Comparison of a multiple free-breathing prescans (MFP) method of coil sensitivity calibration against TGRAPPA during free-breathing myocardial first-pass perfusion

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Introduction: An underlying principle of all parallel imaging methods is required knowledge of the coil sensitivity distributions through some method of calibration. These can be grouped as separate calibration acquisitions ('prescans'), assimilated variable density acquisitions ('integrated') or, in the case of dynamic imaging acquisitions, calculation through filtering of consecutive frames of the data itself ('temporal'). Integrated techniques tend to provide the most faithful sensitivity information but reduce the achieved acceleration, whilst prescans allow full acceleration but can cause large artefacts in the reconstructed image in cases of respiratory motion. For this reason temporal methods are desirable in techniques such as free-breathing myocardial first-pass perfusion (FPP). Acting through either a temporal low-pass filter or a sliding-window moving average on the undersampled data to auto-calibrate the coil sensitivities, they can tolerate respiratory motion during the first-pass. However, there is less certainty about their ability to cope with more extreme breathing motion such as during stress. An alternative coil calibration technique for FPP that uses Multiple Free-breathing Prescans (MFP) to provide accurate prescan calibration through respiratory indexing, even during free-breathing, has previously been presented and examined against the standard prescan method (1). Here a study is made of an updated, fully automatic, version of the MFP calibration technique in comparison to temporal calibration, specifically TGRAPPA, in patients (referred for contrast-agent exams for late-enhancement imaging) with their consent under ethical approval for power-injection and FPP imaging experiments.

Methods: 20 patients underwent resting FPP (Cartesian FLASH, rate 4 temporal undersampling, 48 measurements, 3 slices, ~2.6x2.6x10.0mm). Breathing instructions were to take "slow and deep breaths" throughout both the prescan and FPP acquisitions, to act as a surrogate for potential increased respiratory motion during stress and thereby test the limits of the calibration methods. The MFP method collects multiple prescans during this respiratory motion, so that a prescan at the closest respiratory position to each frame of the FPP series may later be identified by a matching algorithm. This allows respiratory-matched prescans to be used for the coil sensitivity calibration in the parallel imaging reconstruction of each first-pass frame. The matching algorithm was modified to become fully automatic, through a combined high-pass filter cross-correlation technique. A Sobel gradient operator was applied both to the prescan (MFP) images and a basic parallel imaging reconstruction (using TGRAPPA) of the FPP frame. The filtered MFP images underwent thresholding, to leave the top 5% pixels by intensity remaining in each, thereby excluding regions where cardiac motion or contrast change between prescan and FPP frame might affect comparison. Each prescan then underwent a standard 2D-correlation calculation with the FPP frame, indexing the most appropriate prescan via highest coefficient value. This matching process was repeated for each FPP frame and slice before a final reconstruction of the dataset using the appropriate prescans as calibration data. For each dataset the TGRAPPA reconstructed images used for the initial reconstruction were compared with the MFP-GRAPPA reconstructed images, with the GRAPPA algorithm kept identical for both, thereby the reconstructions differing only in the coil calibration method (temporal moving average method vs automated MFP technique). Each reconstructed 48-frame 3-slice perfusion study was randomised for blinded independent dual observer scoring to quantify the parallel-imaging induced aliasing artefacts (0=none to 4=strong, non-diagnostic).

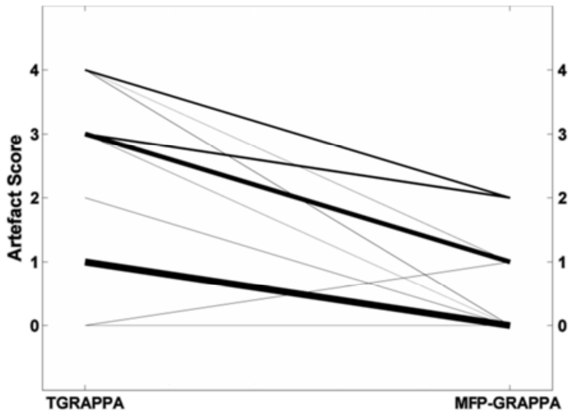

Fig 1: Comparison of consensus visual observer scores of parallel imaging induced artefacts in FPP datasets reconstructed with TGRAPPA and MFP-GRAPPA. Line thickness is proportional to frequency (n=20 joint scores).

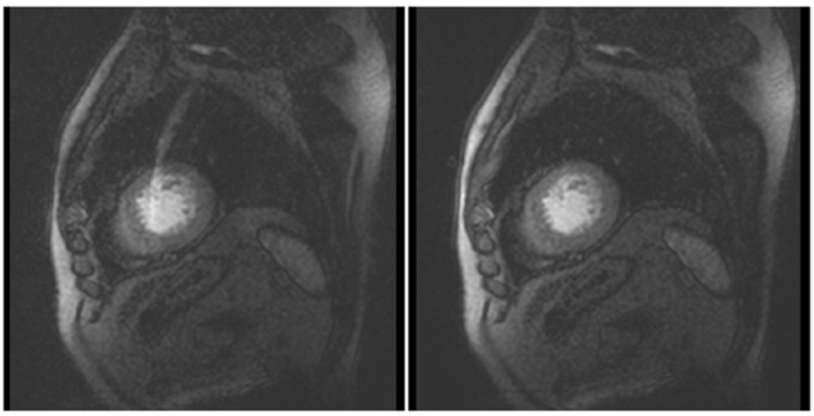

Fig 2: Example FPP frame, reconstructed with TGRAPPA (left) and MFP-GRAPPA (right). The former (consensus score 4) shows an artefact, passing through the heart, which is cleared in the latter (score 0).

Results & Discussion: Scoring showed reasonable agreement (2) between observers (κ=0.48, Cohen's Kappa, n=40) and after consensus scoring gave mean values of 2.3±1.4 for TGRAPPA and 0.7±0.8 for MFP-GRAPPA ($p<0.001$, paired t-test, 20 pairs). Figure 1 gives a visual guide to these results, while Figure 2 shows an example of a detrimental artefact in TGRAPPA cleared by use of MFP-GRAPPA. Whilst a small sample size, use of MFP produced an improvement in 90% of the datasets and with this technique no artefacts remained that were scored as causing a significant impact on perfusion assessment, despite the sometimes extreme respiratory motion. The automatic matching algorithm was successful in all cases. This technique could also be implemented as part of an image domain parallel imaging technique, such as SENSE, or more advanced methods; however, for this comparison with temporal coil calibration, GRAPPA was chosen due to the low-pass filter in TSENSE potentially imparting temporal smoothing effects (3). A potential limitation is the requirement of similar respiratory range for the MFP and undersampled acquisitions, however, breathing motion itself need not be similar as long as the respiratory range of the undersampled acquisitions is covered in the prescans and this could therefore be artificially requested if required.

Conclusions: Use of MFP as a parallel imaging coil sensitivity calibration technique can give an improved correction to respiratory artefacts whilst maintaining maximal acceleration, and has been demonstrated with a reliable fully-automated algorithm.

References: (1) Fair et al., ISMRM, 2014 (2) Cohen, Educ Psychol Meas, 1960 (3) Blaimer et al., MRM, 2011