SNR Enhancement in Radial SSFP Sequences using partial k-space averaging

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Synopsis:
In real-time MR imaging spatial and temporal resolution are mainly SNR- limited. The present work suggests a method to further enhance SNR by improving *k*-space signal sampling. 2D measurements are performed using a radial SSFP sequence with additional sampling on the refocusing gradients for partial and total *k*-space averaging. Tests on phantoms substantiate the relationship between *k*-space averaging and SNR improvement. In vivo tests allowed averaging of 35% of *k*-space corresponding to a SNR improvement in the order of 20% without prolonging the scan time.

Introduction:
Extending the data sampling to the refocusing gradients increases the sampling window per TR, and thus, the SNR significantly. The additional samples may be used for faster *k*-space coverage [1],[2] or - as presented below - for partial averaging of data in *k*-space yielding further noise reduction. Thus, the SNR is additionally improved according to the degree of averaging.

Materials and Methods:
Averaging the complete *k*-space increases the SNR by a factor of $\sqrt{2}$. Averaging *k*-space only partially yields a SNR approximately given by Eq. 1, with P being the original number of *k*-space samples used for reconstruction and p_{av} being the additional number of samples used for averaging. The relationship is based on the definition of the power density spectrum of Gaussian white noise. Note that it is the gridded Cartesian sample arrangement that determines the number of samples p_{av} and P.

Eqn.1:

$$SNR_{av} = \frac{\sqrt{2}}{\sqrt{2 - \frac{p_{av}}{P}}} SNR$$

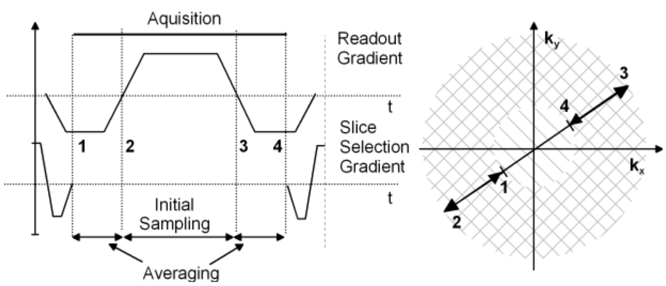


Fig. 1: Sampling gradient waveform and *k*-space trajectory for the radial SSFP

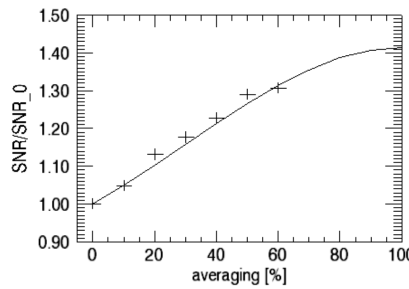


Fig. 2: SNR as function of the degree of averaging in theory (solid line) and measurement (crosses)

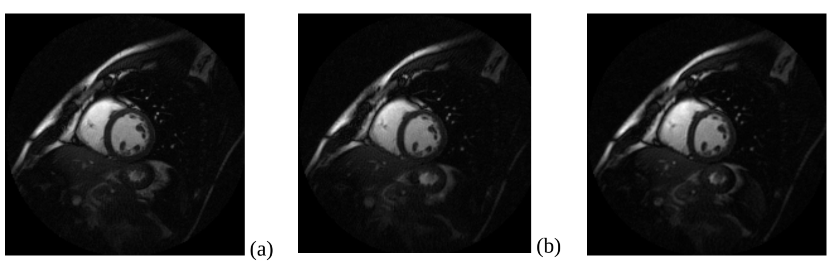
As shown in Fig. 1, the usual data sampling during period 2-3 is extended to the periods 1-2 and 3-4. The time between two slice selection gradients determines the possible duration of sampling, and hence, the degree of averaging. For use in the gridding reconstruction, the nonlinear *k*–space trajectory as well as the density compensation function was obtained by integration of the simulated gradient pattern under consideration of eddy current effects. Gradient simulation parameters were verified by measurements.

For imaging, we used a 1.5 T whole body system (Philips, Intera). The first tests were performed on phantoms to substantiate the theoretical considerations concerning the SNR. A SSFP sequence was used with a FOV of 300mm and a scan matrix of 256×256. The repetition time was set identical to the TR that corresponds to sampling on the constant gradient part only (TR = 4ms). Averaging was then limited to 60% of *k*-space. In addition, in vivo measurements of the heart were performed using a FOV = 340mm, a matrix size of 192×192, a flip angle of 60° and a TR of 3.1ms. Averaging was limited to 35% of *k*-space.

Results and Discussion:
Fig. 2 indicates the relative SNR gain for 0% - 60% of k-space averaging (crosses). The theoretical prediction, represented by the solid line is well met. The fast in-vivo measurements allowed averaging up to 35% of *k*-space corresponding to a SNR improvement of about 20%. The SNR gain may i.e. yield a higher temporal resolution. In this connection, a SNR gain of 20% allows an acceleration of the data acquisition by about 30% neglecting undersampling artifacts [3].

In view of sampling exclusively on the central plateau, the repetition time is shorter since the positive ramps are performed during the initial sampling, and respectively, the time for refocusing the spins is reduced. This time yield allows further averaging and the compensation of the initial loss in SNR due to slope sampling [4]. For reconstruction, either a direct trajectory measurement or an adequate model for eddy current effects on gradient waveforms is required.

Conclusion:
A method was presented that uses an extended sampling window per TR for partial *k*-space averaging leading to additional noise reduction. Efficiency was increased by extending sampling on the negative parts of the gradients. This could either be used for simple SNR improvement or to speed up sequence performance.



(a) (b) (c)

Fig. 3: (a) Sampling on constant gradient, (b) Sampling on slopes, 0% averaging, (c) 35 % averaging, short axis view of cardiac MR function study

References:
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