Noninvasive Blood Flow Mapping with Arterial Spin Labeling (ASL)

Paul Kyu Han and Sung-Hong Park

Department of Bio and Brain Engineering,
Korea Advanced Institute of Science and Technology (KAIST), Daejeon, South Korea

Contents

❖ Introduction

- **Arterial spin labeling (ASL) is a recent magnetic resonance imaging (MRI) technique that allows for noninvasive measurement of blood flow.**
- **The technique employs specially prepared radio-frequency (RF) pulses to magnetically label arterial blood water prior to data acquisition.**
- **Various technical advancements have been made in the past for ASL.**
- **ASL is a popular MRI technique with growing field of interest in both research and clinical applications.**

❖ Arterial Spin Labeling (ASL)

- MRI methods for measuring blood flow
  - Injection of Contrast Agent
  - Arterial Spin Labeling (ASL)
- ASL applies radio-frequency (RF) pulses to invert magnetization of arterial blood water
  - Acquisition of one image with inverted magnetization in arterial blood water (Label)
  - Acquisition of another image with no inverted magnetization in arterial blood water (Control)
  - Perfusion map acquired by subtraction (Control – Label)

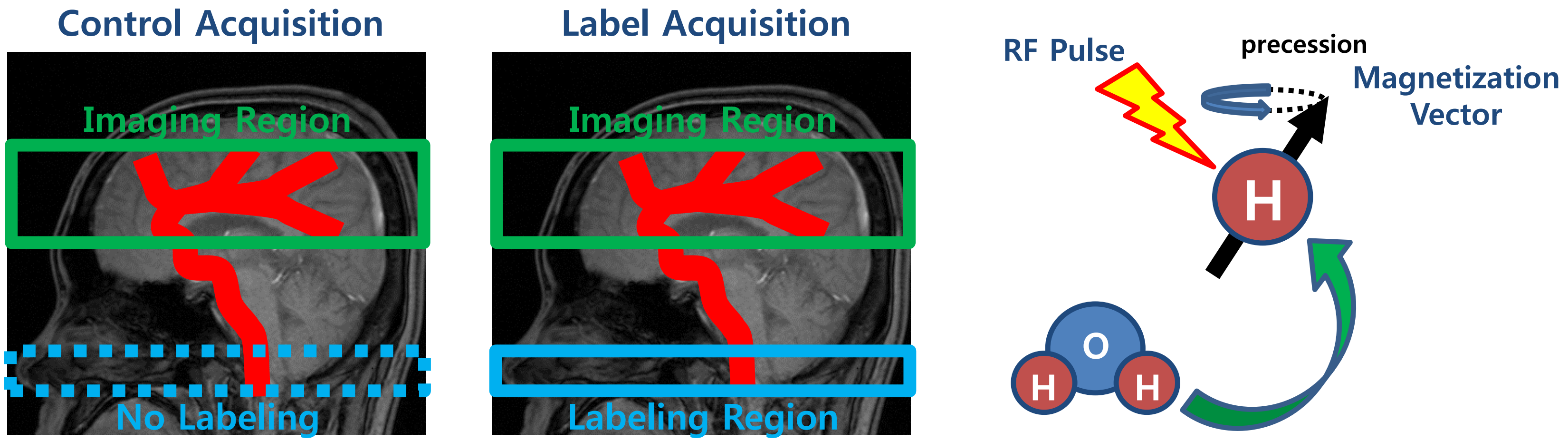


FIG 1. Schematic Diagram of ASL Acquisition and Labeling of Arterial Blood Water

❖ Magnetization Transfer (MT) Effects in ASL

- Application of labeling pulses causes off-resonance saturation, i.e., magnetization transfer (MT)
  - MT effects are not symmetric around water resonance frequency

- MT effect causes measurement errors in ASL
  - Potentially problematic for subtraction from control
  - Signal-to-noise ratio reduction
  - ➔ Suppression of MT effects important for ASL

