SNR requirements for accurate estimation of magnitude and kinetic properties of post-contraction signal transients

E. A. Copenhaver[1], O. A. Sanchez[2], and B. M. Damon[2]
[1]Vanderbilt University, Nashville, TN, United States, [2]Vanderbilt University

Introduction

Following brief isometric contractions of skeletal muscles, transient rises in proton density and blood oxygen level-dependent (BOLD) weighted signals occur in the exercised muscles (1). Gradient echo signal intensities (SI) acquired at TE=6 ms reflect changes in blood volume, while those acquired at TE=46 ms indicate changes in blood oxygenation (2). The magnitude of post-contraction SI changes vary depending on the activity level of the study population (3) and may potentially be used to characterize microvascular responsiveness in patient populations.

The magnitude and kinetics of the post-contraction SI changes can be characterized with the difference between maximum and minimum SI (ΔSI) and the time to peak (TTP). However, the estimation of these parameters may be influenced by image noise. Therefore, the purpose of this study was to use Monte Carlo simulations to determine the minimum signal to noise ratio (SNR) for accurate estimation of post-contraction proton density and BOLD amplitude and kinetic parameters under conditions of varying ΔSI, TTP, and region of interest (ROI) size.

Methods

Model Signal Definition The simulations were performed in Matlab v 7.6.0. Typical post-contraction SI profiles from 6 ms echo (SI_6) were obtained by analyzing imaging data from an experimental subject, described previously in (3). These initial SI time courses had ΔSI_6=2.4% of pre-contraction (baseline) SI and TTP_6=20s. To simulate conditions of low ΔSI, the amplitudes of these signals were reduced to 5, 10, 20, 30, 40, and 50 percent of the initial values (*i.e.*, six ΔSI values equal to 0.12, 0.24, 0.48, 0.72, 0.96, and 1.2 % of baseline). To simulate altered kinetics, the time courses were modified such that TTP_6 = 24 or 28 s (3 TTP values).

Simulated Image Formation A simulated dynamic image dataset was formed containing 145 images of size 20x20. The SI profile of each voxel was defined for each combination of ΔSI and TTP (18 total combinations). For each of these 18 conditions, Rician noise was added to form images with SNR values of 20, 30, 40, 50, 60, 70, and 80 (126 conditions). 2000 independent realizations of noise were performed for all combinations of ΔSI, TTP, and SNR (252,000 total dynamic image series).

Data Analysis For each noise realization, the mean SI was measured in ROI's of size 50, 100, 200, 300, and 400 voxels. The ΔSI and TTP were calculated for each combination of SNR, ΔSI, and TTP; mean and SD values reported across all 2000 trials. To determine the sensitivity of each of SNR/ΔSI/TTP combination to noise, the mean ΔSI and TTP values were expressed as a percentage of the known ΔSI and TTP values.

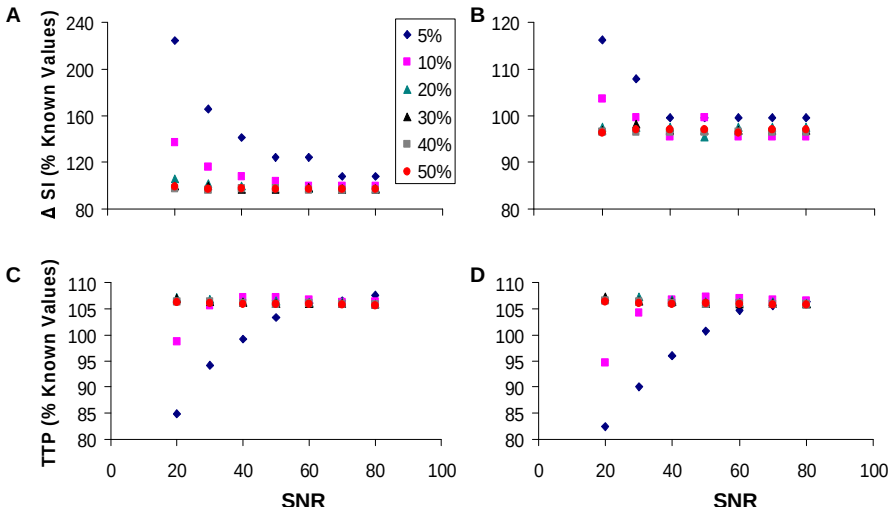

Figure 1. Effects of SNR, ROI voxel size, and % amplitude on estimated value for and and ΔSI (Panel A and B) and TTP (Panel C and D). Known TTP = 20s, TE= 6 ms, ROI size= 50 voxels (left) and 400 voxels (right). Averages for each condition are presented as percentage relative to known TTP and ΔSI . Note scale change of y-axis in Panels C and D.

Results and Discussion

ΔSI data are shown in Figures 1A and 1B. At low SNR, the mean value of ΔSI is overestimated, an effect that is greatest at low ΔSI values. Regardless of the ΔSI, an asymptote is reached at SNR=70 for 50-voxel ROI's and at SNR=50 for 400-voxel ROI's. TTP data are shown in Figures C and D. An artifact of the procedure for automating parameter estimation was that TTP was overestimated even at high SNR values; however, the general trends are that TTP is underestimated at low SNR; this effect is most pronounced at low ΔSI values. Regardless of ΔSI value, an asymptote is reached at SNR=60, irrespective of ROI size. there was no effect of TTP on the accuracy of TTP estimation (data not shown).

Conclusion

For ROI sizes greater than 50 voxels and ΔSI values greater than 0.12%, an SNR of 60 allows accurate estimation of ΔSI_6 and TTP_6.

References

1. Meyer RA, et al. *NMR Biomed* 17:392, 2004.
2. Damon, BM et al. *Magn Reson Med* 57:670, 2007.
3. Towse TF et el, *J Appl Physiol* 99:715, 2005.

Acknowledgements

NIH/NIAMS R01 AR050101
NIH/NIDDK R21 DK076880