

Optimisation of pulsed and pseudo-continuous arterial spin labeling MRI techniques: A phantom study

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Abstract. Arterial Spin Labeling (ASL) MRI is a non-invasive technique using a freely diffusible intrinsic tracer. The main objective of this study is to evaluate two different techniques of ASL MRI; pulsed ASL (PASL) and pseudo-continuous ASL (PCASL) in obtaining the best signal by manipulating the different imaging parameters. We used a fabricated Perspex flow phantom that is magnetically susceptible. The phantom has a straight tube that mimics carotid artery in adult patients and a U-shaped tube with 75% stenosis. We used a mixture of 60:40 distilled water and glycerol respectively as a substitute to blood. The fabricated phantom was scanned with 1.5T and 3T MRI Scanner using PCASL technique and PASL respectively. Two main imaging parameters were studied which were the field of view (FOV) and slice thickness (ST) to obtain the signal-to-noise ratio (SNR) of the region of interests. The 1.5 T PCASL technique gave SNR values of (13, 22, 30.1) for ST (5, 7, 9 mm) and FOV 240. When higher FOV = 320 was selected, the SNR values were (26.8, 15, 37) for different ST (5, 7, 9 mm). The 3.0 T PASL technique gave the SNR values of (9, 9.3, 11) for ST (5, 7, 9mm) and FOV 240mm. In the higher FOV = 320 mm, we obtained SNR values of (15.2, 17.5, 37.2) for ST (5, 7, 9 mm). As a conclusion, the images quality which can be measured by SNR value is affected by types of ASL and also different parameters.

1. Introduction

Many studies data has shown that ASL gave stable noise characteristics over the entire frequency spectrum, which makes it really suitable in studying low-frequency events in brain function [1]. ASL technique has the limitation of having long radiofrequency (RF) pulse, low signal-to-noise ratio (SNR) and difficulty in the planning process. The ASL technique has two main subcategories called pulsed ASL (PASL) and continuous (CASL). CASL has higher signal to noise ratio (SNR) than PASL, but less available on commercial MRI scanners due to the requirement of long and continuous radiofrequency (RF) transmission. The latest technique in ASL is known as pseudo-continuous ASL (PCASL). It divides the long continuous radiofrequency (RF) pulse in CASL into multiple separates short pulses but eventually will have same labeling effects as CASL. As a result, better SNR is achieved compared to CASL and can be convenient to be used in most hardware setup of MRI scanners [2]. This study is to



review two different techniques of ASL MR imaging with the fabricated phantom using PCASL and PASL techniques both at different magnetic strengths of 1.5 T and 3 T respectively.

The non-invasive technique of Arterial Spin Labeling (ASL) technique in imaging will provide as an alternative to the needs of injectable tracers without compromising the results [3]. This method has several advantages as compared with other perfusion techniques such as positron emission tomography (PET), single-photon emission computed tomography (SPECT), CT perfusion and dynamic susceptibility contrast (DSC) magnetic resonance imaging (MRI). All of these techniques need exogenous tracer administration, but in the ASL method no exogenous contrast injection is needed prior the scanning session. The tracer for ASL is the magnetically labelled water [4]. In ASL MRI, the hydrogen protons from the arteries in neck region are inverted and after a while allowing the labeled protons reaching brain tissue, images will be captured. This is called as labeled image. Control images also will be captured to get perfusion weighted images when subtracting them with labeled images [5].

2. Materials and Methodology

2.1. Phantom design

The body of the phantom was made from Perspex because it is solid, stable, non-hazardous, and easy to handle. Perspex also has low mass magnetic susceptibility of $0.50 \text{ m}^2/\text{kg}$ which nearly reflects the tissue composition of tissue. The phantom is compact and portable that can be well suited for reassembly in multi-center research setting. This phantom has a set of straight tube with the diameter of 0.8 cm mimicking adult carotid artery and with u-tube that has 75 % stenosis. The phantom mimics diameter of the carotid arteries because it is capable of reproducibly generating the requisite flow rates and patterns.

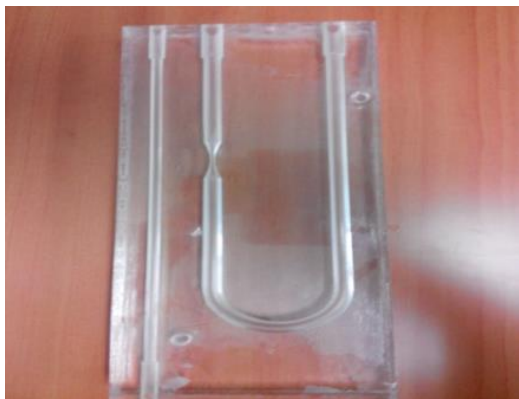


Figure 1. The Fabricated Phantom used during scan.

