Three Dimensional SSFP of Carotid Artery Disease with Diastolic Triggering

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Introduction

Recently SSFP has been promoted for imaging carotid artery disease (1, 2). In a small sample of carotid artery disease, Zavodni (1) found poor performance of steady-state 2D SSFP in cases of significant stenosis (>50%) which accounted for 43% of the sample size. In the work by Gupta (2), the 3D SSFP technique proved successful, however, this patient group had few cases of severe stenosis. Nevertheless, neither of these works gated the acquisition to diastole, although it is well known that SSFP can produce severe pulsatile artifacts. The goal of the present work was to evaluate a triggered version of 3D SSFP for application to carotid artery disease across the full range of stenotic lesions. The technique is compared to the standard 3D time-of-flight technique, and correlated with findings from carotid Doppler ultrasound.

Methods

Twenty-five patients with suspected carotid artery disease were studied at 1.5 T. All had been referred for work-up of suspected or confirmed transient ischemic events or stroke. Doppler ultrasound demonstrated 35 stenoses < 50 %, 8 stenoses between 50 and 70 %, and 7 stenoses > 70 % in the fifty available vessels. The patients ranged in age from 39 to 91 years with a mean and standard deviation of 63±14 years. In addition to the magnetization-prepared (MP) 3D triggered SSFP, 4 other pulse sequences were performed on each patient including 2D black-blood fast spin echo, 3D time-of-flight MRA, 2D SSFP and 3D continuous SSFP. These sequences were optimized for application to the carotid bifurcation. The parameters for the key 3D sequences are listed below.

<u>3D triggered SSFP</u>: 65° flip, 1 mm slice, 64 x 240 x 320 matrix, 200 mm FOV, TE/TR = 1.9/4.7 ms, 1 average, bandwidth 600 Hz/Pixel. The sequence was typically performed twice as a single 64 slice slab and as two overlapping 32 slice slabs. Magnetization preparation preceded each readout period where 51 views were sampled. The preparation phase included both venous saturation and fat saturation. The approach to steady-state used 20 dummy scans of increasing flip angle. Triggering was performed with a finger pulse oximeter, with acquisition beginning following a 200-300 ms delay after the trigger. The diastolic window, including preparation pulses, was 394ms. Shimming was performed prior to all SSFP scans using a rectangular localized volume encompassing only the portion of the carotid arteries to be imaged.

<u>3D continuous SSFP</u>: 70° flip, 1 mm slice, 32 x 240 x 320 matrix, 200 mm FOV, TE/TR = 2.2/5.0 ms, 1 average, bandwidth 601 Hz/Pixel.

<u>3D TOF</u>: 25° flip, 1 mm slice, 32 x 343 x 512 matrix, 2 50% overlapping slabs, 200 mm FOV, TE/TR = 6.9/36 ms, 1 average, bandwidth 81 Hz/Pixel, first order flow compensation in read and slice directions.

The resulting images were analyzed both quantitatively and qualitatively. Quantitative measurements included signal-to-noise and contrast-to-noise ratios (SNR and CNR). The SNR was calculated for blood, muscle and fat, and the CNR for arterial signal relative to background. These measurements were performed for all of the pulse sequences in each patient study at a point proximal to the artery bifurcation. The qualitative analysis was performed by a trained medical doctor and included measures of image quality and vessel sharpness. In this abstract, we report the number of arteries were visualized with adequate diagnostic quality. Adequate diagnostic quality refers to a result that allows for adequate measure of the degree of carotid artery stenosis.

