ASYMMETRIC FAIR - FAIR WITH ACTIVE SUPPRESSION OF SUPERIOR TAGGING (FAIR ASST)

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Introduction

The symmetric application of inversion RF pulses relative to the center of the imaging slab makes FAIR (1) superior in the control of magnetization transfer (MT) effects and more suitable for multi-slice perfusion studies. However, the superior labeling band of FAIR can also label blood, which results in two potential confounds between the single subtraction blood flow quantification model and the experimental data: (a) if there is a contribution of superiorly labeled blood to tissue perfusion, a temporal bolus width for the superiorly labeled blood should be defined by performing superior saturations, just as is done with the Q2TIPS (2) method; (b) if the superiorly labeled blood contains venous as well as arterial blood, adverse venous artifacts can be generated in specific regions, such as the cerebellum, making blood flow measurements there unreliable. Also, the additional superior saturations can also possibly eliminate signals from the inferiorly labeled bolus when imaging slices contain curved or tortuous arteries that allow inferiorly labeled arterial blood to travel through the imaging section to the superior labeling slab and return to the imaging section. These difficulties also exist when using traditional FAIR-based techniques for perfusion studies of other body regions or organs. The previously proposed MDS FAIR (3), due to its incomplete suppression of superiorly labeled blood, cannot provide a completely artifact-free perfusion imaging map in this situation, and its long superior saturation pulse train can inadvertently saturate inferiorly labeled blood in perfusion studies of small regions with tortuous feeding arteries. To address these issues, an asymmetric FAIR method - FAIR with active suppression of superior tagging (FAIR ASST) - is introduced.

Materials and Methods

To suppress the superior tagging of FAIR, extra superior saturation RF pulses in FAIR with Q2TIPS were added before and after the inversion RF pulses during both labeling and control image acquisitions (Fig. 1). Not all possible ways of superior saturation (in terms of the pre-inversion or post-inversion superior saturation number) were found to be effective. To simplify the representation of different methods, two-digit encoding was used with the 1st and 2nd digits for the total number of pre- and post-inversion superior saturations, respectively. By this nomenclature, traditional FAIR with Q2TIPS is FAIR ASST 00, with no superior saturations. Eleven healthy male adults participated in the protocol approved by the local IRB, after providing written informed consent. Five (34 ± 6 years) were subjects for the sequence testing and evaluations of different superior saturation methods and six (32 ± 6 years) volunteered for quantitative comparison of FAIR ASST 12 with FAIR ASST 00. All studies were performed in the cerebellum, where the venous artifacts is the worst (Fig. 2, top right picture shows the position of imaging slab covering the whole cerebellum), on a 3T Siemens TIM Trio whole body scanner with body coil for RF transmission and the 12-channel phased array head coil for signal reception. The effectiveness of superior tagging suppression by different methods was evaluated both visually and quantitatively using labeled venous blood signal in the transverse sinus (Fig. 2). The following parameters were common to all studies: TR = 2500 ms, temporal bolus width (TI_1) /post-bolus delay = 800/1000 ms, inferior saturation number/interval/size = 20/25 ms/20 mm, superior saturation slab size/interval = 100 mm/ 25 ms (if applicable), selective inversion slab = imaging slab + 20 mm, and spatially-confined inversion slab = imaging slab +200 mm. Shortest TE values were used for different resolutions, and image slices were acquired ascendingly with 20% gap. Imaging processing was performed using SPM. A single blood compartment model was used for CBF quantification (4).

