Quantification of DCE-MRI of Knees of Children with JRA: Using an Arterial Input Function Extracted from Popliteal Artery Enhancement

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Introduction

This work deals with quantification of DCE-MRI of knees of children with a history of JRA based on pharmacokinetic modeling. In pharmacokinetic modeling, assigning or determining the functional form of the plasma tracer concentration is a crucial step in order to get physiologically meaningful kinetic parameters. The plasma tracer concentration after a bolus of Gd-DTPA used in most literature is a bi-exponential decay obtained by fitting the data taken from control subjects by Weinmann (1). In this work we employ an average plasma tracer concentration function obtained by fitting the signal enhancement data over the popliteal artery.

Materials and Methods

T1-weigthed perfusion imaging, with a three-dimensional gradient echo (3D-GRE) sequence, during and after intravenous (i.v) bolus of Gd-DTPA was performed on children with a history of JRA (age: 8 to 15.5 , mean = 10.9 years, n = 8) with the following parameters: TR/TE=4.8/1.6, flip angle = 60^0, 128 x 128, 0.5 NEX, 0.8 phase FOV, and 12 sections per 3D slab on 1.5 T GE LX scanner using a quadrature transmit/receive extremity coil. A single dose of 0.1 mm/kg Magnevist® bolus was administered by i.v. injection. Sequential perfusion T1-weighted images were obtained every 5 sec for 40 data sets (200 sec total acquisition time).

The signal enhancement from a 3D-GRE sequence has been shown to be linearly related to the tracer concentration over a given ROI ($S(t)/S_0 - 1 \approx T_{10}r_1C$) (2). The proposed function describing the signal enhancement over the popliteal artery and the corresponding plasma tracer concentration are given by, respectively:

$$\frac{S_a(t)}{S_0} - 1 = a(t - tlag)^{\beta} e^{-\alpha(t-tlag)} + \sum_{i=1}^{2} A_i e^{-\lambda_i (t-tlag)},$$

and $$C_P(t) \approx \frac{1}{T_{10b} r_{1a}} \left(\frac{S_a(t)}{S_0} - 1\right), \qquad (1)$$

where a, α, β, A_i, and λ_i are free parameters, and tlag is arrival time of the bolus. For an open two compartmental model, with isodirectional permeability, the integral equation relating tissue concentration, C_t, to the plasma concentration, C_p,is (3):

$$C_t(t) = K^{trans} \int_0^t C_p(\tau) e^{-k_{ep}(t-\tau)} d\tau,$$

where K^{trans} = transfer constant and is related to the permeability (P), surface area (S) and tissue density (ρ) (K^{trans} = PSρ), and $k_{ep} = K^{trans}/v_e$ (where v_e is the fraction of interstitial/leakage space). Integrating this equation one can arrive at the following relation for tissue enhancement:

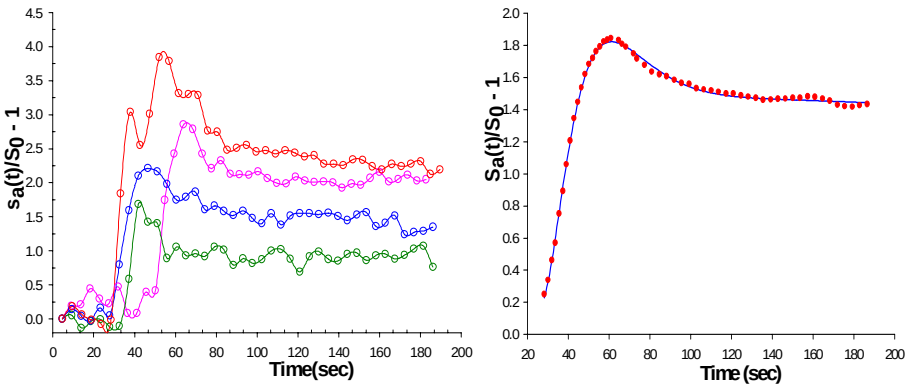

Fig.1. Left: popliteal arterial enhancement data from four children. Right: smoothed average over 8 children. The solid line on the right is the 7 parameter fit: a = 0.006 ± 0.004, β = 2.173 ± 0.255, α = 0.086 ± 0.011 s^{-1}, A_1= -1.33 ± 0.14, A_2= 1.56 ± 0.14, λ_1=0.035 ± 0.017 s^{-1}, and λ_2=0.0005 ± 0.0005 s^{-1}.

