Optimizing CAIPIRINHA multi-band acquisition scheme for 2D multi-slice experiments in the abdomen

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PURPOSE Multi-slice (MS/M2D) sequences, which acquire 2D slices sequentially, are a common used acquisition type for clinically abdominal exams. Due to respiratory motion, these acquisitions are often performed in multiple breath holds, triggered, using a respiratory belt, or gated using a navigator. This severely limits time efficiency and prolongs abdominal exams. Furthermore, breath holds are unpleasant and often challenging for patients to maintain and respiratory belts require careful positioning in order to record reliably the respiratory motion. Acquiring multiple slices within the same acquisition window would accelerate these acquisitions significantly[1]. CAIPIRINHA[2] shifts multiple excited slices with respect to each other in image space through phase cycling in *k*-space resulting in more distinct sensitivity weighting for voxels from simultaneously excited slices that will aliase. Optimizing this phase cycling along with the gap between multiple excited slices can severely increase SNR (i.e. decrease geometry factor). Deshpande[3] calculated the optimal 2D CAIPIRINHA kernel for 3D imaging. Weaver[4] demonstrated that for 3D CE-MRA automated selection of 2D kernels was required to minimize g-factors. The goal of this study was to determine the optimal shifting pattern in combination with slice gap for CAIPIRINHA in a clinical abdomen scan. Additionally, results between subjects and with varying coil setup were compared to determine if online automated optimization is essential for each subject or if a generic acquisition scheme is suitable for multi-slice experiments.

METHODS Two subjects were scanned on a 1.5 T MR (Achieva Philips Healthcare, The Netherlands). A $T2_w$ M2D TSE abdominal scan was acquired in one breath hold (TE/TR = 73/533 ms, $\alpha = 90^0$, FOV = 350x210x105 mm3, voxel size = 0.78x0.79x3.5 mm^3, TSE shot length = 321 ms, halfscan-factor = 0.635, Tacq = 16 s) along with a reference scan for coil sensitivity maps. Thirty slices were acquired in SI direction with no slice gap. A 16 channel Torso XL coil (Philips Healthcare, Best, The Netherlands) was used consisting of an anterior and posterior part which are each composed of 2x4 elements shifted in SI direction. CAIPIRINHA experiments were retrospectively simulated for R = 2 and R = 3. For two simultaneously excited slices (R = 2), the second slice is placed at variable distance from the first, fixed slice, with a maximum of 49 mm (i.e. FOV/2 - slice thickness in SI direction). This way, the whole FOV can be acquired using the same slice gap. Additionally, the linear phase ramp (i.e. phase cycling) applied to the second slice was varied between 0 and $\pi * PE$ with steps of π/6 (where PE is the phase encode line and $\pi * PE$ thus corresponds to a shift of FOV/2 in image space). For R = 3, the applied phase ramp varied between 0 and $\pi * PE$ (in steps of π/6) for the second slice and $2\pi * PE$ (in steps of π/3) for the third slice. The distance between slices is increased but equal for the two gaps. In a second experiment the anterior part of the coil was shifted ~5cm with respect to the posterior part to simulate clinical set-up variation in positioning of the coils. Reconstruction steps were performed using ReconFrame (Gyrotools, Zurich, CH) with an additional SENSE reconstruction to unfold the simultaneously excited slices. G-maps were calculated for all simulations, averaged for simultaneously excited slices to generate a composite g-factor map and mean g-factors were calculated within the whole anatomy. Leakage factor[5] was taken into account as quality measurement