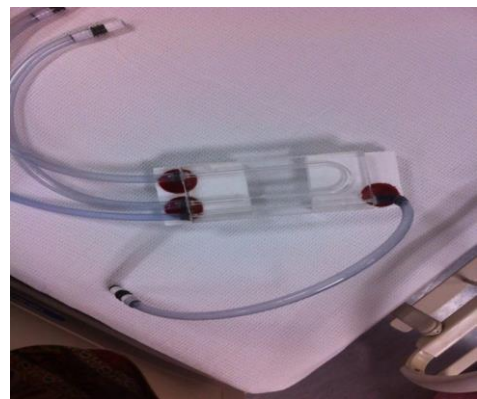


Figure 2. The phantom is permanently secured with water catcher basement.

2.2. Phantom set-up.

In this study, a fabricated flow phantom was scanned with different strength of MRI scanners. A combination of glycerol and distilled water 40% and 60% respectively were used to mimic blood [6]. This water–glycerol mixture possesses a similar density (ρ) and viscosity (μ) as human blood ($\rho=1053 \text{ kg/m}^3$, $\mu=3 \text{ mPa.s}$) [7]. Water pump is placed in the container to pump the blood mimic into the phantom and circulate it during the experiment.

The water pump is switched on to ensure that there was no bubble in the tubes and phantom during circulation of blood mimic. The phantom and tubes were checked to ensure there was no leakage. The velocity of blood mimic was measured to make sure it is close to reference with 75 cm/s for adult and 97 cm/s for paediatric[8]. Velocity was measured by calculating how long the mixture travels in certain distance of tube.

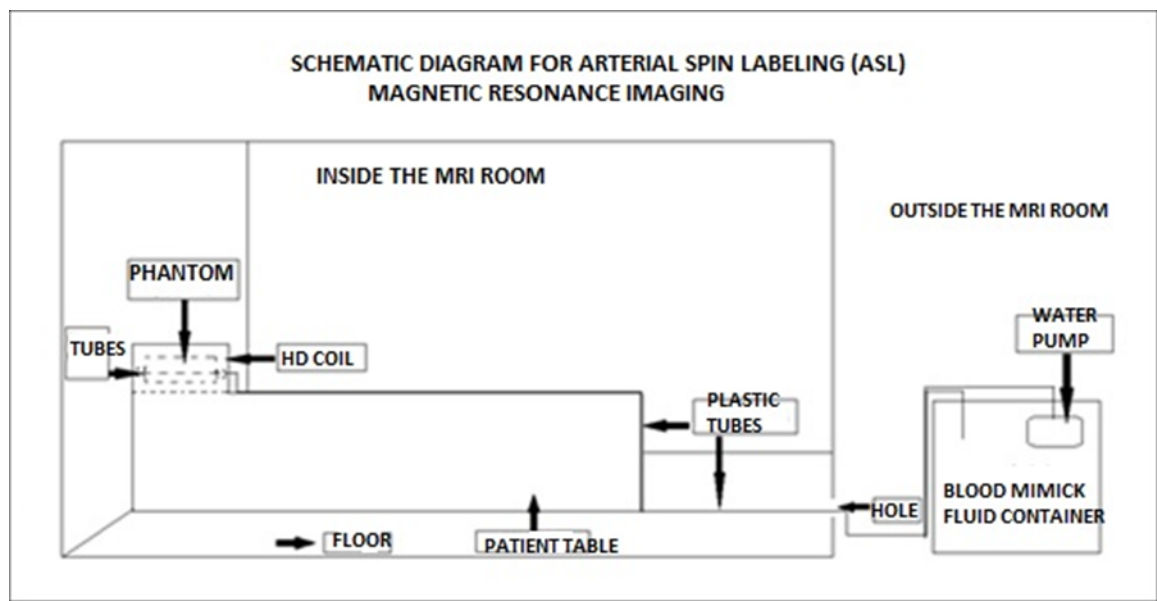


Figure 3. The schematic diagram for setting up ASL phantom.

