Quantitative cerebral perfusion with SCALE-PWI: Accelerated image acquisition and optimized image reconstruction

J. J. Mouannes[1], W. Shin[2], S. Shah[3], A. Sen[4], S. Maheshwari[1], and T. J. Carroll[1,4]

[1]Biomedical Engineering, Northwestern University, Chicago, Illinois, United States, [2]National Institute on Drug Abuse, National Institute of Health, Baltimore, Maryland, United States, [3]Siemens Medical Solutions USA, Chicago, Illinois, United States, [4]Radiology, Northwestern University, Chicago, Illinois, United States

INTRODUCTION

Quantitative cerebral perfusion is a fundamental physiologic parameter that reflects the severity and progression of a broad range of pathologies, such as stroke, cancer, Alzheimer's Disease, cerebrovascular occlusive disease, and multiple sclerosis. An accelerated and simplified implementation of the multi-scan Bookend technique [1,2], which has been shown to provide reproducible, reliable and accurate quantitative cerebral perfusion values [2,3], has been made possible through a Self-CALibrated Epi Perfusion Weighted Imaging (SCALE-PWI) MRI pulse sequence [4]. In one sequence, SCALE-PWI acquires inversion recovery (IR) Look-Locker (LL) EPI modules for a single "calibration" slice containing white matter (WM), before and after a conventional gradient-echo (GRE) EPI dynamic susceptibility contrast (DSC) scan with a gadolinium-based contrast bolus injection, resulting in a total scan time under 2 minutes. SCALE-PWI eliminates the need for technologist training, reduces motion artifacts, and provides the possibility of on-site, inline reconstruction of quantitative images of cerebral perfusion. A study of two different delay times between consecutive SCALE-PWI modules and a water exchange correction parameterization for SCALE-PWI at 1.5 T are presented in this work, which results in accelerating image acquisition and making quantitative perfusion reconstruction of SCALE-PWI more robust and ready for use in clinical settings.

MATERIALS AND METHODS

Imaging Protocol

SCALE-PWI allows an adjustable delay time between its consecutive modules, i.e. between the first IR LL EPI module for T_1 quantification in a "calibration" slice containing WM tissue before contrast injection and the DSC module, and between the DSC module and the second IR LL EPI module after contrast injection. A study of 22 human subjects scanned on a 1.5 T MR scanner (MAGNETOM Espree, Siemens AG Healthcare Sector, Erlangen, Germany) using SCALE-PWI was performed to compare results obtained with two different delay times. The imaging parameters were: TE/TR = 34/1090 ms, flip angle = 20°, FOV = 220 mm x 220 mm, resolution = 128 x 128, GRAPPA with acceleration factor = 2, for 13 slices in the brain with slice thickness = 5 mm, and a total of 50 measurements. Eleven subjects were scanned with a delay time of 0 s, and 11 other subjects were scanned with a 20 s delay time. Images were acquired with a single-dose injection of Gd-DTPA (0.1 mmol/kg b.w.) at a rate of 4 ml/s. In this setting, 35 time series of LL measurement for T_1 mapping were acquired after each IR pulse for the "calibration" slice, with a time gap between acquisitions = 84 ms. The total scan time of SCALE-PWI was 1 min 7 s in the 0 s delay case and 1 min 47 s in the 20 s delay case. The SCALE-PWI scan was preceded and followed by a segmented IR LL EPI scan of the same "calibration" slice, according to the conventional Bookend protocol [2,3], in order to obtain a reference calibration for the relative DSC perfusion measurements.

Image Postprocessing

Both SCALE-PWI groups and their conventional Bookend (reference) scans were processed using a standalone program in MATLAB V7.2 [3], which has been ported into Siemens Image Calculation Environment (ICE) as an inline reconstruction code [5]. Quantitative cerebral blood volume (qCBV) in WM was calculated to determine a global calibration factor for relative cerebral blood flow (CBF) and cerebral blood volume (CBV), using post-gadolinium T_1 changes in the blood pool and WM of the "calibration" slice, and using a water exchange correction factor (WCF) based on the T_1 change in blood, according to Shin et al [2]. A new WCF parameterization was determined for the SCALE-PWI sequence, according to the Hazlewood water-exchange model [6], to mitigate a 7% inaccuracy, due to T_2*-decay effects, in T_1 values measured by the single-shot IR LL EPI modules of SCALE-PWI, as compared to the segmented IR LL EPI sequence of the conventional Bookend protocol. No empirical scaling of white matter to "normal" flow was needed.