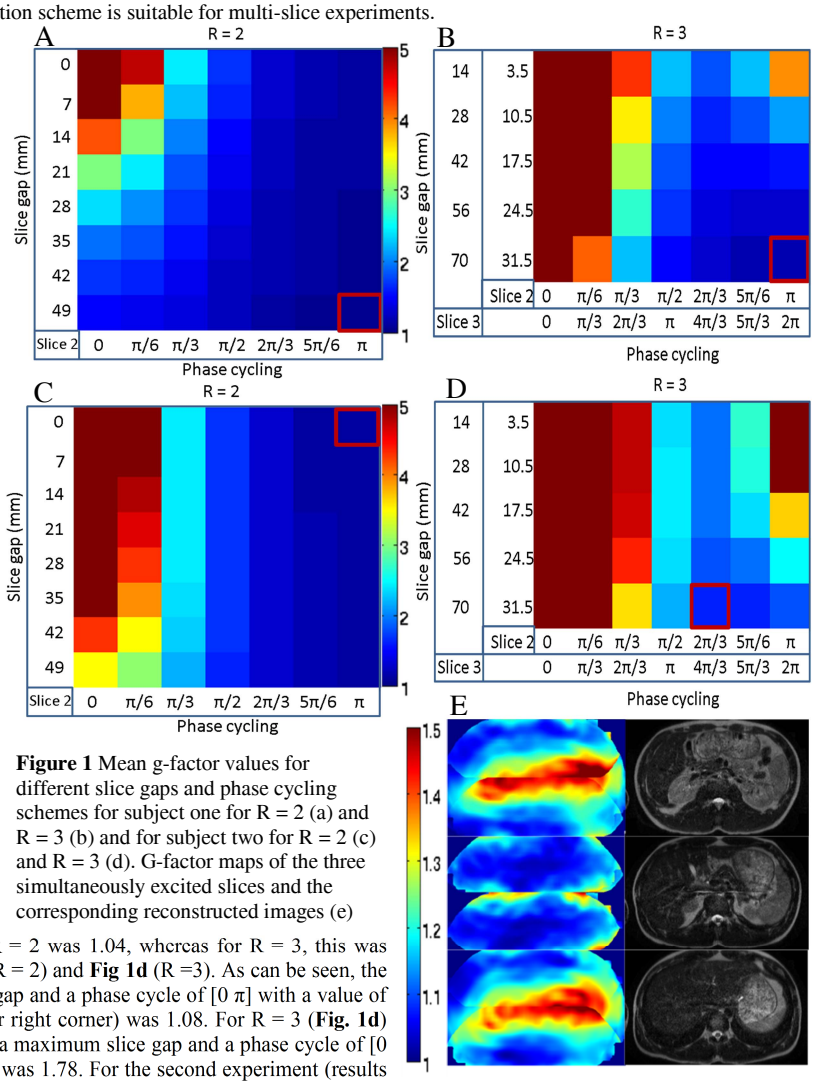

Figure 1 Mean g-factor values for different slice gaps and phase cycling schemes for subject one for R = 2 (a) and R = 3 (b) and for subject two for R = 2 (c) and R = 3 (d). G-factor maps of the three simultaneously excited slices and the corresponding reconstructed images (e)

RESULTS **Fig 1a** shows the mean g-factor values for R = 2. The phase cycling is projected on the x-axis, while the gap is on the y-axis for the different slices. Minimum values can be observed in the right column, representing a phase cycling of [0 π] and a maximum slice gap. Similarly, in **Fig 1b** minimum values can be observed in the lower right corner for R = 3, corresponding to a large slice gap and a phase cycling up to [0 π 0], resulting in a FOV/2 shift for the second slice and no shift for the third slice. This implies that for large gaps, encoding power in SI-direction outperforms in-plane encoding. Minimum mean g-factor for R = 2 was 1.04, whereas for R = 3, this was 1.18. The g-factor values for the second subject are displayed in **Fig 1c** (R = 2) and **Fig 1d** (R =3). As can be seen, the minimum g-factor for R = 2 for this subject was achieved using no slice gap and a phase cycle of [0 π] with a value of 1.07. The g-factor for maximum slice gap and phase cycling [0 π] (lower right corner) was 1.08. For R = 3 (**Fig. 1d**) the minimum g-factor shifted from the lower right corner to the left with a maximum slice gap and a phase cycle of [0 2π/3 4π/3], with a value of 1.57. The value for a phase cycling of [0 π 0] was 1.78. For the second experiment (results not shown), the anterior part of the coil was slightly shifted and this resulted for subject 1 in higher minimum g-factor, 1.05 for R = 2, and 1.41 for R = 3, which is an increase of 19%. Furthermore, the optimal sampling scheme shifted from [0 π 0] to [0 5π/6 5π/3] for R = 3. The value in the lower right corner was 1.51. For subject 2 the minimum g-factor decreased from 1.07 to 1.05 when the coil was shifted for R = 2. Also for R = 3, a decrease in minimum g-factor was found, from 1.57 to 1.42 and the optimum phase cycling was [0 5π/6 5π/3]. The value in the lower right corner was 1.45. These lower minimum g-factor values for the second experiment imply that the coil was not placed correctly during the first experiment, leading to higher minimum g-factor values. **Fig. 1e** shows the g-factor maps for subject one using the optimal sampling as calculated in **Fig. 1b** and the corresponding reconstructed images. G-factor is highest in the center of the slice for the first and third slice, since they completely overlap. The reconstructed images also show some residual aliasing artifacts.

DISCUSSION AND CONCLUSION Results show the importance of the phase cycle for R = 2. Increasing the slice gap between the two slices gave only little deviation in g-factor. The differences between the subjects were minor and shifting the anterior coil a few centimeters only had a small impact on the g-factor values. For R = 3, the differences were much larger between the subjects and the two experiments. Here, maximizing the slice gap is an important parameter for minimizing the g-factor, in combination with a phase cycling between [0 2π/3 4π/3] and [0 π 0]. Differences between optimum phase cycles were observed between subjects and between coil placements. Results from this study show that optimizing CAIPIRINHA parameters can greatly decrease g-factor, and thus increase SNR after unfolding. This shows that patient specific parameters have to be established, but this problem can greatly be constrained by minimizing the parameter space for which the g-factor will be calculated.

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