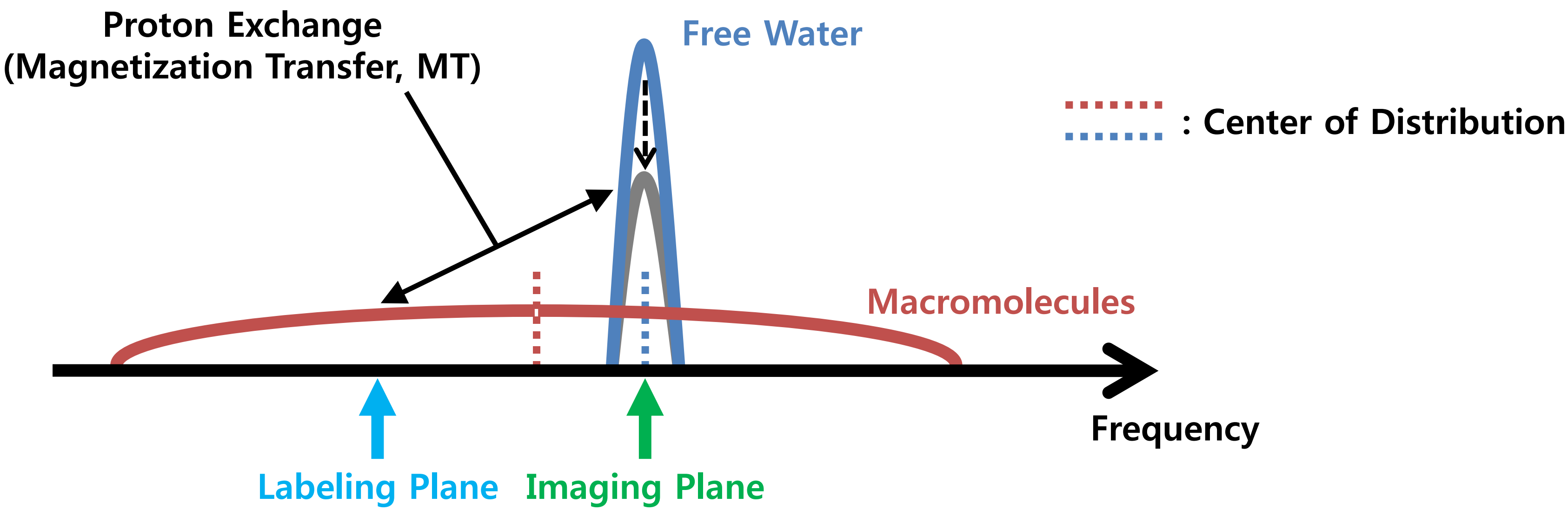


FIG 4. Precession Frequency Distribution and Magnetization Transfer Effect in ASL

❖ Arterial Spin Labeling (ASL)

- Three main categories based on labeling scheme:
  - Continuous ASL (CASL)
  - Pulsed ASL (PASL)
  - Pseudo-Continuous ASL (pCASL)

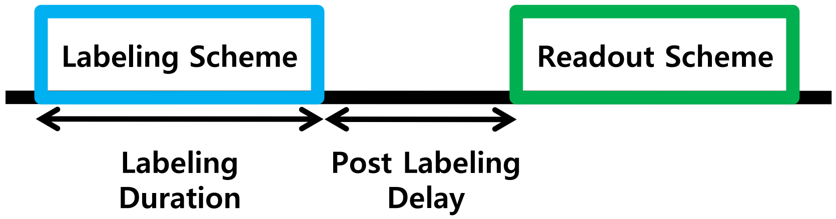


FIG 2. Schematic Diagram of ASL Pulse Sequence

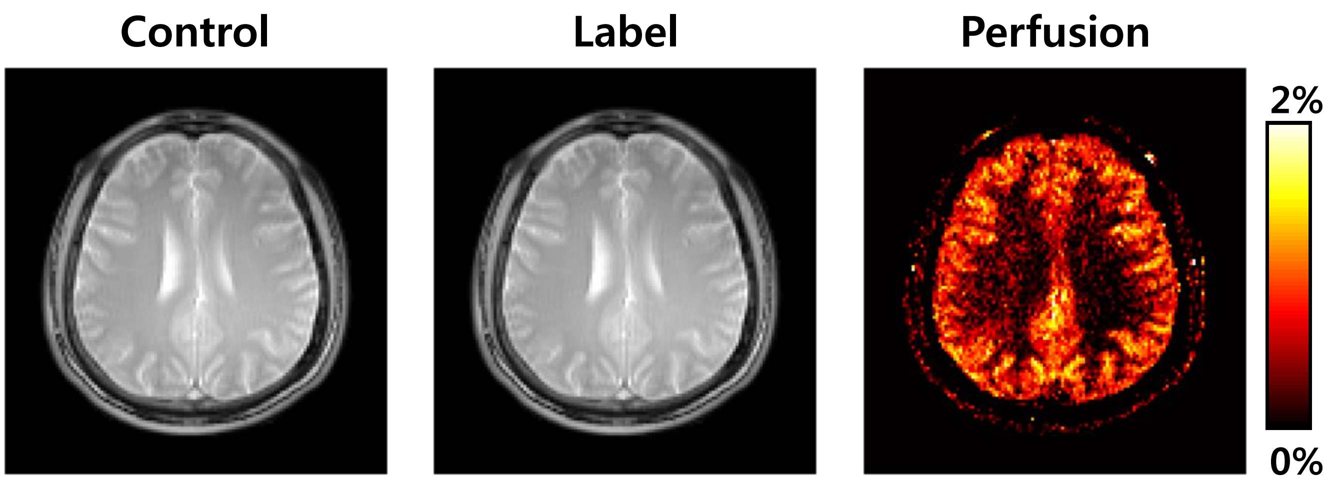
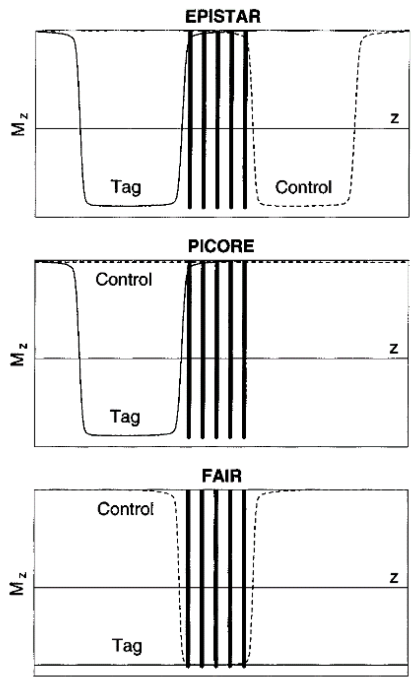


