Optimization of pulsed CEST imaging using genetic algorithm

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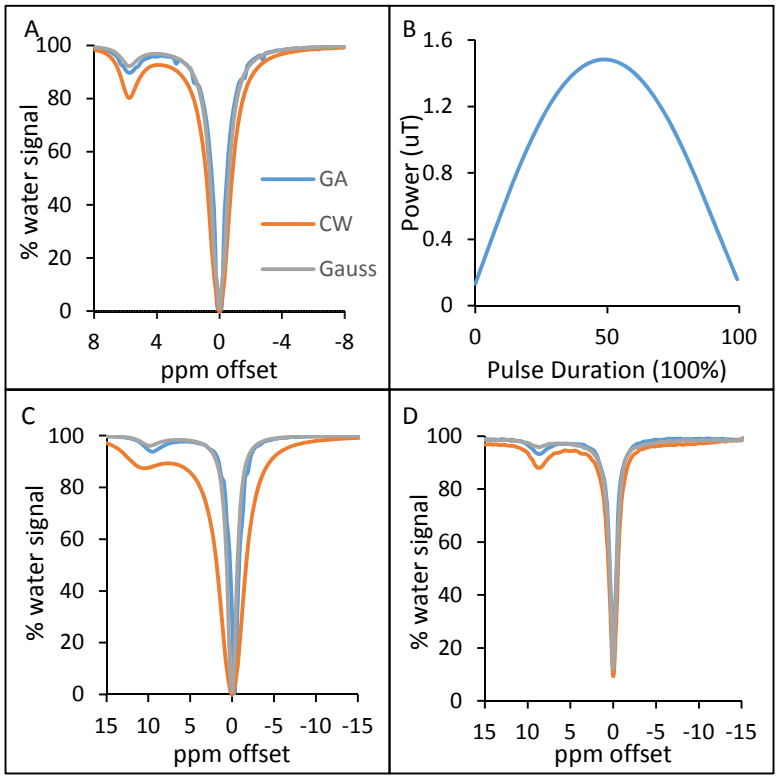
Background: Achieving strong and resolvable signal with Chemical Exchange Saturation Transfer (CEST) MRI typically requires long pre-saturation times using low power continuous wave (CW) RF pulses. However, this may not always be possible with clinical systems due to hardware duty cycle limits and SAR restrictions. To circumvent this problem, a pulsed CEST technique is used where a series of shaped pulses are played out at a lower duty cycle [1, 2]. One of the most common waveform used is the Gaussian lineshape [3, 4]. Previous reports have optimized the maximum and average power, saturation time, and interpulse delays [1, 4], however, these reports are limited to the few waveforms selected by the authors. Optimization of pulsed CEST parameters using the genetic algorithm (GA) allows the flexibility to simultaneously evaluate a range of pre-saturation parameters with arbitrary waveforms.

Methods: CEST spectra were simulated using modified Bloch-McConnell equations for a 2 pool model at three exchange rates (K_{ex} = 50, 400, 1000 s^{-1}) at an offset of 5.6 ppm and 10 ppm for the fastest exchange rate. The simulation at 10 ppm closely represents to the parameters for salicylic acid at pH 7.1. Using the optimization toolbox available in MATLAB, the GA was used to design pre-saturation waveforms and to determine the pulse parameters that would maximize the CEST effect ($CEST_{eff}$), while restricting the maximum and average pulse power, maximum duty cycle, and total saturation time. The $CEST_{eff}$ achieved by the waveform designed with the GA was compared to the $CEST_{eff}$ achieved with a 1 μT CW saturation and a train of Gaussian pulses that were also optimized using the GA at K_{ex} = 50 s^{-1}. All pulsed CEST simulations were carried out at 50% duty cycle. Finally, the pulses designed using the GA was implemented on a Siemens 3T Skyra system and data was collected on a salicylic acid phantom at pH 7.1.



Results: Simulated results show that at an exchange rate of 50 s^{-1}, both the GA designed and Gaussian waveforms achieved $CEST_{eff}$ close to that of the CW (data not shown). At K_{ex} of 400 and 1000 s^{-1}, it was possible to increase the $CEST_{eff}$ using a waveform designed by the GA compared to a train of Gaussians, and was able achieve 50% $CEST_{eff}$ of CW (Figure 1A, 1C). The simulated $CEST_{eff}$ results were as follows: at K_{ex} = 400 s^{-1}, 18.4%, 9.5%, and 7.1% for CW, GA designed waveform, and Gaussian, respectively. At K_{ex} = 1000 s^{-1}, 10.6%, 5.9%, and 3.6% was achieved. Phantom studies showed similar results to simulation, where CW achieved the highest $CEST_{eff}$, followed by the GA designed waveform and Gaussian (Figure 1D).

Figure A) simulated CEST spectrum at K_{ex} = 400 s^{-1}. **B)** Waveform designed using the GA to optimize the $CEST_{eff}$ at K_{ex} = 400 s^{-1}. The maximum peak power was limited to 1.5 μT. **C)** Simulated CEST spectrum at 10 ppm offset and K_{ex} = 1000 s^{-1}. **D)** CEST spectrum collected on a salicylic acid phantom at pH 7.1 with the pulses used to simulate C.

Discussion: We were able to demonstrate the use of GA to design and optimize pulsed CEST parameters. The GA parameter optimization can easily be adapted to optimize a multi-pool system. In general, at medium and higher exchange rates, the pulsed CEST is less effective [4]. By optimizing the waveform and pulse parameters using the GA, an increase in $CEST_{eff}$ was achieved at K_{ex} = 400 and 1000 s^{-1}, compared to the Gaussian waveform that was also optimized using the GA. However, CW still achieved the best $CEST_{eff}$ at higher exchange rates. It is important to note that the Gaussian pulses were optimized for slow exchange rates, which emphasizes the necessity of optimizing all pulsed CEST parameters at the exchange rates and offsets of interest.

References: 1. Zu, et al. MRM. 66:1100-1108. 2011. 2. Schmitt, et al. MRM. 65:1620-1629. 2011 3. Sun et al. MRM. 60:834-841. 2008. 4 Sun et al. MRM. 66:1042-1048. 2011