

Clinical Evaluation of CAIPIRINHA: Comparison against a GRAPPA Standard

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Introduction: Image acquisition time is among the most important factors in clinical MRI. Parallel imaging has made huge advancements in imaging speed with wide ranging clinical impact [1-3]. The well-known limitations of parallel imaging are a decrease in signal-to-noise ratio (SNR) and residual aliasing artifacts at high acceleration factors, which lead to a loss in image quality. CAIPIRINHA (Controlled Aliasing In Parallel Imaging Results IN Higher Acceleration) [4-6] is a parallel imaging technique that modifies aliasing artifacts during image acquisition.

Aliasing is controlled by altering the phase encoding sampling strategy, specifically by applying gradient offsets during set points of data acquisition. This change in phase encoding results in a modified aliasing reduces the quantity or severity of aliased pixels, which allows for a more robust parallel imaging location that reconstruction with fewer aliasing artifacts [5,6]. Clinically, this could allow for acquisition of higher quality images even at high acceleration factors, which is especially attractive for application in patients with breath-hold difficulties or those with poor compliance. Here, we propose to evaluate the image quality of CAIPIRINHA clinically in comparison to standard GRAPPA [1] to validate the expected improvement in image quality in highly accelerated breath hold liver scans.

Methods: To evaluate image quality, CAIPIRINHA and standard GRAPPA undersampling patterns were used (as depicted in Figure 1). CAIPIRINHA 2x2_1 GRAPPA image, with a total reduction (R) factor of 4, reduction factor of 2 in both phase encode directions, and reordering shift of 0, will produce the sample pattern seen in Figure 1A. A 2x2_1 CAIPIRINHA image, with a total reduction factor of 4, reduction factor of 2 in both phase encode directions, and a reordering shift of 1 will produce the sample pattern seen in Figure 1B, leading to modified aliasing. Following informed written consent, CAIPIRINHA (2x2_1) and GRAPPA (2x2_0) datasets of the abdomen were obtained for 20 patient volunteers scheduled for a routine abdominal MRI exam on a Siemens Avanto 1.5T scanner (post contrast) over a four month period. These additional sequences were added on during a quiescent period in our protocol, between 3 min and 5 min after injection of contrast, during which no imaging is routinely performed. The 2x2_1 CAIPIRINHA pattern was chosen for its similar parameters to standard GRAPPA, except for the added reordering shift. Both sequences had a TR of 5.11ms, TE of 2.29ms, bandwidth of 300Hz/pixel, Flip Angle of 13°, and an acquisition time of 9 seconds per data set. Three radiologists blinded to the sources of the data and overall goal of the study (one fellow with 1 year experience in body imaging and two attending level subspecialty trained radiologists with over five years experience in body imaging) were asked to evaluate images for both the GRAPPA and CAIPIRINHA cases. The comparison was presented to the raters as a two alternative forced choice test, where the rater was asked to select their preferred image set based on overall image quality. A Wilcoxon test was used to distinguish whether the resulting mean ranks of the sequences significantly differed from one another ($\alpha=0.05$). Using SPSS Statistics, Kappa and Intraclass correlation (ICC) values were calculated to determine interrater reliability [7,8].

Results/Discussion: Statistical analysis results are summarized in Figure 2. Among readers, CAIPIRINHA was selected 70% of the time while the GRAPPA standard was selected 30% of the time. A Wilcoxon test of the data showed a significant difference in mean ranks ($p < .01$). Intraclass correlation (ICC) showed very good agreement for all raters, with an ICC of .85 (95% Confidence Interval of .72 to .93). Kappa (κ : interrater reliability) among the raters was very good to high, with $\kappa=.77$ for rater combinations 1:2 and 2:3, and $\kappa=1.0$ for raters 1:3. The average kappa for all raters was high, where $\kappa=.84$, with no significant difference between the ratings from the fellow versus the subspecialty trained radiologists. In many cases CAIPIRINHA dramatically improved image quality, as shown in Figure 3 depicting representative images; standard GRAPPA in Figure 3A and CAIPIRINHA in Figure 3B. The CAIPIRINHA image shows both a reduction in both noise and aliasing artifacts when compared to the GRAPPA standard.