Table 1: Mean qCBF and qCBV values obtained with SCALE-PWI and Reference Bookend protocol

Tissue Type	qCBF (ml/100 g/min) WM	qCBF (ml/100 g/min) GM	qCBV (ml/100 g) WM	qCBV (ml/100 g) GM
0 s delay				
SCALE-PWI	22.5 ± 5.4	77.8 ± 21.4	1.51 ± 0.29	3.23 ± 0.70
REFERENCE	22.3 ± 5.8	78.0 ± 18.0	1.53 ± 0.33	3.27 ± 0.67
Student's *t* test (p/r)	0.83/0.76	0.96/0.77	0.83/0.68	0.83/0.69
20 s delay				
SCALE-PWI	19.5 ± 3.8	71.2 ± 12.6	1.49 ± 0.25	3.35 ± 0.48
REFERENCE	17.8 ± 2.6	66.5 ± 12.4	1.38 ± 0.21	3.12 ± 0.46
Student's *t* test (p/r)	0.20/0.19	0.21/0.55	0.21/0.29	0.21/0.27

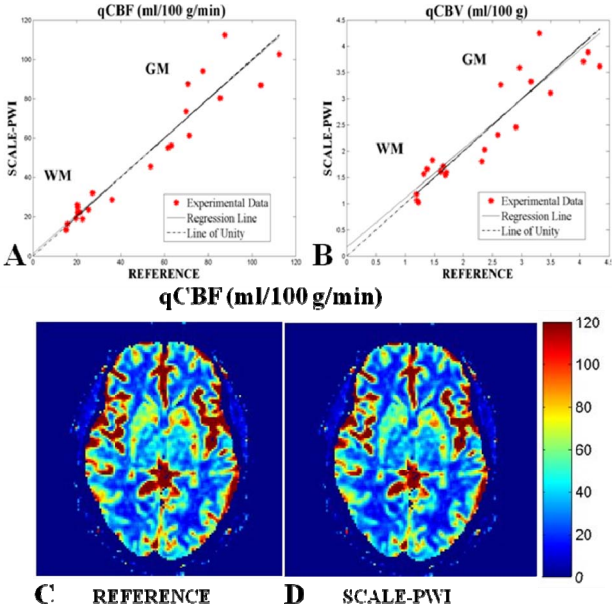

Figure 1. *A and B are WM and GM correlational plots for qCBF and qCBV, respectively, for the 0 s delay subjects. C and D are representative qCBF images for a brain slice obtained with the reference protocol and SCALE-PWI, respectively, in a 0 s delay subject.*

RESULTS/DISCUSSION

Table 1 compares mean quantitative CBF (qCBF) and qCBV values in WM and gray matter (GM) regions of interest (ROIs) for both delays: Student's *t* test p- and r-values are given. A correlational analysis between SCALE-PWI and reference measurements, in WM and GM ROIs combined resulted in: slope/intercept/r = 0.98/1.2/0.95 for qCBF and 0.91/0.18/0.92 for qCBV in the 0 s delay case, and slope/intercept/r = 1.00/3.02/0.95 for qCBF and 0.96/0.25/0.90 for qCBV in the 20 s delay case. An excellent agreement was therefore depicted between SCALE-PWI and the reference Bookend measurements in both 0 sec and 20 s delay cases. The Student's *t* test and correlational analyses results for qCBF and qCBV indicate that a faster imaging protocol (1 min 7 s) with an appropriate WCF parameterization results in quantitative perfusion values that are as accurate as the ones obtained with a slower imaging protocol (1 min 47 s) which pauses between consecutive modules to allow complete relaxation of the tipped magnetization. Figure 1(A,B) shows correlational plots of qCBF and qCBV, and Figure 1(C,D) shows representative qCBF images, in the 0 s delay case.

CONCLUSIONS

An accelerated SCALE-PWI image acquisition and a new WCF parameterization for more accurate image reconstruction were validated in this work against our conventional Bookend protocol, which has been validated through direct comparison with $H_2[O^{15}]$ PET (the "gold standard" for perfusion imaging) [7]. SCALE-PWI perfusion values are in agreement with previous PET literature values [8]. This will facilitate the direct utilization of this technique in emergency clinical settings, such as acute stroke, to obtain immediate and accurate diagnosis.

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