Automated Selection of 2D-CAIPIRINHA Kernels and Application to 3D CE-MRA

Paul T Weavers[1], Eric A Borisch[1], and Stephen J Riederer[1]
[1]*MR Research Laboratory, Mayo Clinic, Rochester, Minnesota, United States*

Introduction: 2D Sensitivity Encoding (SENSE) [1, 2] at high acceleration (R≥8) has become routinely used in 3D Contrast Enhanced MR Angiography (CE-MRA) e.g. [3]. Another technique, 2D CAIPIRINHA [4], shows promise in reducing the quality degradation associated with high acceleration factors by moving aliasing off the principal phase encode axes of the acquisition by adjusting the k_Y-k_Z-space sampling kernel. For relatively low accelerations of R = 3 and 4, Despande [5] found the best CAIPIRINHA kernel for an abdominal acquisition based on observing the g-factor results for each possible kernel. However, as the acceleration increases the number of possible CAIPIRINHA kernels also increases, and non-automated examination of each possible pattern becomes impractical. The purpose of this work was to develop the methodology and implementation for selection of the optimum CAIPIRINHA sampling kernel which is: (i) subject-specific; (ii) accommodates large R (≥8); (iii) comprehensive, in that all CAIPIRINHA kernels are considered for a given R; (iv) prospective, performed before the accelerated exam; and (v) practical, allowing selection as part of a prescan process. This allows for immediate application of the best CAIPIRINHA pattern in the accelerated exam. This work is based on methodology developed for tuning 2D-SENSE accelerations (R_Y,R_Z) to patient-specific values [6].

Methods: The method uses the acquired coil sensitivity images, already necessary for implementation of CAIPIRINHA. For a given R, for each possible CAIPIRINHA kernel the g-factor [1] map for the entire 3D volume is calculated from the coil sensitivities. A scalar quality metric is then determined by projecting the g-factor volume in the frequency encode (S/I) direction, and choosing the maximum value from the resulting 2D plane. This process is followed to ensure the scalar quality metric is both tolerant of calibration data noise via the projection operation, but also sensitive to image quality changes for different kernels. That kernel producing the g-factor volume with the lowest quality metric number is chosen as optimum.

The methodology was evaluated with retrospective analysis of previous studies as well as in a prospective CE-MRA exam. The retrospective analysis considered nine CE-MRA exams of the feet performed previously using R = $R_Y \times R_Z$ = 2 × 4 = 8 2D SENSE [3]. The coil sensitivity data used therein was subjected to the CAIPIRINHA-directed optimization discussed above, and each of the 15 possible kernels was considered for each study. The 10th, 25th, median, 75th and 90th percentile g-factors over the volume using the optimum kernel were noted and compared with those from the reference 2D SENSE exams. The prospective study was conducted by performing 3D time-resolved CE-MRA on a volunteer twice: first, using a standard $R_Y \times R_Z$ = 2 × 4 = 8 acceleration and several days later with the optimal CAIPIRINHA pattern. For the latter, the optimization was performed with online, custom-built computation hardware and was done within 10 seconds from the time the coil sensitivity images were available to the scanner. Vessel contrast-to-noise (CNR) measurements from this comparison study were made from the axial volume images.

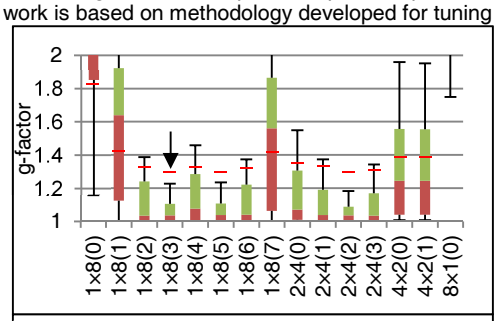

Figure 1: g-Factor statistics for the 15 possible CAIPIRINHA patterns for R=8 for a foot CE-MRA exam. The red lines indicate the relative cost function values, with the minimum cost function denoted by the arrow.