Conclusion: This work shows that for acceleration factor 4, a 2x2_1 pattern CAIPIRINHA accelerated VIBE is significantly improved in comparison to the current GRAPPA standard for image quality and artifacts. Clinically, this may allow for reduced imaging time in comparison to standard GRAPPA for similar spatial resolutions, which is particularly important in abdominal scans in patients who may not be able to comply with long breath-hold requirements in critical timed post contrast studies.

References: [1] Griswold MA, et al. Magn Reson Med 2002; 47: 1202-1210. [2] Sodickson DK, et al. Magn Reson Med. 1997 38:591-603. [3] Pruessmann KP, et al. Magn Reson Med 1999; 42: 952-962. [4] Breuer FA, et al. Magn Reson Med. 2006 55:549-556. [5] Yutzy SR, et al. Magn Reson Med. 2011 65:1630-1637. [6] Breuer FA, et al. Magn Reson Med. 2005 53:684-691. [7] Shrout PE, et al. Psychol Bull. 1979 Mar;86(2):420-428. [8] Landis JR, et al. Biometrics. 1977 Mar;33:159-174.

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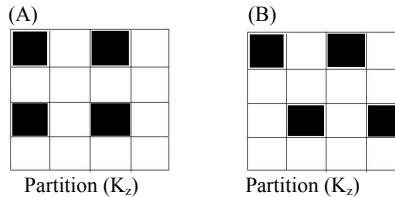


FIG. 1: Comparison of sequence sampling patterns given a reduction factor of R=4. (A) 2x2_0 GRAPPA pattern. (B) 2x2_1 CAIPIRINHA pattern.

| Intraclass Correlation | Result |
|------------------------|-----------|
| ICC | 0.85 |
| 95% Conf. Interval | .72 - .93 |

| Wilcoxon Test | Result |
|--------------------------|----------|
| p Value ($\alpha=.05$) | <0.01 |
| Test statistic Z | 2.69 |
| CAIPIRINHA selections | 42 : 70% |
| GRAPPA selections | 18 : 30% |
| Total image sets rated | 60 |

| Kappa | Result |
|---------------|--------|
| Rater 1 and 2 | 0.77 |
| Rater 2 and 3 | 0.77 |
| Rater 1 and 3 | 1 |
| Average Kappa | 0.84 |

FIG. 2: Statistical analysis shows significance of CAIPIRINHA preference and rater reliability.

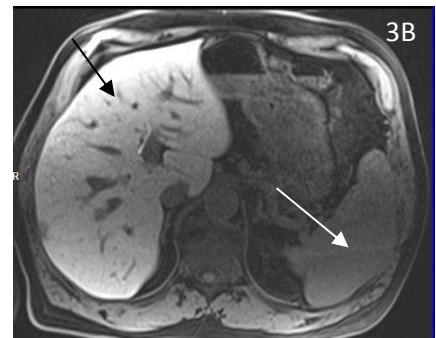
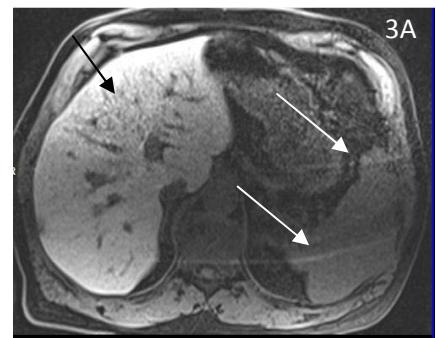


FIG. 3 GRAPPA CAIPIRINHA image comparison. (A): GRAPPA standard image shows noise (black arrow) and aliasing artifacts (white arrows). (B): 2x2_1 CAIPIRINHA image of the same slice displayed reduced noise (black arrow) and reduced aliasing (white arrow).