T1-Weighted Perfusion Studies using a Hollow Fiber Cartridge Perfusion Phantom: A preliminary Study to Simulate Clinical Data from the Knees of Children with JRA

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Introduction

Dynamic contrast enhanced MR imaging (DCE-MRI) has been shown to be a useful technique to investigate disease activity in organ systems, such as: brain, breast, and in musculoskeletal disorders. After a bolus administration of Gd-DTPA the MR signal intensity – time course over a region of interest (ROI) in the tissue can be mathematically modeled to assess different physiological activities of tissues, in our case the disease activity of juvenile rheumatoid arthritis (JRA) synovium. In this study a phantom that simulates capillary perfusion from DCE-MRI protocols is presented. The phantom is able to simulate signal enhancement from the synovium and physes of knees in children with JRA and can be used to investigate the permeability of capillary membranes based on pharmacokinetic modeling.

Materials and Methods

The two major components of the phantom are a pump and capillary bed. The pump was designed and built in the Imaging Research Center of Cincinnati Children's Hospital Medical Center and was presented at the 6th ISMRM meeting (1). The pump has front panel controls for setting the average flow rate, pulsatile flow, amplitude, period, and duty cycle. The pump can also produce steady flow. All components operate safely within 3 meters of our 3.0 T Bruker Biospec MRI scanner (Bruker Biospin, Ettlingen, Germany)

The capillary bed consists of a F–80 hollow fiber cartridge (HFC) (Fresenius Medical Care, Bad Homburg, Germany) used for kidney dialysis. The cartridge typically used for dialysis have a molecular weight (MW) cut-offs larger than that of the Gd-based MR contrast agent used for DCE-MRI studies (Magnevist®, Berlex Laboratories, Wayne, NJ, MW = 938) hence the contrast agent can cross the capillary walls in to the space between the capillaries (the exctracellular - extravascular space).

Water from a cylindrical container was allowed to flow through the cartridge via a tube with cross sectional area of 0.053 cm^2 (0.029 cm inner diameter) with an average flow rate of 1.85 ml/sec and pulsating rate of 100 beats/sec. During the course of water flow 3 ml (a 0.013 mM/ml) of Gd-DTPA was administered as a bolus via a butterfly connector placed at about 1m from the cartridge (illustrated in Figure 1).

A series of T1-weigthed images (60 to 65 data sets), with a 2D-GRE sequence, were acquired before, during and after simulated intravenous (i.v) bolus of Gd-DTPA with the following parameters: TR/TE=14/4 ms, flip angle = 60^0, 256 x 128, FOV = 6 mm x 18 mm, on 3.0 T Bruker Biospec Scanner using a 12 cm diameter Litz coil (Doty Scientific, Inc., Colombia, SC). Image processing was performed with Cincinnati Children's Hospital Image Processing Software/Interactive Data Language (CCHIPS/IDL) (RSI, Inc., Boulder, Co).

Results and Discussion

The signal enhancement curves from HFC phantom and typical clinical data from a child with a history of JRA are shown in Fig. 1. The clinical data were obtained from two ROIs, the synovium and physes (2, 3). Comparison of Fig. 2a with Fig. 2b demonstrates that the HFC perfusion phantom mimics perfusion in the knees of children with JRA. The HFC phantom enhancement data that looks like the clinical data from synovium was obtained by closing valve 1 and slightly opening valve 2. On the other hand the HFC phantom enhancement data that looks like the clinical data from the physes was obtained by slightly opening both valves (Fig. 1).

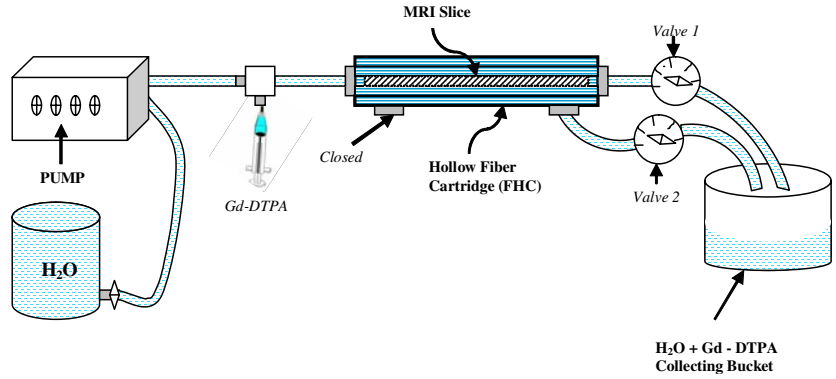

Figure 1. Components and experimental set up of HFC perfusion phantom.

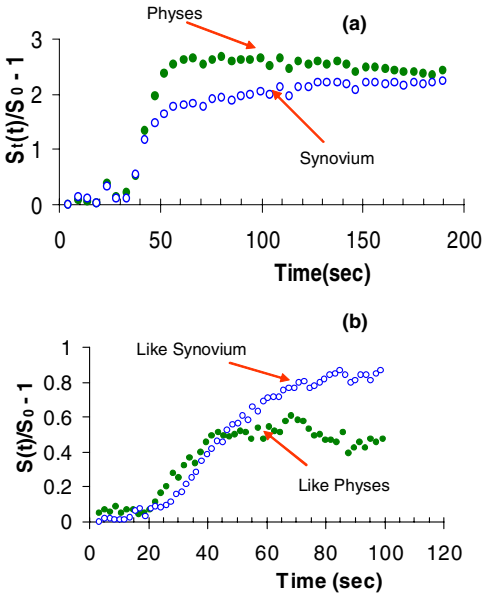

Figure 2. DCE-MRI signal enhancement: (a) from a knee of a child with JRA and (b) from the HFC perfusion phantom.

Conclusions

The growing interest inT1–weighted DCE-MRI in medicine fosters the need to quantify the enhancement data based on pharmacokinetic modeling. Quantitative investigations of the enhancement data from HFCs with different capillary membranes can help to asses the correlation of different pharmacokinetic parameters with permeability. Therefore, the HFC perfusion phantom can be used as a tool, without the need for direct human investigation, to investigate the feasibility of quantitative methods to monitor disease activity in JRA. More work is required to represent the synovium in the HFC Phantom.

References

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