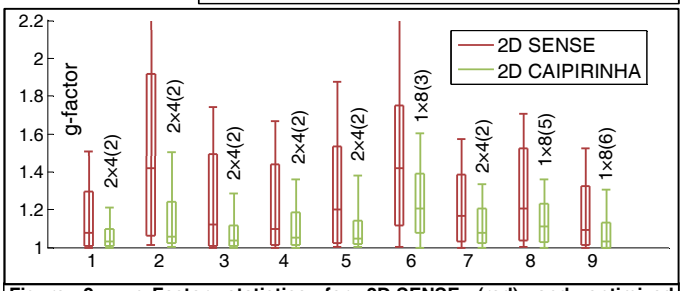

Figure 2: g-Factor statistics for 2D-SENSE (red) and optimized CAIPIRINHA (green) for nine volunteer studies. The optimum CAIPIRINHA kernel is noted for each.

Results: Figure 1 shows the g-factor statistics for the 15 CAIPIRINHA patterns for R=8 for a representative study used for retrospective analysis. The optimum kernel identified by our methodology is designated (arrow). Figure 2 is a comparison of the g-factor statistics for the 2D SENSE vs. the optimized CAIPIRINHA for each of the nine retrospective studies, with the specific optimum kernel noted for each. Note that over the nine studies four different kernels were found to be optimal. Figure 3 shows a comparison of the single-foot sagittal maximum intensity projections (MIPs) from (a) the standard 2D SENSE acceleration ($R_Y \times R_Z$ = 2 × 4 = 8) and (b) the optimal CAIPIRINHA pattern ($R_Y \times R_Z$ (Shift) = 1 × 8 (3)) accelerated study. Note the reduced visible noise amplification in the latter, particularly the improvement in visibility of the small vessels in the midfoot indicated by the arrows. CNR comparisons (not shown) between the two CE-MRA exams showed consistently improved vessel CNR in the CAIPIRINHA case.

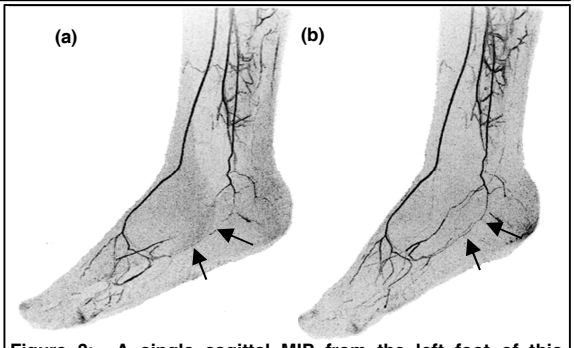

Figure 3: A single sagittal MIP from the left foot of this bilateral 0.75 × 0.75 × 0.9375 (S/I × L/R × A/P) mm acquisition. (a) shows the default $R_Y \times R_Z$ = 2 × 4 = 8 acquisition, and (b) shows the $R_Y \times R_Z$ (Shift) = 1 × 8 (3) = 8 acquisition. Note in the CAIPIRINHA acquisition the reduction in visible noise contours related to g-factor noise amplification from the contours of the heel.

Conclusion: In each of the nine cases of retrospective analysis, the CAIPIRINHA-based acceleration strategy showed improvement over traditional SENSE acceleration values with equivalent total acceleration. Additionally, an automated algorithm was able to identify the optimum pattern in less than ten seconds. This type of approach can be applied to other anatomical areas as well, both for CE-MRA and other types of imaging. The CE-MRA example illustrates the quality improvement, showing qualitatively improved MIPs and improved CNR from the volume images. In summary, we have shown how the optimum CAIPIRINHA sampling kernel can be determined prospectively for large (R≥8) acceleration values and how the optimum can vary subject-to-subject.

References: [1] Pruessmann KP, MRM 42:952(1999); [2] Weiger M, MAGMA 14:10(2002); [3] Haider CR, JMRI 34:2(2011); [4] Breuer F, MRM 55:549(2006); [5] Deshpande V, ISMRM 2012 (104); [6] Weavers P, ISMRM 2012 (2224);