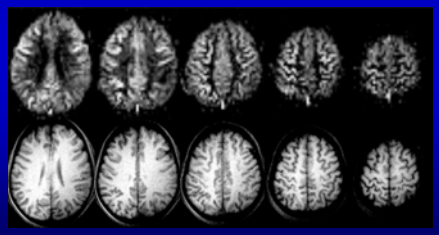
EPI Sequence Scheme



PASL EPI

EPI-readout, 60 averages, measurement time = 5 min,

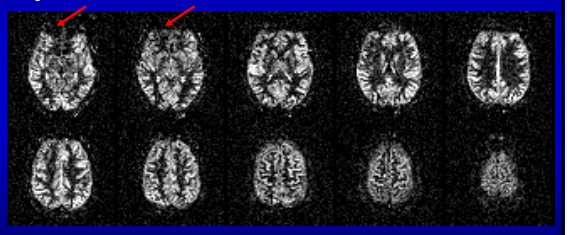
3T MR-Scanner



Wen-Ming Luh et al. MRM 41:1246–1254 (1999)

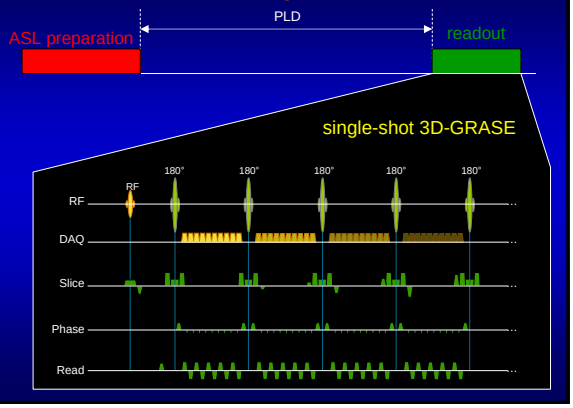
PCASL EPI

Signal loss and distortion artifacts



Fernández-Seara et al

3D-GRASE Sequence Scheme

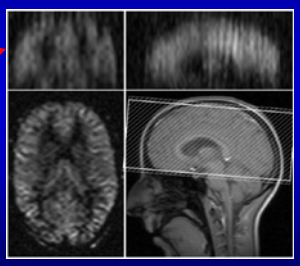


PASL 3D GRASE

FAIR and single-shot 3D GRASE data set
Measurement time: **2 min,** TI =1600 msec

TIM Trio 3T

Blurring in slice direction

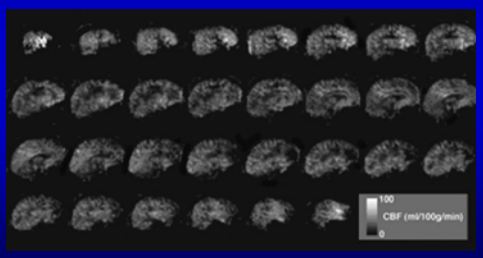


Günther et al, MRM 54:491-8 (2005)

CASL 3D GRASE

Single shot 3D GRASE with acceleration factor of 2

4 mm isotropic resolution, whole brain coverage

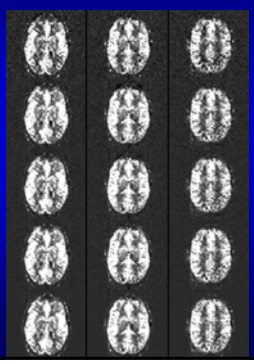


Fernández-Seara et al, MRM 54:1241–7 (2005)

PCASL Single-shot 3D GRASE

Snap-shot ASL

Single shot 3D GRASE with PCASL



1 pair

2 pairs

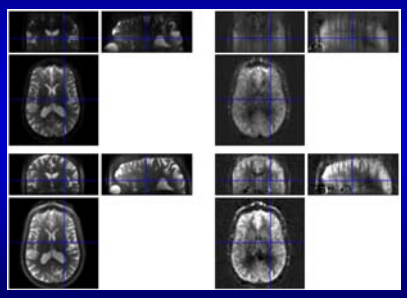
4 pairs

6 pairs

96 pairs

Fernández-Seara et al, MRM 59:1467–71 (2008)

PCASL 3D GRASE



Single-shot

Multi-shot

(4 segments)