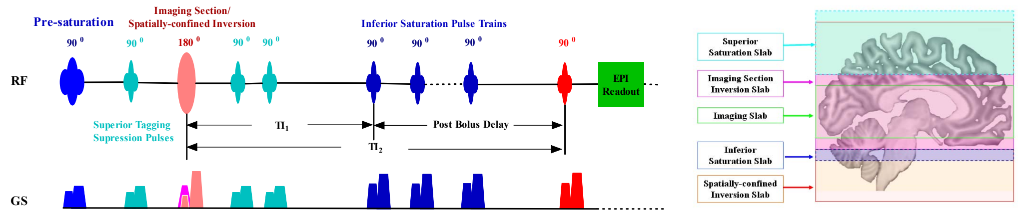

Fig. 1 Diagram for FAIR ASST sequence (left) and spatial definitions for different slabs (right) with imaging slab placed in the middle of brain as an example. Superior tagging suppression pulses and the corresponding saturation slab are displayed in cyan. Inferior saturation pulses and the corresponding saturation slab are indicated by dark blue. The stronger gradient (in pink) for the imaging section inversion (labeling) and the weaker gradient (in light red) for the spatially-confined inversion (control) are superposed on the diagram.

Results and Discussion:

Evaluation studies of different FAIR ASST methods indicated that using one pre-inversion and two post-inversion superior saturations is an efficient and effective way to suppress FAIR's superior tagging (Fig. 2), and that different schemes for the two post-inversion superior saturations, e.g. with/without a 180° phase difference between two RF pulses in control image acquisition with each RF pulse followed by a spoiler gradient or using two concatenated RF pulses with a 0° phase difference in labeling image acquisition and a 180° phase difference in control image acquisition and one spoiler gradient at the end (similar to those used in TILT (5) for arterial labeling but here for tagging suppression purposes) all gave similar artifact-free results (data not shown here). Due to the contamination from labeled venous blood, grey matter and white matter CBF can be significantly overestimated by traditional FAIR with Q2TIPS (Figs. 3 and 4); a number of voxels with very high values from superior arterial/venous artifacts significantly increased the mean CBF values and variances, especially in grey matter. The added superior saturations should not have side effects: (a) magnetization transfer (MT) effects due to these superior saturations will be cancelled out automatically via pair-wise subtraction in CBF quantification; (b) the large superior saturation slab interferes or overlaps with the imaging section, but should just behave like presaturations for the imaging section because these superior saturations are performed within just tens of milliseconds of the labeling or control preparation stages, and the possibility of affecting the inferiorly labeled blood bolus is quite small since inferiorly labeled blood takes a much longer time (on the order of hundreds of milliseconds) to arrive from the labeling site. FAIR ASST, with its active suppression of superior tagging, confers the advantages of asymmetric PASL techniques, such as PICORE (6), in which only the inferiorly labeled blood is used for perfusion quantification, to the symmetric PASL technique FAIR, while preserving the robustness of FAIR against MT effects. That is, FAIR ASST possesses the advantages of both asymmetric and symmetric PASL techniques.

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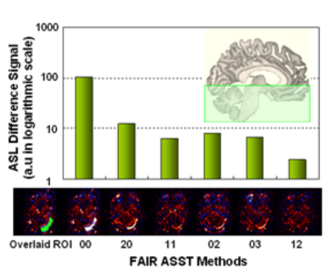

Fig. 2 Labeled venous blood signals in transverse sinus from one subject of FAIR ASST evaluation study (10 imaging slices with resolution 3.44 x 3.44 x 5.0 mm ^{3}).

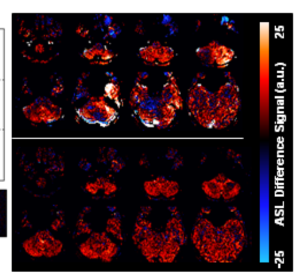

Fig. 3 Perfusion – weighted imaging maps of one subject using FAIR ASST methods 00 (top) and 12 (bottom) (10 imaging slices with resolution 2.5 x 2.5 x 5.0 mm ^{3}).

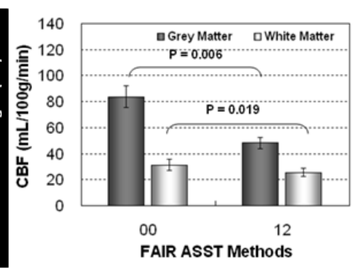

Fig. 4 Comparisons of CBF measurements between FAIR ASST methods 00 and 12 (16 imaging slices with resolution 3.5 x 3.5 x 3.5 mm ^{3}).