FIG 3. Example Brain Slice Image of Control, Label, and Perfusion Map

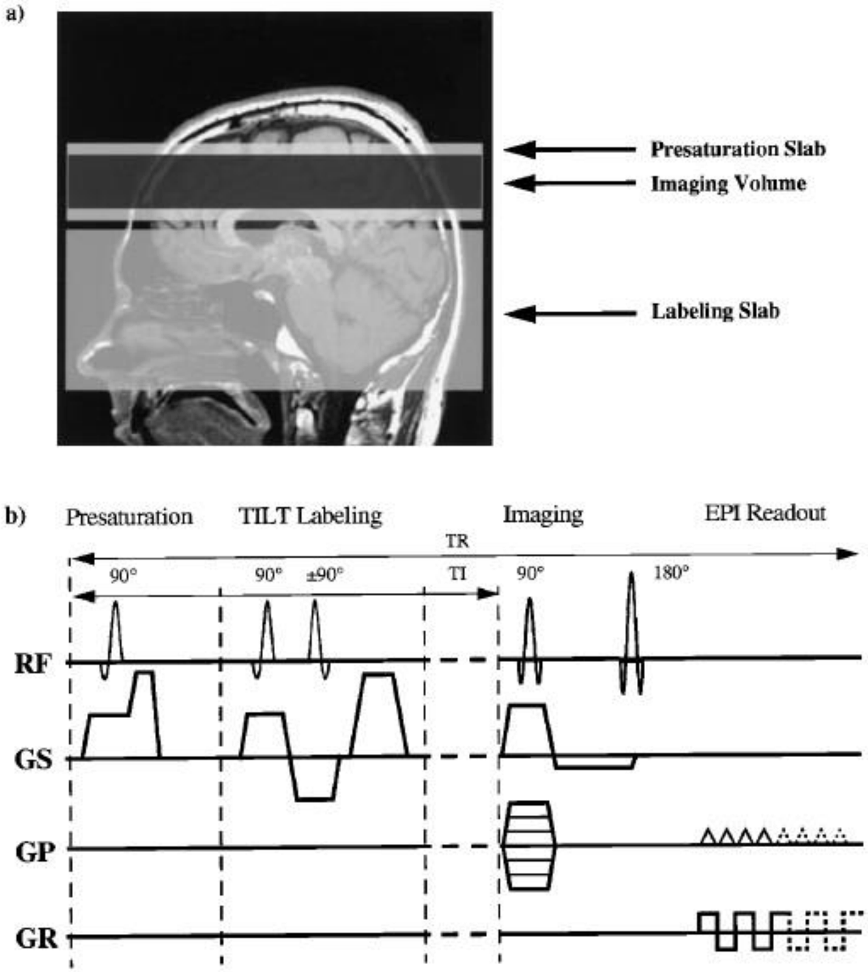
❖ Pulsed ASL (PASL)

- **Application of instantaneous RF pulse as labeling**
  - **RF pulse typically 10-20 ms duration**
  - **High tagging efficiency**
  - **Largely insensitive to blood flow variations**

- **Examples**
  - **FAIR**
  - **EPISTAR**
  - **PICORE**



Wong et al., 1997 [1]

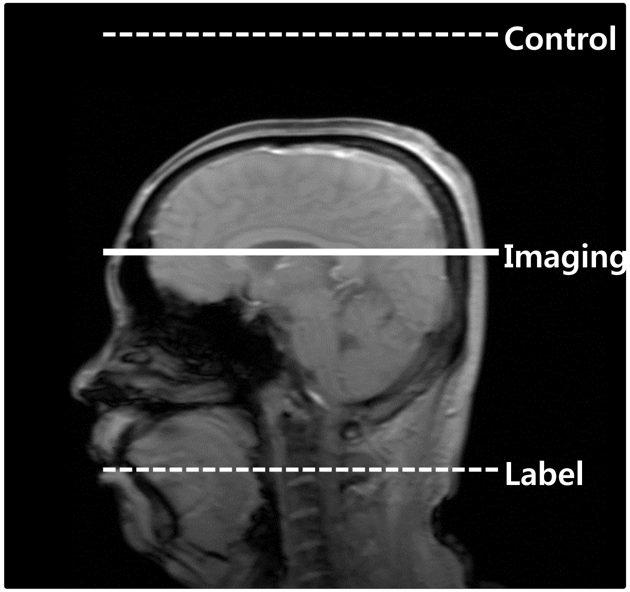


Golay et al., 1997 [2]

❖ Continuous ASL (CASL)

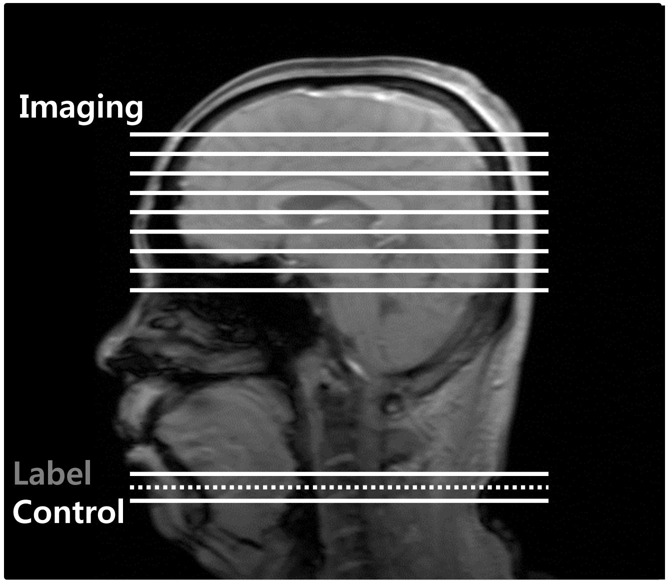
- Application of continuous RF pulse as labeling
  - RF pulses with 1-2 second duration
  - Longer duration of labeling provides higher SNR
  - Application of long RF pulse limited in many commercial scanners

Single Slice



Williams et al., 1992 [3]