Reduced blurring in z

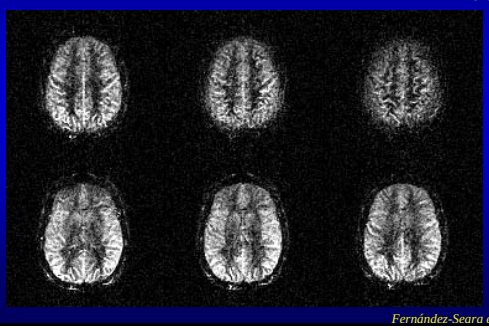
Increased SNR (shorter TE)

Balteau et al.

PCASL Segmented 3D GRASE

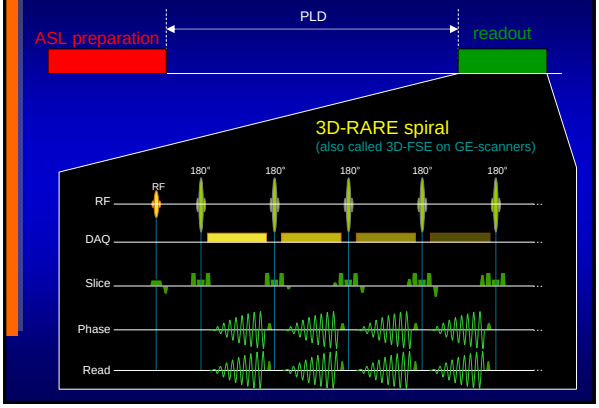
High resolution ASL 2x2x4, 8 shots

TIM Trio 3T

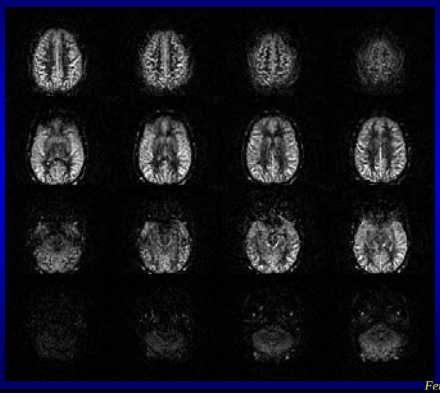


Fernández-Seara et al.

3D-RARE Spiral Sequence Scheme



3D RARE-Spiral ASL



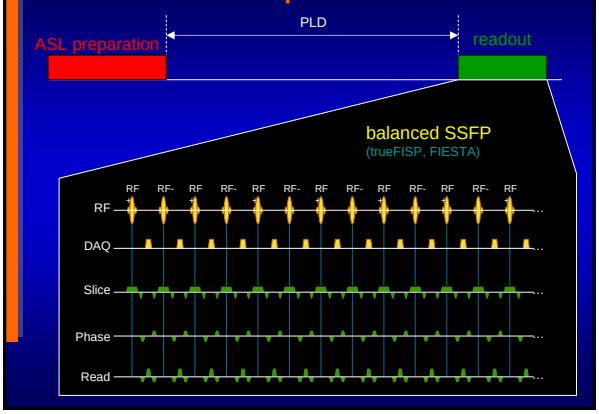
High resolution 2x2x4

Whole-brain

Segmented 8 shots

Fernández-Seara et al.

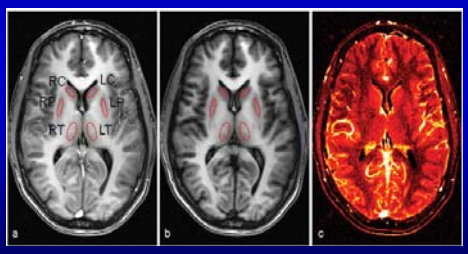
bSSFP Sequence Scheme



bSSFP ASL

ASL in the brain, healthy male volunteer

segmented true FISP ASL images acquired using eight averages, TI=1200ms, measurement time for single slice 2.5 min



Grossman et al., JMRI 29(6): 1425–1431 (2009)

Readout Comparison

	2D EPI	3D GRASE	3D RARE spiral	bSSFP
Acquisition scheme	2D multi-slice	3D	3D	Single-slice
SNR	Low	High	High	Middle
Image quality	Off-resonance artifacts	Good in-plane Blurring along z	Good in-plane Blurring along z	Excellent
Other remarks	Broad availability, quasi standard	BS Segmentation to reduce blurring	BS Segmentation to reduce blurring Lower sensitivity to motion (oversampling of k-space center) In-plane blurring due to off-resonance	Inflow-weighted (bright vessels!)

