Towards tailored refocusing in minimum time

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RF pulses are typically designed to satisfy a trade off between slice profile fidelity, maximum signal amplitude and required RF power. Another challenge is the pulse duration, specifically RF pulses for simultaneous multi-slice (SMS) imaging with a large flip angle tend to get unacceptable long. These long pulse durations limit the minimal echo time and increase the sensitivity to physiological movement and the off-resonance influence. We show that time optimal control theory and constrained optimization can be applied to significantly reduce the minimal pulse duration of 180 degree SMS refocusing pulses for realistic hard constraints. Both, the RF pulse and the gradient amplitude are optimized jointly, together with the pulse length subject to various inequality constraints given by representative 3T MR hardware restrictions. The presented time-optimal control approach was applied to the test set of 31 examples of diffusion and turbo-spin echo pulses of the 2016 ISMRM Challenge. The results were the winner of the SMS contest based on the overall duration. The optimized RF and gradient shapes are validated with phantom and in-vivo experiments.