# Simultaneous outer volume and blood suppression by quadruple inversion-recovery

V. L. Yarnykh[1], C. Yuan[2]

[1]Radiology, University of Washington, Seattle, WA, United States, [2]Radiology, University of Washington, Seatthe, WA, United States

**Introduction:** Outer volume suppression (OVS) allows increasing resolution and reducing scan time in high-resolution imaging of anatomic structures deeply positioned within the body. Imaging of vascular structures also requires suppression of the blood signal. Usually, these goals are achieved by different technical approaches. For effective blood suppression one needs using a double inversion-recovery method (1), while OVS can be achieved by several techniques, such as spin-echo-based sequences with excitation and refocusing pulses applied to orthogonal planes (2), excitation using 2D spatially-selective pulses (3), and spatial pre-saturation of outer volume regions by different pulse schemes (4,5). A recently developed quadruple inversion-recovery (QIR) blood-suppression method (6) offers a promising way to incorporate outer volume and blood suppression into a single preparative sequence.

**Methods:** The scheme of the modified QIR sequence (named below as small-field-of-view QIR, SFQIR) is presented in Fig. 1. As compared to the original QIR sequence (6), non-selective inversion pulses are replaced by slab-selective ones applied in the plane orthogonal to imaged slice and parallel to frequency encoding direction. An action of the sequence is convenient to consider for three regions:

- Inner volume is outlined by crossing between Z-slice and Y-slab (Fig. 1). Consecutive inversions compensate each other and the signal is produced by a readout sequence (fast spin-echo (FSE) in the particular case).
- Outer volume is subjected to two inversions followed by inversion times, $TI_{1o}$ and $TI_{2o}$, respectively. Outer volume is also affected by the FSE sequence.
- Inflowing blood within the Y-slab is periodically inverted with delays between inversion pulses $TI_{1b}$ and TR- $TI_{2b}$. Of note, inversion times for outer volume ($TI_{1,2o}$) and for blood ($TI_{1,2b}$) are not identical due to considerable length of an adiabatic inversion pulse (~10 ms).

The SFQIR sequence was implemented on a 1.5T MR scanner (GE Signa). OVS efficiency was tested with a phantom containing media with different relaxation properties: 1, 0.5, and 0.2 mM solutions of Gd (Omniscan), corn oil, and water ($T_1$=203, 392, 754, 246, and 2570 ms, respectively). In vivo images were obtained from the abdominal region of two healthy volunteers.

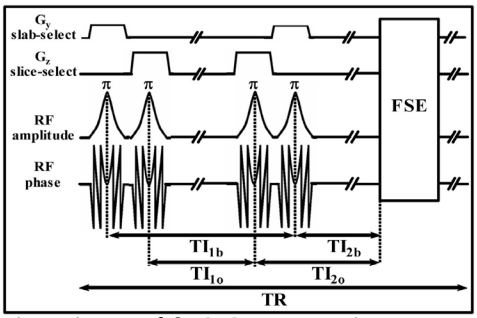


**Fig.1. Diagram of the SFQIR preparative sequence**

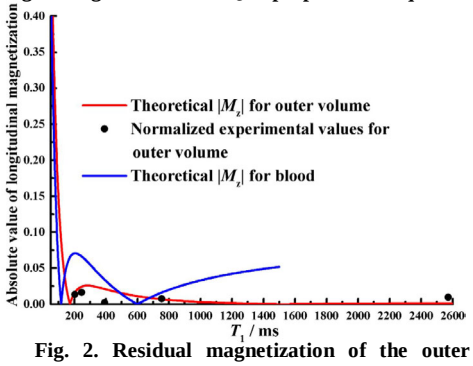


**Fig. 2. Residual magnetization of the outer volume and blood as functions of $T_1$. Plots were computed for TR=500 ms, $TI_{1o}/TI_{2o}$= 208/73 ms, $TI_{1b}/TI_{2b}$= 226/64 ms, *N*=8, τ=8.5 ms. Points correspond to phantom experimental data obtained with the same parameters.**

