

DENSE and HARP: two views on the same technique of phase-based strain imaging

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Introduction

Recent papers in the field of myocardial strain analysis show an increasing interest in phase-based strain quantification, using either the DENSE [1] or the HARP [2] technique. In literature, both techniques are still regarded as distinctly different techniques [3], where a more general treatment of the technique is justified [4]. This abstract discusses differences between HARP and DENSE in imaging and reconstruction, showing that apparent differences are in fact non-existent. Once it is realized that both frameworks are easily merged, the benefits are 1) less confusion about the (dis)advantages of either technique, and 2) a more general understanding of phase-based strain imaging.

History

While the HARP method was introduced as a post-processing method for SPAMM-tagged images [5], DENSE arose from the framework of stimulated echo (STE) and displacement encoding using bipolar gradients. Both techniques have evolved since their introduction, thereby becoming more similar over time and losing their distinct features. Newly introduced improvements have successfully been applied in both methods. DENSE is now used without its distinct STE timing, and for cine acquisition in conjunction with k-space filtering [6]. HARP is used in conjunction with peak suppression methods that alleviate the need for band-pass filtering [7], and with a readout window targeted at one single tagging peak [8].

Discussion: Differences and similarities

Acquisition It has already been argued that HARP and DENSE use the same motion encoding scheme [4]. When comparing the original tagging sequence in Fig. 1a with the original DENSE sequence in Fig 1b, similarities clear. The main differences are the presence of an explicit “decoding” gradient lobe in the DENSE sequence, and a repeated excitation using a low flip angle in SPAMM, versus a single 90° excitation for readout after the labeling in DENSE. The differences are now discussed.

- *Decoding gradient & k-space sampling.* DENSE uses a decoding gradient before the readout. HARP decodes the phase labeling during post-processing, and does not explicitly show a decoding gradient in the pulse sequence. At the time the tagging peak in k-space is sampled using SPAMM/HARP, the zeroth gradient moment is equal to that of the DENSE technique, at the time the STE is sampled. Therefore, “STE” and “tagging peak” are identical. FastHARP [8] explicitly introduces the decoding gradient, and samples the tagging peak in the center of the readout. In that respect fastHARP is identical to DENSE.

- *Imaging strategy.* Initially DENSE and HARP focused to slightly different applications. DENSE targeted imaging of a single temporal phase in the cardiac cycle, whereas HARP focused on multi-phase cine gradient echo imaging. However, these differences are not fundamental to DENSE or HARP, as has been illustrated by publication of DENSE cine imaging [6].

- *Peak suppression.* From the beginning, DENSE has aimed to sample the STE signal only, suppressing the FID and STAE (stimulated anti-echo) signal with crusher gradients in the slice direction (Fig 1b). Later, FID suppression using an inversion pulse was introduced. Also, FID suppression (using CSPAMM) is beneficial for HARP analysis [7]. Subsequently, the CSPAMM phase-cycling scheme was introduced in conjunction with DENSE for FID suppression [9]. More complex schemes for FID and STAE suppression exist in both frameworks, supporting the conclusion that there is no fundamental difference in the effect of peak suppression in the HARP and DENSE frameworks.

- *RF pulse amplitude.* Originally there was a difference in RF pulse amplitudes. However later studies with HARP used larger flip angles for tagging and DENSE used lower flip angles for readout, thus making both methods identical in this respect.

- *Sequence timing.* Originally, DENSE had a constraint on the timing parameters, based on the STEAM framework. This predicts that phase accumulation (from off-resonance effects and B₀ inhomogeneities) is compensated in the STE. However, DENSE has also been employed without this constraint on sequence timing [6].

Reconstruction and postprocessing

- *K-space position.* At the time of image reconstruction, DENSE places the STE signal at the center of k-space, whereas HARP places the FID signal at the center of k-space and thus the STE signal off-center. Because in DENSE part of the gradient switching is being considered as a decoding gradient, it is not considered an imaging gradient. In HARP the same gradient is considered an imaging gradient, leading to shift in k-space.

- *Calculated phase maps.* As the STE signal is placed at the center of k-space in DENSE, the displacement is directly accessible by the phase of the image after FFT. For HARP the image is still modulated with the tag signal and thus requires subtraction of the applied tagging phase (known from the moment of the encoding gradient). It then results in the same displacement related phase as in DENSE.

- *Filtering of k-space.* In DENSE, unwanted peaks in k-space (STAE/FID) are suppressed in acquisition or by subtraction techniques, or just not sampled (when well separated). In HARP, band-pass filters suppress unwanted peaks and isolate the desired peak, but also subtraction techniques such as CSPAMM have been implemented. Historically, there have been differences between both approaches, but these are not fundamentally related to either HARP or DENSE.

- *Spatial resolution of the strain map.* In DENSE the spatial resolution is equal to the image resolution, whereas in HARP the band-pass filter lowers the spatial resolution. However, filters have been applied with DENSE as well to remove remaining FID signal [6]. Whereas in HARP, by suppressing other peaks, the band pass filter can be widened [7] or omitted.

Conclusion

The features that previously distinguished both variants of phase-based strains analysis are clearly not unique to either method. Accordingly, we conclude that HARP and DENSE are actually one and the same technique. This also illustrates the need for future papers to clearly describe what sequence timing, FID suppression, band-pass filtering, and phase correction methods were used. Overall the authors believe that a general framework for phase-based strain analysis is of more value than the DENSE and HARP frameworks separately.

References

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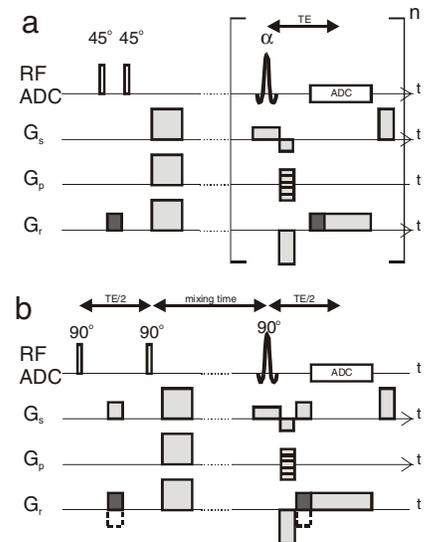


Fig. 1: Original sequence diagrams **a)** SPAMM with SGRE imaging. Dark-shaded gradient lobes are identical to the 'encoding' and 'decoding' gradient in DENSE. **b)** DENSE. A different encoding/decoding gradient strength along the read axis is used (dotted line) for phase correction. Later variants of DENSE do not have encoding/decoding gradients in the slice or phase direction but use either an additional inversion pulse or RF phase cycling for FID suppression.