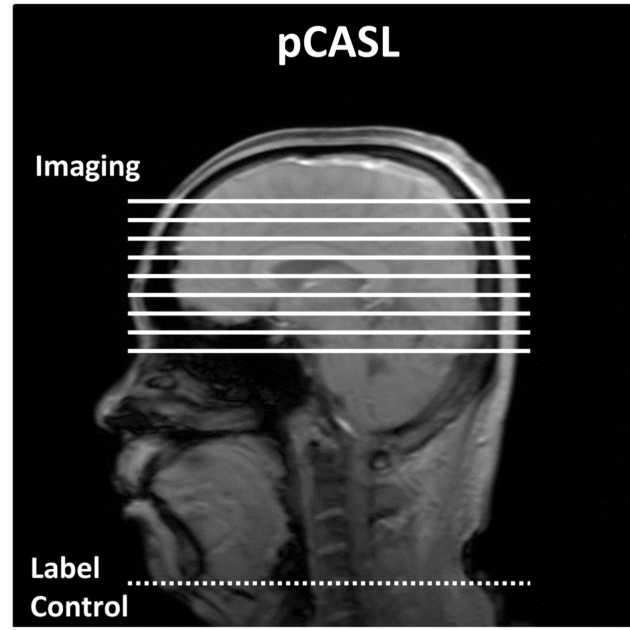
Multiple Slice

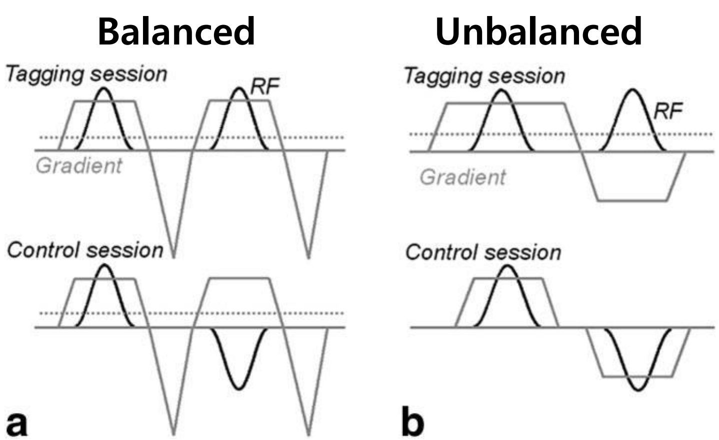


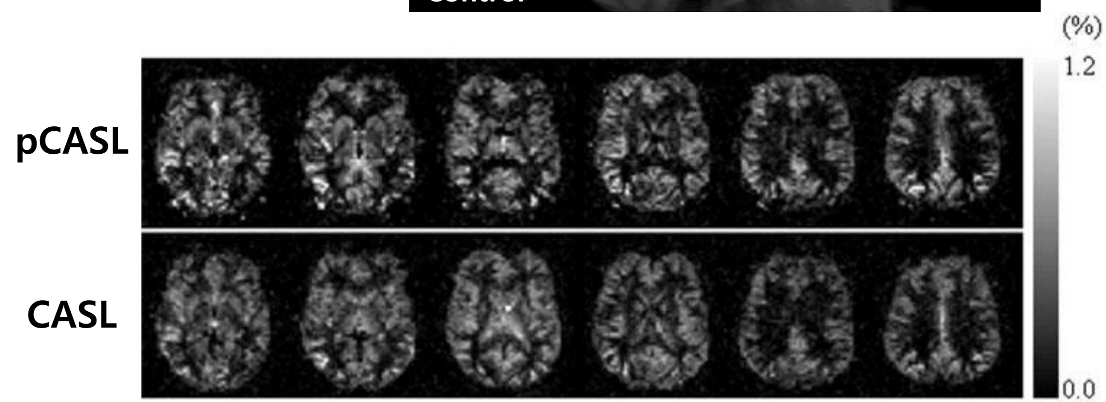
Alsop et al., 1998 [4]

❖ Pseudo-Continuous ASL (pCASL)

- Application of train of multiple short RF pulses as labeling
  - Developed to take advantage of both PASL and CASL
  - High tagging efficiency
  - High SNR
- Variations
  - “Balanced” Gradient Method
  - “Unbalanced” Gradient Method