2.3. Imaging Protocol and Hardware

We used two different magnetic field strengths of ASL MRI that are available in our university campus in AMDI and HUSM. We want to gather data of new advanced technique in ASL and by testing different parameters using the new fabricated phantom.

i. PCASL :

All data and imaging sequences were carried out at Advanced Medicine and Dentistry Institute (AMDI), Universiti Sains Malaysia. The phantoms were scanned using 1.5 Tesla magnetic field MRI scanner (GE Signa HDxt) with 16 channel array head coil.

ii. PASL :

The image acquisition of the phantoms was performed by using Philips Achieva 3.0 T X- series MR imaging in Radiology Department of Hospital Universiti Sains Malaysia.

As a result of low signal in ASL protocol, agarose gel blocks were used to provide the background signal (figure 4). This will help in increasing the SNR and also the image quality [9]. Agarose gel slabs (35 g agar, 80 mL glycerol per liter of water) were prepared prior to scan. They will cut according to phantom size and put above and under the phantom.



Figure 4. The agarose gel slabs placed on the top and bottom of the fabricated phantom.

2.4. Parameters

The parameters that are manipulated in this study are field of view (FOV) and slice thickness (ST). We used two different FOV values which were 240 mm and 320 mm. Slice thicknesses were gradually increased from 5 mm, 7 mm and 9 mm. Matrix size is kept constant at intermediate value which is 256 x 256 throughout the study. Meanwhile, the Bandwidth is kept constant at value of 62.5 kHz.

2.5. Data Analysis

We used imageJ software for the analysis of SNR. ImageJ is a freely downloadable image analysis software developed at the National Institute of Health (NIH) to assist in clinical and scientific image analyses [10]. Relevant MRI slices were chosen and downloaded as JPEG images. The images were retrieved with window explorer and opened in imageJ by dragging them to the imageJ main window. The SNR is measured by drawing a circle at region of interest (ROI) in each slice of image. The ROI is the highest signal region obtained during scanning. The selected slice of image with clearest signal was picked out individually for different parameters used. The darkest region of image is the noise background. Same size of circle is also drawn in this region.

Mathematically, the SNR is the quotient of the signal intensity measured in a region of interest (ROI) and the standard deviation of the signal intensity in a region outside the anatomy or object being imaged (i.e. a region from which no tissue signal is obtained) as shown in equation 1 (Gudbjartsson & Patz, 1995). Signal-to-noise ratios (SNR) were calculated according to equation 1.

$$SNR = \frac{\text{Signal of Region of Interest (ROI)} - \text{Signal of background}}{\text{Standard deviation of background}} \quad (1)$$

3. Results and Discussions

We found that in 1.5 T PCASL technique (figure 5), with the value of FOV=240 and by increasing ST parameters from 5 mm, 7 mm, and 9 mm, the values of SNR were also increasing from 13, 22, to 30.1. Meanwhile, when FOV=320, the SNR value decreased at ST=7 mm (SNR= 26.8, 15, 37). For 3.0T PASL technique (figure 6), the SNR values using FOV=240 gradually increased with ST. The values for SNR obtained were 9, 9.3, and 11. By using higher FOV=320, the SNR values also increased with higher ST. The SNR values were 15.2, 17.5, and 37.2. The images quality and SNR values are affected by several parameters such as field of view (FOV) and slice thickness. In this study, matrix size is kept constant at medium value (256x256). Generally, SNR increase with higher FOV, slice thickness and low matrix size. When FOV increase, more area will receive the signal. But thinner slices are associated with more noise thus lower the SNR value. Increase the matrix size will decrease the signal because there are fewer photons per photon so the signal is less. This study protocols are intended to evaluate two different ASL techniques using the fabricated flow phantom. The images acquired by 1.5 T and 3 T MR imaging scanner of two different ASL MRI techniques are satisfactory. There are still images that are appeared not so clear.