Results and Discussion

Table 1 illustrates the qualitative results at left, and the quantitative results at right. At left, the number of adequate diagnostic results are classified for each artery by degree of stenosis as measured by ultrasound. The results suggest that triggered MP-SSFP is as effective as 3DTOF in the regime of stenosis less than 50%. However, as the stenotic lesion increases to severe, all of the SSFP alternatives fail more frequently than 3DTOF. Based on ultrasound findings, this suggests that the SSFP sequences are failing in the regime of extremely high blood velocities. Even with diastolic gating, the extreme jet flow seen in many severe stenosis is not fully overcome. Thus triggering the acquisition in diastole did not make a significant difference in overall diagnostic quality. The loss of signal in the SSFP techniques may have been due to the lack of flow compensation. In order to keep the TR short for these high resolution scans, flow compensation was not used in SSFP, but the TE was only 1.9- 2.2 ms. Nevertheless, in the presence of highly complex flow, the dephasing is significant. The TOF had a TE of 6.9 ms with first order flow compensation and suffered less flow voids from dephasing. The mean quantitative results in Table 1 illustrate SNR and CNR values. Note that the SSFP sequences, normally considered high SNR, have similar SNR to the 3DTOF because of the greater than seven-fold increase in bandwidth needed in SSFP to maintain a short TR time. This bandwidth increase offsets the increased flip angle. The 3D triggered SSFP scan has improved fat suppression but a lower SNR value than the other techniques. The lower SNR versus continuous SSFP may partly arise from the use of fat saturation and partly from the lack of a proper steady-state signal. Example images are shown in the figures for moderate and sever stenosis.

Table 1: *Qualitative and Quantitative Results: Success rates and SNR and CNR values*

	Internal Carotid Artery Stenosis			Signal – to – Noise Ratio			Contrast – to – Noise Ratio	
Pulse Sequence	**< 50 %**	**50–70 %**	**> 70 %**	**Blood SNR**	**Muscle SNR**	**Fat SNR**	**CNR (Blood – Muscle)**	**CNR (Blood – Fat)**
2D Continuous SSFP	29 / 32	2 / 6	1 / 3	47 ± 11	7 ± 2	32 ± 9	40 ± 10	15 ± 8
3D Continuous SSFP	21 / 22	6 / 8	1 / 5	51 ± 10	6 ± 1	33 ± 10	45 ± 10	17 ± 7
3D Triggered SSFP	33 / 35	7 / 8	2 / 5	39 ± 12	7 ± 2	20 ± 5	32 ± 11	19 ± 11
TOF	32 / 34	5 / 8	5 / 5	51 ± 12	13 ± 3	17 ± 4	38 ± 9	33 ± 10

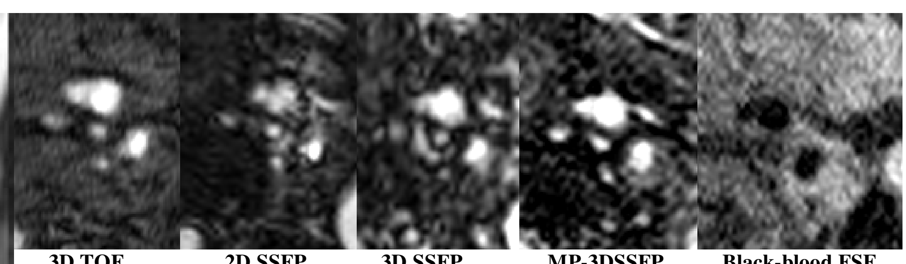

Fig 1 A 65 year-old man with a 50 – 70% internal carotid stenosis on Doppler ultrasound. At left, MIP images fromtriggered (A) MP-SSFP and (B) 3DTOF . The SSFP MIP is of poor quality. Axial source images slightly distal to the bifurcation from each sequence are shown above.

Fig 2 (right) The tortuous left carotid artery of a 78 year-old woman with > 70% stenosis on Doppler. From left to right are TOF source, and MIP, 3D triggered SSFP MIP and source images. This SSFP image demonstrates is nondiagnostic.

In conclusion, the triggered MP-3DSSFP performed well in cases of stenosis less than 50%, however, in cases of stenosis greater than 50, the technique performed poorly, and was only slightly preferable to continuous 3D SSFP.

<u>References</u> 1) Zavodni et al JMRI 21:86-90 (2005). 2) Gupta et al JMRI 22:354-360 (2005).