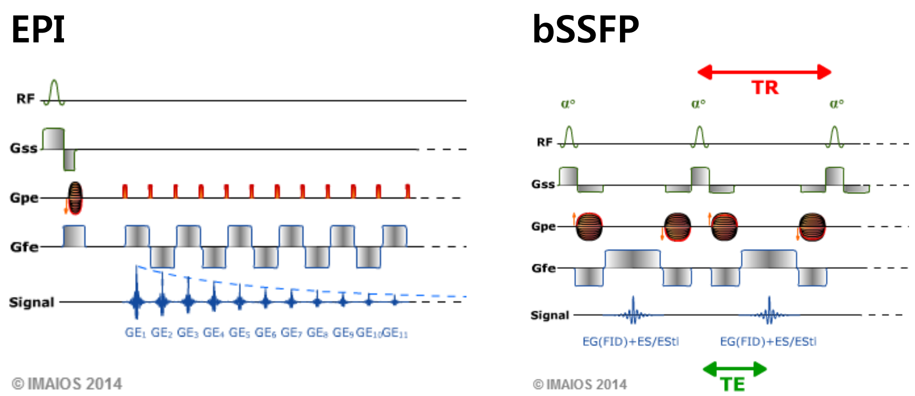




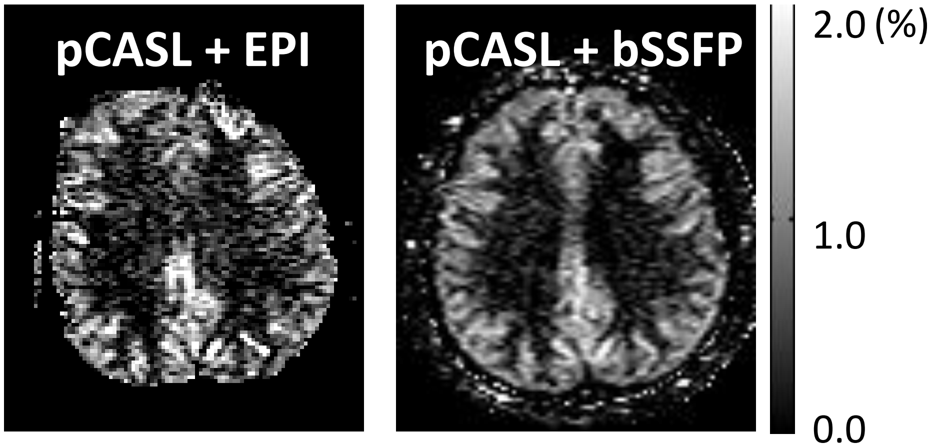
Wu et al., 2007 [5]
Dai et al., 2008 [6]

❖ Different Readout Schemes

- Fast data readout scheme preferred due to typically long duration of labeling in ASL
  - Echo planar imaging (EPI) typically used since fastest acquisition method in MRI (e.g. ~0.1s/image)
  - EPI susceptible to magnetic field inhomogeneity and image distortions
- Recently, non-EPI readout schemes have been applied to ASL
  - Rapid Acquisition with Refocused Echoes (RARE)
  - GRadient- And Spin Echo (GRASE)
  - Balanced Steady-State Free Precession (bSSFP)



IMAIOS 2014 [7]



Park et al., 2013 [8]

❖ 3D pCASL-bSSFP: Preliminary Results

- Advancement of pCASL-bSSFP for 3D acquisition
  - Long labeling duration required in ASL
  - 3D acquisition to increase efficiency