But, we still able to captured images by testing several parameters and measure the mean SNR values in the region of interests (ROIs). Adjusting the parameters can also reduce the artifacts in the images [11]. Some of the images captured by ASL technique have flow artifacts. It is known that flow effects in MRI produce a range of artifacts due to flowing blood flow. Blood flow artifact is considered as a special subgroup of motion artifacts. It can be reduced with flow compensation and pre-saturation process [12]. In this study, the artifacts most probably are caused by turbulence flow of liquid inside the phantom. Correctly identified common imaging artifacts will help precise interpretation. We also suspected that the phantom might has some debris of metal dust which is left during its cutting process. The presence of foreign body produce susceptibility effects that produce artifactual dark signal which can be misinterpreted as region of low signal [13]. Our findings in the present study show the capability of noninvasive ASL to enable optimal image acquisition measured by the SNR. With the use of 1.5 T MR imaging scanner, PCASL has showed that it also can give reasonable amount of SNR in the region of interest. While in higher strength of scanner using 3 T PASL technique, the SNR also has relatively same value when highest FOV and ST are used. The application of PCASL has better balance between tagging efficiency and SNR, as well as reducing Magnetization Transfer effects and Radio Frequency power deposition [14]. This experiment shows that the best parameters value to be set for the phantom was FOV: 320 x 320 mm and slice thickness: 9 mm regardless of the different ASL techniques. In this study, the various labeling parameters are tested one by one to enable the best images to be captured. As proposed by previous studies, higher magnetic field MRI scanners (> 1.5 Tesla) able to give longer T1 and increase in SNR. Longer T1 value can increase the amount of labeled protons thus it will affect how quickly the net magnetisation vector (NMV) recovers to its ground state in the direction of external magnetic field (B0) [15]. This can significantly enhance image quality. The consensus from the Perfusion Study Group of the International Society for Magnetic Resonance in Medicine (ISMRM) 2012 has suggested that the optimal label duration is greatly influenced by the relaxation time of the label (T1) and the repetition time (TR).

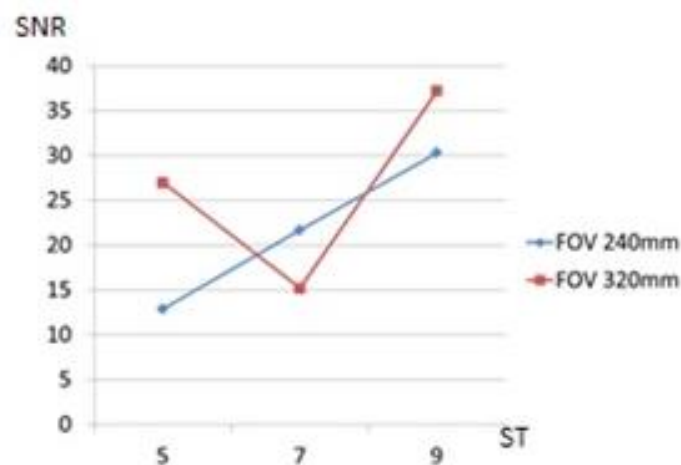


Figure 5. SNR against slice thickness for FOV 240mm and FOV 320mm using PCASL.

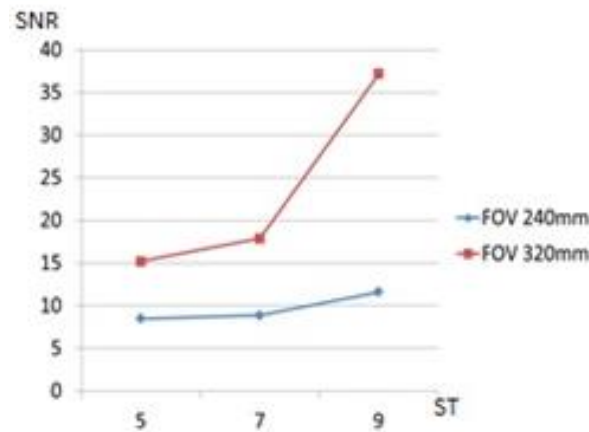


Figure 6. SNR against slice thickness for FOV 240mm and FOV 320mm using PASL.

4. Conclusion

SNR is important to be quantified in each image. It will show how much the true signal is gained at the ROI versus how much background noise a particular image has. Improvement of the SNR of ASL measurements is crucial so that it could take a more central role in Magnetic Resonance Imaging (MRI) studies. Compared with pulsed ASL, pulsed continuous ASL is more advantageous as we can obtain good SNR values even with lower magnetic strength field. Vendors are currently taking the advantages of promoting the PCASL technique as it requires less hardware settings, yet can produce desirable SNR values. More studies using ASL are actively conducted and researchers are encouraged to share the results so that this technique can be utilized widely in clinical platform. It can bring a tremendous benefit for patients using this non-invasive method MR imaging and preferable as it also can be used in continuous monitoring of patients such as in pharmacological and chronic renal disease.

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Acknowledgment

The authors would like to thank the financial support from Universiti Sains Malaysia (USM) through the Short Term Grant Scheme.