**Results:** ***Theoretical analysis:*** Effect of the SFQIR-FSE sequence on the outer volume is described by following equations:

$$M_z^r = 1-(1-M_z^{FSE})\exp(-(TR-(N-1/2)\tau)/T_1) - 2\exp(-TI_{2o}/T_1)[1-\exp(-TI_{1o}/T_1)],$$

$$M_z^{FSE} = C[(1-E^{1/2})(CE)^{N-1} + (1-E)(1-(CE)^{N-1})/(1-CE)],$$

where $M_z^r$ is the residual z-magnetization before a readout pulse; $M_z^{FSE}$ is the z-magnetization after the echo train; *N* is the echo train length; τ is the echo spacing; $E=\exp(-\tau/T_1)$; and $C=\cos(\beta)$, where $\beta$ is the flip angle of a refocusing pulse. Theoretical model presumes 90° readout pulse, 180° inversion pulses, and complete destroying of transverse components after the echo train. Optimal inversion times can be found by minimization of the integral of the residual magnetization over a specified range of $T_1$ using the algorithm described in ref. (6). Generally, inversion times represent functions of TR, echo spacing, echo train length, and flip angles of refocusing pulses. Simulations (Fig. 2) suggest that efficient suppression (<2-3% of the residual signal) can be simultaneously obtained for the virtually whole range of $T_1$ expected in biologic tissues (200-3000 ms). Blood suppression effect of the prototype QIR technique has been described in detail previously (6). Due to pulse sequence constraints (delays between inversion and re-inversion should be as short as possible to avoid signal loss), SFQIR sequence with $TI_{1o}$ and $TI_{2o}$ optimized for OVS provides suboptimal $TI_{1b}$ and $TI_{2b}$ for blood suppression. Nevertheless, the residual magnetization of blood (Fig. 2) appears to be reasonably small (<7-8%) at these conditions that is sufficient for obtaining proper black-blood contrast.

***Imaging experiments:*** In agreement with theory, the SFQIR sequence provided efficient OVS in phantom experiments for media with a wide range of $T_1$ (Fig. 2). In vivo test in abdominal region (Fig.3) shows effective removal of the strong signal in regions proximal to the coil surface. It is important to note, that the method also removes motion artifacts caused by movements of the abdominal wall (all images are obtained with free breathing). As a result, uncompromised high-resolution black-blood images can be obtained from abdominal aorta and adjacent vasculature without breath hold or respiratory triggering.

**Conclusions:** The described method demonstrates a new technical solution for inner-volume imaging and can be recommended for a variety of applications requiring high resolution in small regions within the body. This technique also provides efficient blood suppression in a wide range of $T_1$ that makes it especially useful for cardiovascular imaging including contrast-enhanced applications.

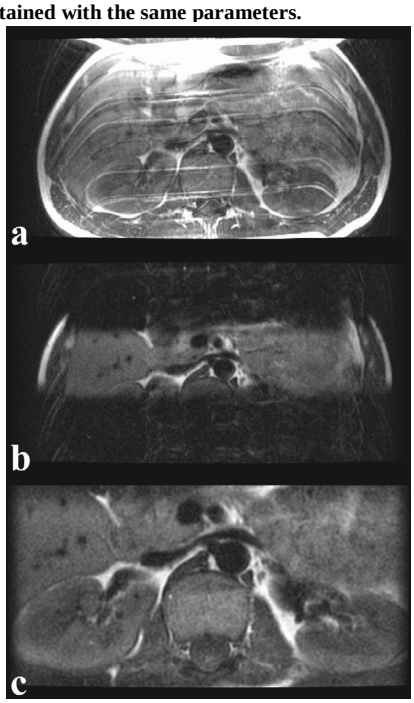


**Fig. 3. Imaging of the abdominal aorta with the SFQIR-FSE method (TR/TE=500/11 ms, ETL=8, slice thickness 4 mm, NEX=2) : (a) routine FSE image without SFQIR preparation: FOV=32x16 cm, resolution 1.25 mm; (b) illustration of OVS with the same FOV; (c) inner-volume image: FOV=20x10 cm, resolution 0.78 mm.**

**References**

1. Edelman RR, et al. *Radiology* 1991;181:655-660.
2. Feinberg DA, et al. *Radiology*.1985;156:743-7.
3. Alley MT, et al. *Magn Reson Med* 1997; 37:260-7.
4. Le Roux P, et al. *J Magn Reson Imaging* 1998;8:1022-32.
5. Luo Y, et al. *Magn Reson Med* 2001;45:1095-102.
6. Yarnykh VL, Yuan C. *Magn Reson Med* 2002; 48: 899-905.