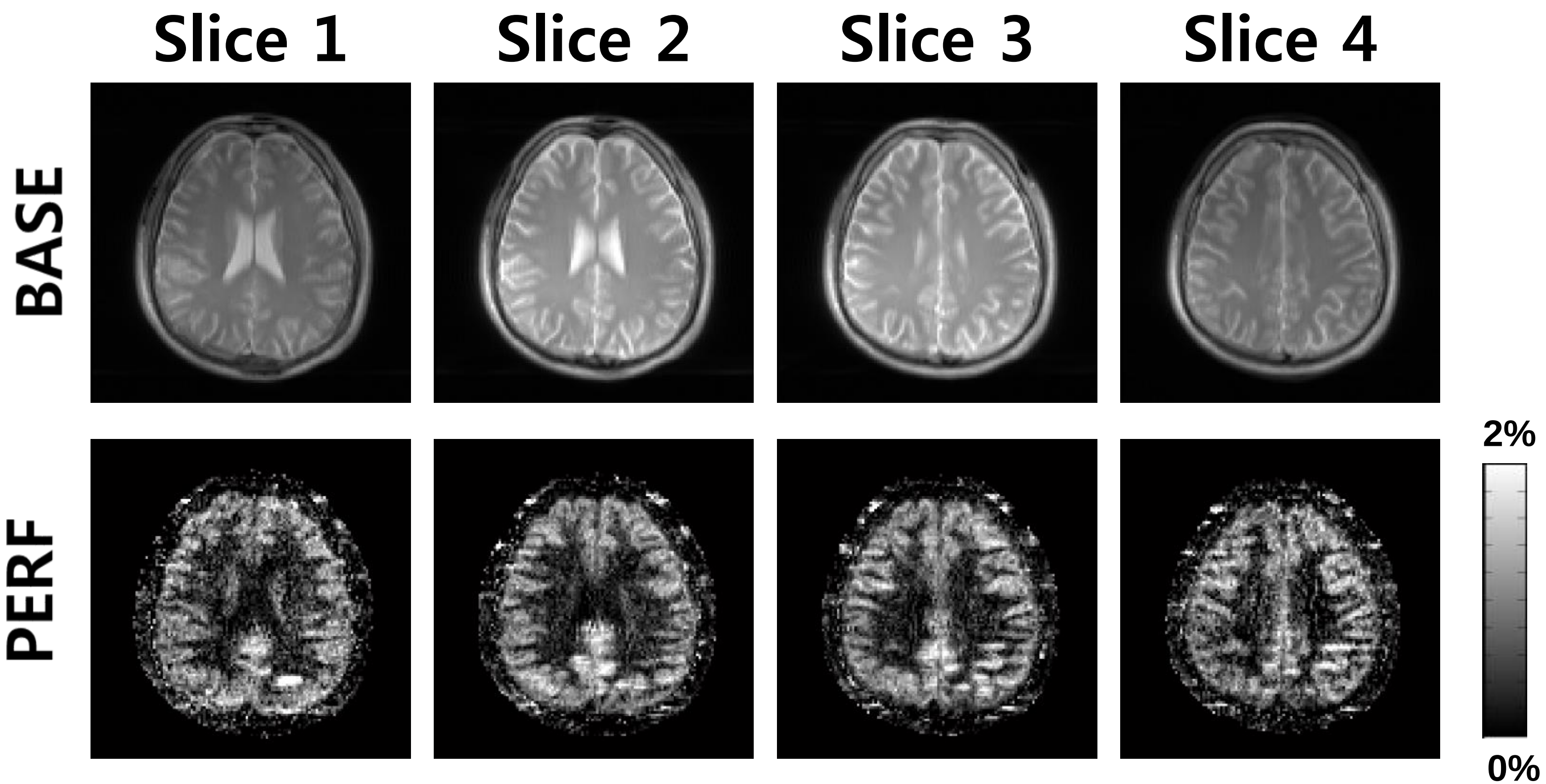


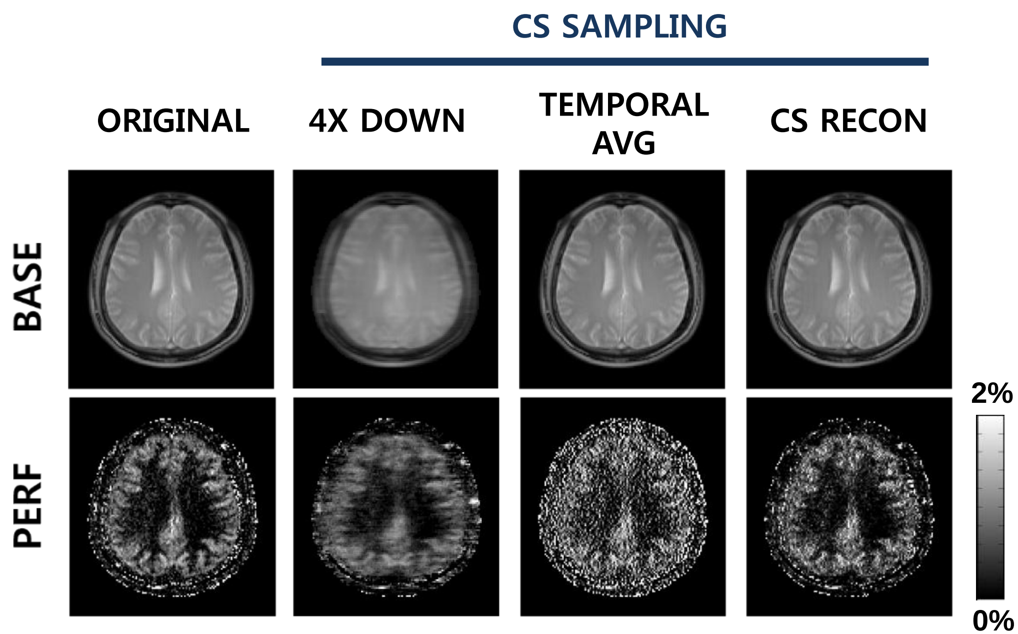
FIG 5. Example Baseline and Perfusion Images of 3D pCASL-bSSFP (4 Slice)

❖ pCASL-bSSFP with Compressed Sensing (CS)

- **Combination of pCASL-bSSFP with CS to increase spatial coverage**
