MR Angiography using Steady State Free Precession

Thomas K.F. FOO[1], Vincent B. HO[2], Hani MARCOS[3], Maureen N. HOOD[2], Peter CHOYKE[3]
[1]GE Medical Systems, Johns Hopkins University, Room 110-MRI, Baltimore, MD USA; [2]Uniformed Services University of the Health Sciences, Bethesda, MD USA; [3]National Institutes of Health, Building 10, Room 1C660, Bethesda, MD ;

Introduction

In coherent steady-state free precession (SSFP) the FID (S-plus signal) and spin echo (S-minus signal) from a train of rf pulses are refocused in each TR interval to give the same amount of transverse magnetization after each rf pulse is applied. This increases the available image S/N. However, in standard 3D SSFP images (also known as FIESTA), signal from fat is high and does not decrease with increasing flip angles at short TR times as in more conventional gradient-recalled echo acquisitions. In addition, water signal is also bright. Thus, both fat and water in 3D SSFP (FIESTA) images can obscure vascular structures. We propose a technique for improving 3D SSFP (FIESTA) vascular imaging that uses weighted S-minus SSFP images as a mask.

As shown in Fig. 1a, all zeroth gradient moments are nulled at the end of each TR interval for an SSFP (FIESTA) acquisition. As such, the sequence is flow compensated at the rf pulse but not at the echo (during the readout). For an S-minus signal, the FID off the rf pulse is crushed by a large dephasing gradient (Fig. 1b). This results in greater flow-related dephasing for an S-minus signal acquisition. Consequently, this mode of acquisition results in a black-blood image.

Since the 3D SSFP (FIESTA) generates an image with high signal from blood, and a corresponding S-minus 3D SSFP acquisition generates a black blood image, the two acquisitions can be combined to subtract out the stationary fat and water tissue signal, producing an MR angiogram with higher vessel-to-background contrast than a traditional 3D SSFP (FIESTA) acquisition. Since the signal in the vessels is dark for the S-minus SSFP image, a weighted subtraction can also be employed to improve background suppression.

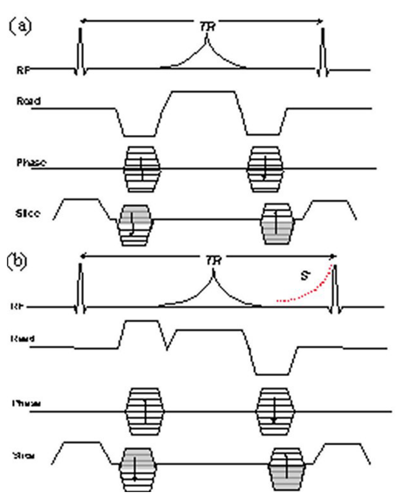

Figure 1: Pulse sequence diagram for (a) coherent SSFP where all zeroth gradient moments are nulled in each TR interval and (b) S-minus SSFP which rephases the FID from the previous TR interval.

Methods

Six healthy adult volunteers were enrolled in this IRB-approved protocol and imaged on a GE CV/i 1.5T scanner. Arterial and immediate delayed phase contrast-enhanced MRA studies were first performed using conventional fast 3D gradient recalled echo (GRE) pulse sequences. During the late delayed phase, an S-minus SSFP 3D acquisition was performed (384 x 256 matrix; 40 cm FOV; TR/TE = 4.0/5.8 ms) to serve as the mask image set. This was followed immediately by a 3D SSFP (FIESTA) acquisition (TR/TE=4.0/1.8 ms). A magnitude subtraction was then performed (with different weighting of the mask) and an MIP image generated. The non-subtracted MIP images and the S-minus SSFP mask subtracted mask images were then compared.

Weighted subtraction MIP images were also generated by multiplying the S-minus SSFP mask images by weighting factors of 1.0, 1.2, 1.4, 1.6, and 1.8 and subtracting the result from the 3D SSFP (FIESTA) images. The resulting images were evaluated for baccground suppression.

Results

Figure 2a shows a typical immediate delayed phase fast 3D GRE image. Image S/N measured in the aorta and the inferior vena cava (IVC) were 21.3 and 19.8, respectively. In Fig. 2b, the 3D SSFP (FIESTA) non-subtracted image shows substantial arterial and venous enhancement even at 24 minutes after contrast administration. In Fig. 2c, the same image (Fig. 2b) after mask subtraction (SSFP - S-minus signal), shows much improved background suppression and vascular contrast. The normalized image S/N in the aorta and the IVC with SSFP (FIESTA) were 36.4 and 34.6, respectively. Significant image S/N was observed in the delayed 3D SSFP (FIESTA) images (Fig. 2b and 2c) as compared to the earlier post-contrast GRE images (Fig. 2a). The weighted subtraction images (Fig. 2c) demonstrated a higher degree of soft (stationary) tissue suppression. However, with weighting factor >1.5, increased noise in the images were noted. Optimal suppression with acceptable increase in image noise was noted for mask subtraction weights of 1.0 to 1.4.

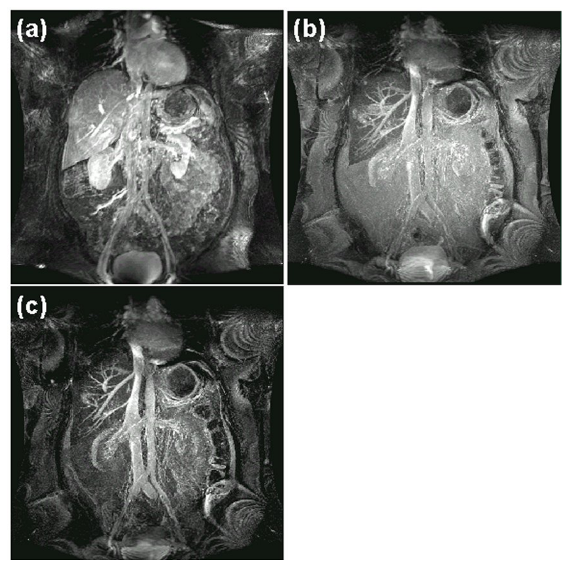

Figure 2: (a) Gradient recalled echo MIP about 1 min post contrast injection. (b) 3D SSFP (FIESTA) MIP about 24 min post injection showing that high image S/N in the arteries and veins persists even at a long period after the contrast injection. (c) The same image as in (b) but after S-minus 3D SSFP mask subtraction. Note the improved vessel C/N and stationary spin suppression obtained with the proposed subtraction technique.

Discussion

Our approach generated high S/N vascular visualization well after the arterial phase of the administration of extra-cellular Gd-chelates as a contrast agent. The visualization of the veins, in particular, was significantly improved in the post contrast 3D SSFP (FIESTA) images as compared to that acquired using conventional gradient-recalled echo imaging. Furthermore, S-minus mask images could be acquired at any time and not necessarily as a pre-contrast mask as in conventional contrast-enhanced MRA. The improved S/N and short acquisition times of a 3D SSFP sequence also allowed higher resolution images to be obtained. The improvement in image S/N would be even more substantial if intra-vascular contrast agents are used.