Combining Sensitivity Encoding (SENSE) and Foldover Suppression to Overcome FOV Restrictions In Thoracic 3D CE-MRA

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Introduction

Coronal thoracic contrast-enhanced MRA (CE-MRA) is typically performed with the arms overhead to avoid aliasing artifacts – often difficult for elderly patients and potentially disruptive to scan flow if the arms need to be moved mid scan. Most modern CE-MRA protocols use parallel imaging techniques such as SENSE to achieve high spatial and temporal resolution. With SENSE, however, foldover artifacts are particularly problematic given that aliasing wraps into the middle rather than edge of the image (Figure 1a). We describe here a generalized technique termed foldover-suppressed MRA (fs-MRA) whereby aliasing is eliminated without time or SNR penalty when using parallel imaging (SENSE), and demonstrate that this technique allows for artifact-free, arms-by-the-side thoracic CE-MRA.

Methods

Pulse Sequence Description. Foldover suppressed MRA is performed by implementing foldover suppression (also called "no phase wrap"), acquiring two signal averages (NSA), and increasing the nominal SENSE factor (SF) by a factor of two. By taking two NSA with foldover suppression, the sequence acquires a phase encoding step between each nominal phase encoding step (rather than collect each nominal phase encode step twice), thereby doubling the acquired phase field of view (FOV). The two signal averages double the scan time, which is then counteracted by doubling the SF. Since doubling the SF effectively "skips" every other phase encode, the net result is unchanged scan time (same number of phase encodes) with double the acquired FOV, thus eliminating aliasing artifacts (assuming no tissue lies outside the double FOV). For this study, we chose to implement the "doubling" of the SF by increasing the phase (LR) SENSE factor from 2.5 to 4.0, and then adding a small amount of slice SENSE factor (1.5). Due to a small degree of inherent oversampling, this combination with two NSA gave the same acquisition time (9 s) as the conventional SF 2.5 study.

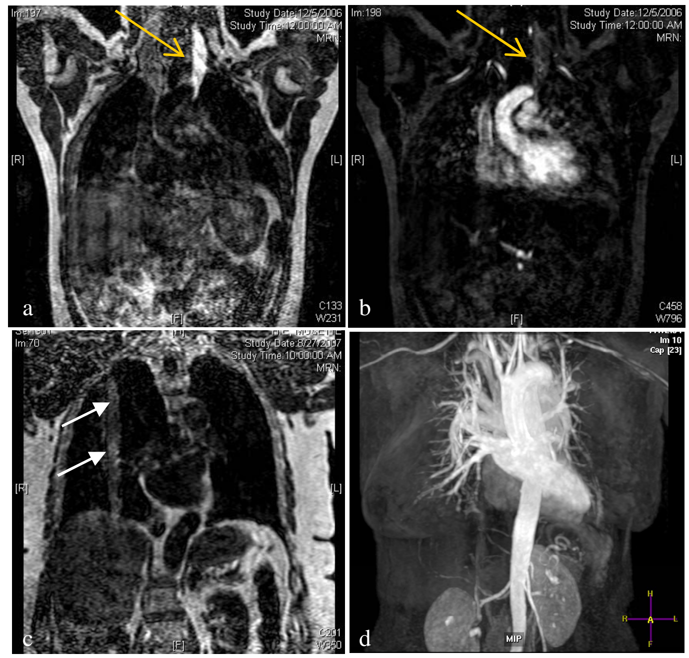

Figure 1. (a,b) c-MRA pre and post contrast source images with arms overhead. Note aliasing from the arms (grade 2-arrows) that can cause artifactual defects in structures such as the neck vessels and subclavian arteries. (c) fs-MRA pre contrast with arms down showing some mild LR foldover (grade 1-arrows). (d) Full volume MIP of arms down fs-MRA showing no detectable LR aliasing of the arms/subclavian arteries.

Study Population/Imaging Parameters. This was a retrospective study of 40 patients undergoing cardiac and/or thoracic MR, performed in compliance with the guidelines of the local Institutional Review Board. Twenty consecutive "conventional" thoracic coronal CE-MRA studies (c-MRA; SF in phase 2.5, arms overhead, 1 NSA, 9 sec) were compared with twenty later consecutive foldover suppressed CE-MRA (fs-MRA; SF in phase/slice = 4/1.5, arms down, 2 NSA, 9 sec). All imaging was performed at 1.5T (Achieva release 2, Philips Medical Systems, Best, the Netherlands) using a commercial 5 channel cardiac coil. The CE-MRA was typically the last sequence performed as part of the clinical cardiothoracic exam, and all patients received 0.1 mmol/kg of Gd-BOPTA (MultiHance, Bracco diagnostics, Princeton, NJ) at 1.8 mL/s.

Data Analysis. Quantitative and qualitative measures were assessed. Vessel edge sharpness was determined by measuring the upslope of a line profile through the aorta on a source image, and aorta-muscle contrast ratio (CR) was measured with ROI's in the aorta and paraspinous muscles. A single reader subjectively graded phase (LR) and slice (AP) foldover artifacts (0 = none, 1 = barely detectable, 2 = interfering but diagnostic, 3 = impairs interpretation), contrast to noise ratio (CNR), vessel sharpness, and overall image quality. Any apparent subclavian stenoses were noted and graded as "real" vs. "artifactual". Statistical analysis was performed using Student t-test (quantitative) and Mann-Whitney U test (qualitative).

Findings

There was no significant difference between the techniques in quantitative vessel sharpness, quantitative CR, or subjective CNR/edge sharpness/image quality (all $p \gg 0.05$). LR foldover artifact with fs-MRA was improved (average grade, 0.35 vs. 1.03, $p \ll 0.05$), with no compromising (grade 2/3) foldover seen, whereas c-MRA had compromising LR foldover (grades 2/3) in three patients (15%). AP foldover artifact with fs-MRA was more severe (average grade 1.0 vs. 0.2, $p \ll 0.05$), but none were compromised (no grade 2/3) with either technique. Artifactual subclavian artery stenosis was observed in four (20%) c-MRA exams due to foldover obscuring the subclavian artery, but was not seen with fs-MRA (Figure 1a,b).

Discussion

As compared to c-MRA, fs-MRA was equivalent in acquisition time, contrast ratio, edge sharpness, and subjective measure of CNR/image quality; yet had no instances of compromising foldover or artifactual subclavian stenosis. LR foldover was significantly improved (despite the arms being by-the-side and outside the prescribed FOV - Figure 1), although somewhat greater AP foldover was apparent (all instances grade ≤ 1). Generally, increasing SF beyond 2.5-3 severely degrades image quality due to coil geometry-related precipitous drops in SNR. In this technique, however, the net acceleration factor was kept constant, with LR SF increased from 2.5 to 4, but 2 NSA combined with foldover suppression effectively reducing the net LR SF back to 2. Then an increase in AP SF from 1 to 1.5 equated to the same nominal 9 sec scan time and SF of 2.5 as in c-MRA (given some system oversampling inherent to 2D SENSE). While accurately measuring SNR can be problematic with SENSE due to spatially varying noise, surrogate CR and subjective CNR analysis did not detect any difference between the two techniques, suggesting our assertion that SNR is not compromised is correct. In summary, the fs-MRA technique allows for uncompromised arms by-the-side imaging without the time penalty of opening up the prescribed FOV to clear all tissue. This has the benefits of patient comfort and improved workflow. Furthermore, foldover that can cause artifactual subclavian stensosis is eliminated (Figure 1d). We now use this technique for all thoracic MRA, and are investigating its use for abdominal MRA.