- **CS Problem Formation:** $$\min_{x} \{ \|Ax - b\|^2 + \lambda \|x\|_1 \}$$

  where x : *x-f* **domain information and** Ax, b : *k-t* **domain information**

- **Exploits temporal redundancy for reconstruction of perfusion information**



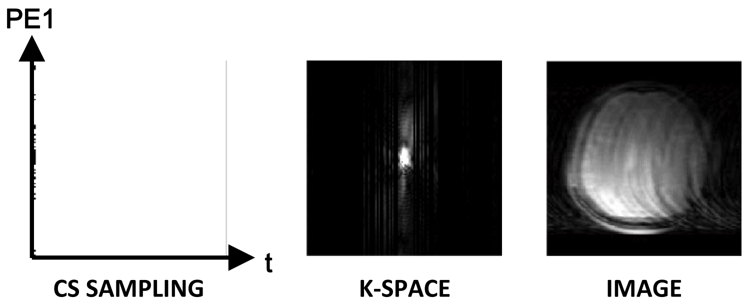
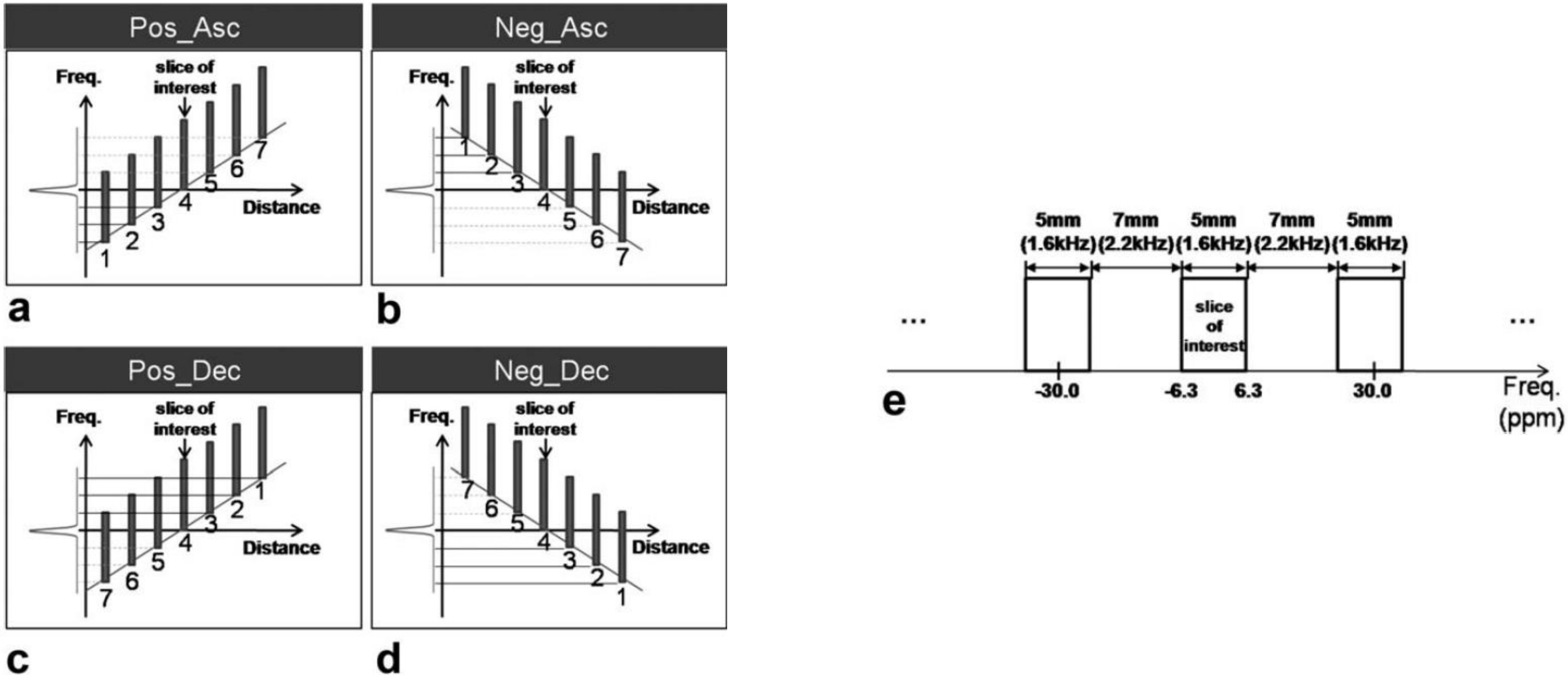