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  - ➢ **Background suppression**

Background Suppression

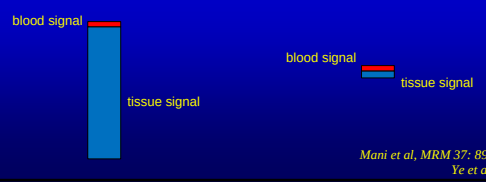
ASL signal (blood signal) very small compared to tissue signal (e.g. about 2-3% in human brain)

→ small fluctuations in tissue signal corrupt ASL signal

Idea of BS: reduce tissue signal by (closely) nulling it at time of readout

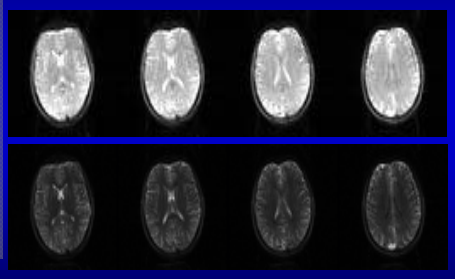
→ tissue signal and ASL signal of same order

→ small fluctuations in tissue signal does not corrupt ASL signal



Mani et al, MRM 37: 898-905 (1997)
Ye et al, MRM 2000

Background Suppression

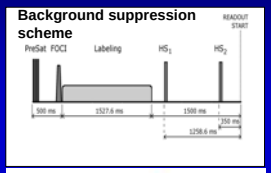


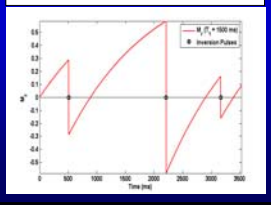
No BS images

BS images

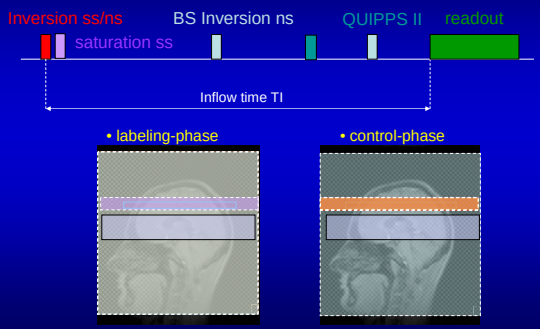
Background Suppression

- Signal is nulled at time of readout, using an extension of an inversion recovery sequence.
- BS pulses attenuate the ASL signal due to T2 and T1 decay
- Number of BS pulses: trade-off between degree of suppression, ASL signal attenuation and SAR



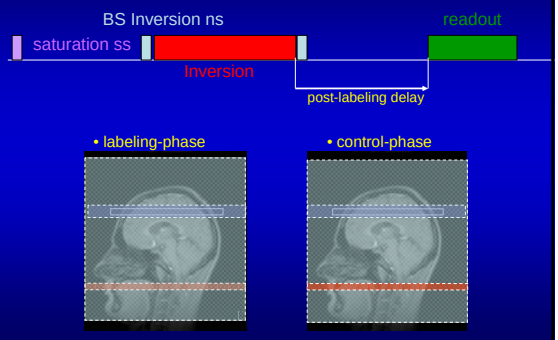


BS with PASL



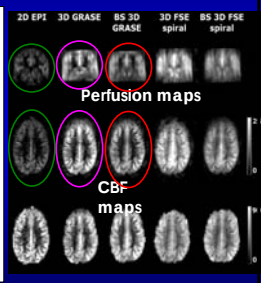
readout slice inversion slab saturation slab BS inversion

