Validation of Quantitative Blood Flow with 3D Gradient Echo (GRE) Dynamic Contrast-enhanced Magnetic Resonance Imaging (DCE-MRI) using Blood Pool Contrast Medium in Skeletal Muscle of Swine

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Purpose: To validate the feasibility of absolute regional perfusion quantification by dynamic contrast-enhanced magnetic resonance imaging (DCE-MRI) with shared k-space sampling and a blood pool contrast agent in low-perfusion tissue in an animal model.

Material and Methods: A total of seven female pigs were investigated. An ultrasonic Doppler probe was attached to the right femoral artery to determine the total flow in the hind leg musculature. The femoral artery was catheterized to enable continuous local administration of adenosine to increase blood flow up to four times the baseline level. Three different stable perfusion levels were induced [1]. The MR protocol included a 3D gradient-echo sequence with a temporal resolution of approximately 1.5 seconds. Before each dynamic sequence, static MR images were acquired with flip angles of 5°, 10°, 20° and 30°. Both, static and dynamic images were used to generate relaxation rate change maps with a flip angle method. 0.1 mL/kg body weight of blood pool contrast medium was injected via the central venous catheter, delivery rate: 5 mL/s. The right hind leg was segmented in 3D in: medial, cranial, lateral and pelvis thigh muscles, lower leg, bones, skin and fat. The first 80 seconds of the relaxation rate change-time curves of the voxels in these segments were used for model fitting. The temporal resolution of the curves was increased to 0.1 seconds using interpolation. The arterial input function (AIF) was measured in the aorta. The perfusion of the different anatomic regions was calculated using a one- and a two-compartment models with delay and dispersion corrected AIFs (as suggested by [2]). The F-test for model comparison was used to decide whether to use the results of the one- or two compartment-model fit (Fig. 1). The total flow was calculated by integrating the volume weighted perfusion values over the whole measured region.

Results: The resulting values of delay, dispersion, blood volume, mean transit time and flow were all in physiologically and physically reasonable ranges. In 107 of 160 ROIs the blood signal was separated using a two compartment model into a capillary and an arteriole signal contribution, proven by the F-test. The overall flow of the hind leg muscles, as measured by the ultrasound probe, highly correlated with the total flow from the MRI measurement, $r = 0.89$ and $P = 10^{-7}$ (Fig. 2B). Linear regression yielded a slope of 1.2 and a y-axis intercept of 259 mL/min. With respect to the mean total volume of the investigated muscle tissue this corresponds to a offset perfusion of 4.7 mL/(min·cm³). Exclusive use of the one-compartment model yielded a significant lower correlation, $r = 0.51$ and $P = 0.02$ (Fig. 2A).

Conclusions: The DCE-MRI technique of the present study using blood pool contrast media (as suggested in [3]) in combination with a two-compartment tracer kinetic model allows for the absolute perfusion quantification of low perfused organs like muscles.

References: [1] Sauerbrey et al. Biomed Res Int, 390506 (2014). [2] Calamante et al. MRM, 55(5):1180–1185 (2006).
[3] Sourbron et al. NMR BIOMED, 26(8):1004–1027 (2013).

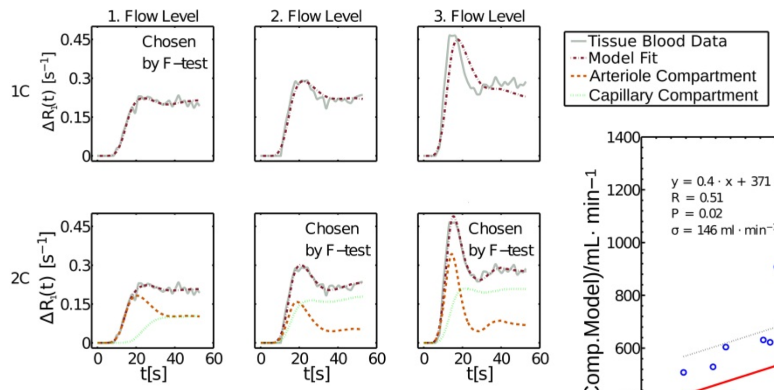

Figure 1: Fitting results for the two different models (one-compartment (1C) and two-compartment (2C)) and for different flow levels. The solid line represents the tissue blood data and the dashed-dotted line represents the fitting result. The dotted (dashed) line shows the fitting result for the capillary (arteriole) compartment.

Figure 2: Regression of the DCE-MRI model results with the Doppler flow values for the one-compartment model (A) and for the F-test selection method (B).