Loss of contrast-to-noise in parallel imaging compensated by choice of contrast agent use

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Introduction

Venous enhancement is a frequently occurring problem in peripheral CE-MRA for long acquisition times. Recently, parallel imaging has been introduced and this technique is increasingly being applied to speed up many MRI sequences [1-3]. Although decreasing acquisition time with parallel imaging is theoretically advantageous, reduced acquisition time is inherently associated with reduction in signal-to-noise ratio (SNR). Novel contrast agents with higher T1 relaxivity are expected to be beneficial in offsetting this drop in image quality. The objective of the present work was to investigate enhancement properties of different contrast agents under various parallel imaging conditions.

Materials and Methods

To investigate the evolution of signal and noise under parallel imaging conditions, successive scans with increasing acceleration factors were obtained in a series of 50 mL bottles with increasing concentrations [ranging from 0 (no contrast agent) to 35 mM] of Gd-DTPA (Magnevist, Schering, Berlin), Gadobutrol (Gadovist, Schering, Berlin) and MS-325 (Epix Medical, Cambridge, MA). To mimick the in vivo situation, all contrast agents were diluted in human plasma. Phantoms were imaged using a spoiled gradient echo pulse sequence with parameters: TR/TE 4.4/1.4 ms, FA 30°, FOV 470×470 mm, matrix 512×512, 100 slices with 1.5 mm slice thickness. Acquisition voxel size was 0.92×0.92×1.5 mm. Parallel imaging was done using incremental SENSE factors (R), ranging from R=1.0 (no acceleration) to R=4.0 (in increments of 0.5). All measurements were performed on a clinical 1.5 T system (Intera, Philips Medical Systems, Best, The Netherlands, R9.1.1) with a commercially available four-element quadrature phased array surface coil. To investigate signal enhancement the contrast values of the three contrast agents were plotted against the concentration. Contrast was defined by the signal intensity of a specific concentration minus the signal intensity corresponding to the concentration of 0 mM. To determine the trade-off between increasing SENSE factors and signal enhancement relative contrast-to-noise ratio (CNR) was plotted as function of both arterial contrast concentration and SENSE factor. Noise for different SENSE factors was taken to be the standard deviation of a region of interest with homogeneous signal intensity after subtracting two subsequent scans and was corrected by $\sqrt{2}$ for error propagation due to subtraction. Subtraction was used to avoid spatial noise variability due to aliasing artifacts.

Results

At increasing SENSE factors SNR decreased according to: $\log(\Delta SNR) = -\alpha \log(\Delta R)$, with $\alpha = 0.55 \pm 0.11$, which corresponds well with the theoretical value of 0.5. Because signal intensity is not dependent on the SENSE factor, this equation also applies to CNR in the steady state situation for the contrast agent concentration. Figure 1 shows the results for the three contrast agents. MS-325 had the highest T1 relaxivity, a concentration of 1 mM MS-325 results in a twice as high contrast value as 1 mM Gd-DTPA or Gadobutrol. All agents showed about the same maximum signal enhancement. In clinical practice first-pass bolus imaging is often used. Assuming CE-MRA, R=3.0, an injection rate of 2.0 mL/s, a cardiac output of 5.0 L/min and use of Gd-DTPA with molarity of 0.5 mol/L, a first pass arterial concentration of 12 mM is obtained. According to Figure 1 these parameters almost result in the maximum contrast. In this case it is not possible to improve signal intensity by simply increasing contrast concentration.

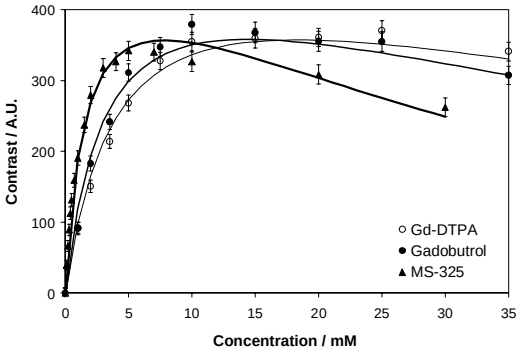

Figure 1: Contrast versus concentration

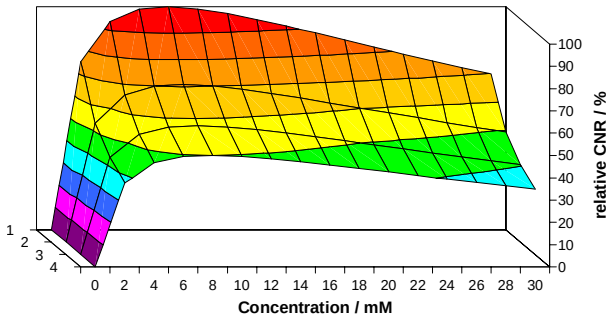

Figure 2: Relation between concentration, SENSE factor and relative CNR for MS-325

Because of the relatively high half-life of MS-325, this agent may also be useful in steady state imaging, which is done at much lower concentrations (about 2-3 mM). The trade-off between contrast concentration, SENSE factor, and CNR for MS-325 is shown in Figure 2. CNR is scaled to the maximum CNR, which is set to 100%. The results are shown for R=1.0-4.0. Different colors refer to the percentage of maximum enhancement. For instance: a concentration of 2 mM MS-325 and R=1.0 results in about 70% of the theoretical maximum CNR. Figure 2 shows that the same relative CNR could be reached by a concentration of 8 mM MS-325 and R=2.0. Thus, scan time is halved while CNR stays the same. This demonstrates that in some cases CNR can be maintained while increasing the SENSE factor.

Discussion and Conclusions

The type as well as the concentration of contrast agent can be used to compensate for CNR loss due to parallel imaging, depending on the kind of imaging and the CNR loss that has to be overcome. When optimized first-pass strategies are used it is not possible to maintain CNR at higher SENSE factors by using different contrast agents because there is hardly any difference between contrast agents in the maximum achievable signal enhancement. Moreover, T2* effects decrease signal enhancement at high contrast concentrations. This effect is more pronounced for MS-325. However, MS-325 is superior for steady state imaging because (near) maximum CNR is already reached at relatively low concentrations (2-3 mM).

References

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