BS with PCASL



The Effect of Readout and BS on SNR

Sequence		2D EPI	3D GRASE	BS 3D GRASE
Whole-brain mean CBF (before calibration)		46.4 ± 8.6	48.9 ± 11.4	38.1 ± 8.0
Calibration factor (%)		87.2 ± 13.2	92.2 + 19.4	71.2 ± 11.6
Perfusion time-series	Mean	6.7 ± 1.4	13.0 ± 3.4	10.1 ± 2.4
	tSD	2.1 ± 0.5	3.9 ± 0.8	1.1 ± 0.2
	tSNR	3.5 ± 1.2	3.5 ± 1.5	10.1 ± 3.8
	SD_{noise}	0.31 ± 0.04	0.28 ± 0.03	0.20 ± 0.01
GM-WM CBF Contrast		3.9 ± 1.1	3.1 ± 0.9	3.0 ± 0.6



Vidorreta et al, Neuroimage 66:662-671 (2013)

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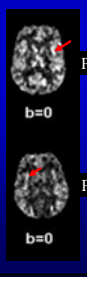
  - ➢ **Bipolar gradients for intravascular signal suppression**

Intravascular Signal Suppression

- In cases of prolonged transit time, PLD can be shorter than arterial transit time
- Intravascular signal from labeled blood on its way to perfuse more distal slices can lead to vascular artifacts (bright spots) and overestimation of perfusion in the current slice

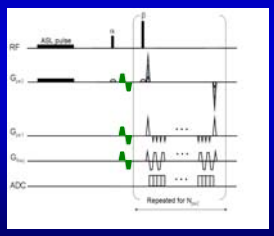


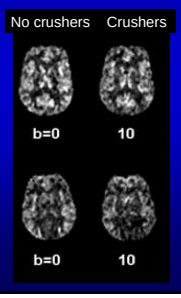
PLD = 1200

PLD = 1500

Vascular Crushers

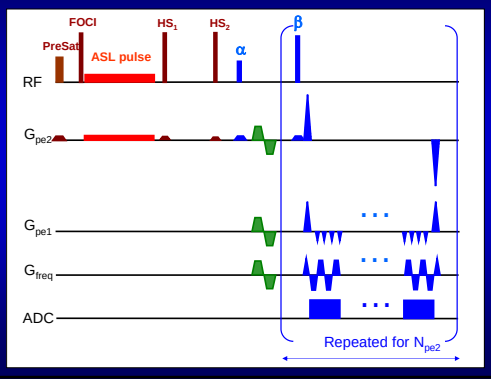
- Bipolar gradients can be applied to suppress the signal from flowing spins – flow crushers
- The effect of the crushers is determined by Venc
- Spins moving at V > Venc are dephased





Recommended Venc = 4 cm/s

The ASL Pulse Sequence



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ASL Protocol

Required
- ASL sequence

Optional
- Angiogram
- T1 measurement
- Calibration scan for blood M_0 estimation
- Calibration scan for coil sensitivity estimation
- PCMRI for efficiency measurement

Product ASL - Siemens

ASL preparation	PASL (FAIR, QUIPPS II)
Readout VB series VD series	 2D EPI 3D GRASE
BS VB series VD series	 No Yes
Multi-TI/PLD	No

Product ASL - Philips

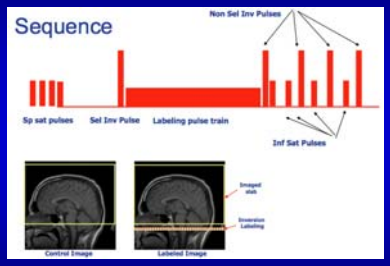
ASL preparation R3 (achieva), R4 (ingenia)* R5**	 PASL (STAR) PASL (STAR), PCASL
Readout	2D EPI
BS R3 (achieva), R4 (ingenia) R5	 No Yes
Multi-TI/PLD	Yes

* PCASL in Clinical Science Key ; ** Available end of 2013.

Product ASL – General Electric

ASL preparation	PCASL
Readout	3D-FSE-spiral (segmented)
BS	Yes
Multi-TI/PLD	No

ASL Sequence Picture - GE



Arterial Spin Labeling Basics
Take home messages

- Methodological advances have dramatically improved the quality of ASL perfusion MRI
- ASL is non-invasive, repeatable, flexible
- In general, ASL preparation and image acquisition are independent
- Optimal combination depends on application, knowledge of available methods necessary
- For single delay time CBF measurements:
  - PCASL is the optimum labeling strategy
  - Segmented 3D readouts are preferred to 2D

Thank you for your attention !