$$\frac{S_t(t)}{S_0} - 1 \approx K^{trans'} a e^{-k_{ep}(t-tlag)} (\alpha - k_{ep})^{-1-\beta} \Gamma_I(1+\beta, x)\Gamma(1+\beta) + K^{trans'} \sum_{i=1}^{2} \frac{A_i}{k_{ep} - \lambda_i} \left[e^{-\lambda_i (t-tlag)} - e^{-k_{ep}(t-tlag)} \right], \qquad (2)$$

where Γ and Γ_I are gamma and incomplete gamma functions, respectively (4), x = (t-tlag)(α-k_{ep}), $K^{trans'}$ = ($T_{10t}r_1/T_{10b}r_{1b}$) K^{trans} ($T_{10t,b}$=value of T_1 before contrast over the tissue and arterial blood, respectively, and $r_{1t,b}$ = relaxivities in tissue and arterial blood, respectively). The parameters: (a, β, α, A_i, λ_i) and ($K^{trans'}$, k_{ep}, tlag) were calculated by fitting enhancement data over the popliteal artery and tissue with equations 1 and 2, respectively. Data analysis was performed with SigmaPlot 8.0 (SPSS, Inc., Chicago, IL) and IDL (RSI, Inc., Boulder, CO).

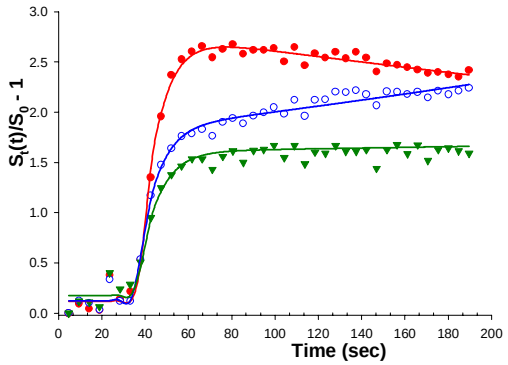

Fig. 2. Gd-DTPA enhancement data over different ROIs in a child with JRA and the corresponding fit (solid lines): ●- distal femoral physis ($K^{trans'}$= 18.24 ± 1.20 min^{-1}, k_{ep} = 6.88 ± 0.52 min^{-1}), ○ -synovium ($K^{trans'}$= 12.39 ± 1.40 min^{-1}, k_{ep} =7.17 ± 0.9) min^{-1}, and ▼- proximal tibial physis ($K^{trans'}$ = 9.58 ± 1.27 min^{-1}, k_{ep} = 6.67 ± 0.9 min^{-1}).

Results and Discussion

The plasma concentration was extracted from enhancement data over the popliteal artery and was found to be well described by a combination of gamma variate and bi-exponential functions. The model was found to fit the experimental enhancement data over different regions-of-interest (ROI) (Fig.2). Provided one could measure $T_{10b,t}$ and relaxivities, the physiologic parameter K^{trans} = PSρ could be determined.

Conclusions

Once one can show that the enhancement for a given imaging pulse sequence is linearly related to the tracer concentration it is possible to extract the plasma concentration expression from the enhancement data over the nearby artery. The kinetic parameters $K^{trans'}$ and K_{ep} over the synovium could give a useful quantitative mentoring of the disease activity and the response to therapy of JRA and RA patients.

Reference

1. Weinmann, HJ, et. al. (1984), Physiol Chem Phys Med NMR 16:167-172
2. Workie, DW, Dardzinski, BJ, et.al. (2003), ISMRM 11th annual meeting
3. Tofts, PS, Brix,G, et.al. (1999), J.Magn. Reson. Imaging 10:223-232
4. Abramowitz, M and Stegun, IA, (1972), Handbook of Mathematical Functions, Dover Publications, Inc., NY.

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