FIG 7. Demonstration of 1/4th CS Sampling Pattern Application

FIG 6. Retrospective Down-Sampling Results for 2D pCASL-bSSFP

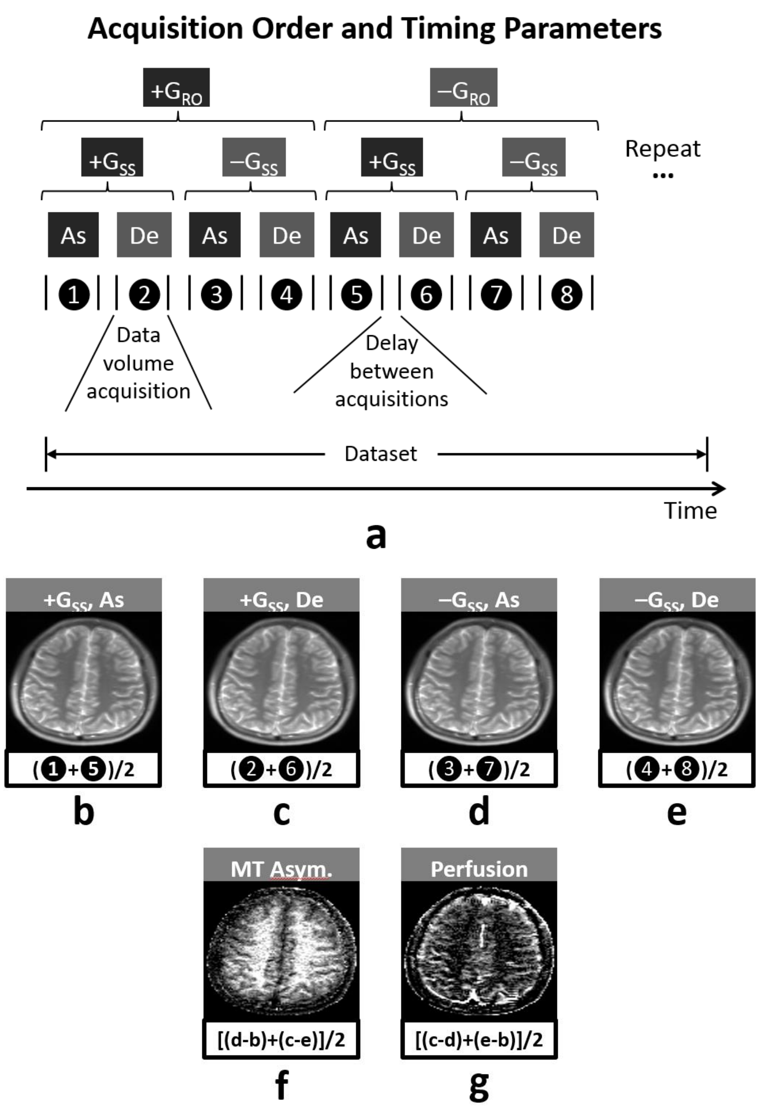
❖ ALADDIN

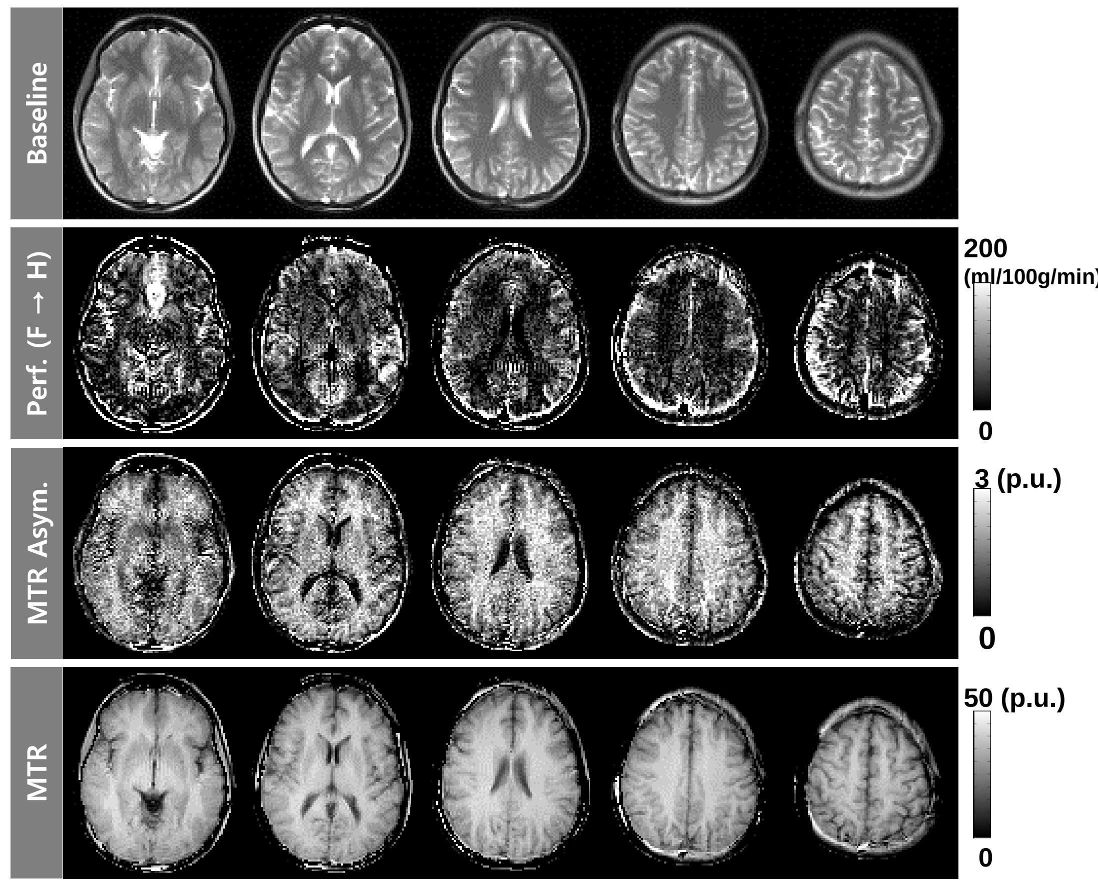
- **Alternate Ascending/Descending Directional Navigation (ALADDIN)**
  - **Usage of 2D inter-slice blood flow and MT effects**
  - **Allows for simultaneous acquisition of perfusion, MT asymmetry imaging**
  - **Separation of perfusion and MT signals via combination of different datasets**



Park et al., 2011, 2012 [9][10][11]

❖ ALADDIN


Acquisition Order and Timing Parameters
+G_RO
−G_RO
+G_SS
−G_SS
+G_SS
−G_SS
Repeat
...
As De As De As De As De
1 2 3 4 5 6 7 8
Data volume acquisition
Delay between acquisitions
Dataset
Time
a
+G_SS, As
+G_SS, De
−G_SS, As
−G_SS, De
(1+5)/2
(2+6)/2
(3+7)/2
(4+8)/2
b
c
d
e
MT Asym.
Perfusion
[(d-b)+(c-e)]/2
[(c-d)+(e-b)]/2
f
g


Baseline
Perf. (F → H)
200
(ml/100g/min)
0
MTR Asym.
3 (p.u.)
0
MTR
50 (p.u.)
0

❖ Conclusion

- **ASL is a noninvasive MRI technique that allows for measurement of blood perfusion via magnetic labeling of arterial blood water.**
- **ASL is categorized into three main categories depending on labeling scheme: PASL, CASL, and pCASL.**
- **Various data readout schemes have been developed for ASL.**
- **New developments are being made to improve the technique in various aspects.**
- **ASL is a promising tool for clinical diagnosis as a substitute for contrast-agent based perfusion imaging.**

THANK YOU
FOR YOUR ATTENTION!

❖ References

[1] Wong, Eric C., Richard B. Buxton, and Lawrence R. Frank. "Implementation of quantitative perfusion imaging techniques for functional brain mapping using pulsed arterial spin labeling." *NMR in Biomedicine* 10.45 (1997): 237-249.

[2] Golay, Xavier, et al. "Transfer insensitive labeling technique (TILT): application to multislice functional perfusion imaging." *Journal of Magnetic Resonance Imaging* 9.3 (1999): 454-461.

[3] Williams, Donald S., et al. "Magnetic resonance imaging of perfusion using spin inversion of arterial water." *Proceedings of the National Academy of Sciences*89.1 (1992): 212-216.

[4] Alsop, David C., and John A. Detre. "Multisection cerebral blood flow MR imaging with continuous arterial spin labeling." *Radiology* 208.2 (1998): 410-416.

[5] Wu, Wen-Chau, et al. "A theoretical and experimental investigation of the tagging efficiency of pseudocontinuous arterial spin labeling." *Magnetic Resonance in Medicine* 58.5 (2007): 1020-1027.

[6] Dai, Weiying, et al. "Continuous flow-driven inversion for arterial spin labeling using pulsed radio frequency and gradient fields." *Magnetic Resonance in Medicine* 60.6 (2008): 1488-1497.

[7] *IMAIOS*. Web. 10 July. 2014. <http://www.imaios.com/en/e-Courses/e-MRI/>.

[8] Park, Sung-Hong, Danny JJ Wang, and Timothy Q. Duong. "Balanced steady state free precession for arterial spin labeling MRI: Initial experience for blood flow mapping in human brain, retina, and kidney." *Magnetic resonance imaging*31.7 (2013): 1044-1050.

[9] Park, Sung-Hong, and Timothy Q. Duong. "Brain MR perfusion-weighted imaging with alternate ascending/descending directional navigation." *Magnetic Resonance in Medicine* 65.6 (2011): 1578-1591.

[10] Park, Sung-Hong, and Timothy Q. Duong. "Alternate ascending/descending directional navigation approach for imaging magnetization transfer asymmetry."*Magnetic Resonance in Medicine* 65.6 (2011): 1702-1710.

[11] Park, Sung-Hong, et al. "Suppression of effects of gradient imperfections on imaging with alternate ascending/descending directional navigation." *Magnetic Resonance in Medicine* 68.5 (2012): 1600-1606.