In vivo MR measurement of arterial pulse pressure in the murine aorta

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Introduction: Mouse models are increasingly used to investigate functional and cardiovascular parameters. Measurements of blood flow patterns, vessel wall strain and pulse wave velocity have been used for the evaluation of the arterial function and cardiovascular risk [1]. However noninvasive methods for measuring hemodynamic parameters such as blood pressure are not yet available. In this work we present an approach to noninvasively estimate the arterial pulse pressure by measuring the time dependant blood flow pulse and the local pulse wave velocity.

Methods: ***Theory:*** By solving the Navier-Stokes equations for incompressible fluids it can be shown, that the frequency dependant complex impedance can be calculated for each pair of harmonics of the blood volume flow pulse and the pressure pulse [2,3]: $Z(\omega) = \frac{P(z,t,\omega)}{Q(z,t,\omega)} = \frac{\rho c_0 \sqrt{1 + N(\omega) F_{10}(\omega)}}{R_0^2 \pi}$ **(1)**

with the vessel wall radius R_0 and the blood density ρ.

$$N(\omega) = \frac{(c/c_0)^2 (1-\sigma^2) - (1-2\sigma)}{F_{10}(\omega) - 2\sigma} \quad \textbf{(2)} \qquad \text{and} \qquad F_{10}(\omega) = \frac{2J_1(i^{3/2}\alpha)}{i^{3/2}\alpha J_0(i^{3/2}\alpha)} \quad \textbf{(3)}$$

with the Bessel functions J_1 and J_0 , the Womersley parameter $\alpha = R_0\sqrt{\omega\rho/\mu}$ and the blood viscosity μ. The ratio c/c_0 of the complex wave velocity to the simple wave speed in inviscid flow can be calculated by the so-called frequency equation [2,3]. To determine the complex impedance and thus to calculate the harmonics of the pressure pulse, the flow pulse, c_0, the Poisson ratio σ, μ, ρ, the vessel wall radius R_0 and the vessel wall thickness h has to be known. All parameters except the Poisson ratio σ and the constants μ, ρ can be estimated from the MR-measurements. Calculations could show, that the results are not very sensitive to variations of the Poisson ratio, therefore estimates form the literature were taken for σ (0.45) as well as for the constants μ (4.5 mPas) and ρ (1.055 g/cm^3).

MR-measurements: To measure the time course of the blood flow velocity Q and the cross sectional area A, a high resolution PC-Cine-FLASH sequence was performed perpendicular to the arterial vessel with through plane flow encoding. The local pulse wave velocity c_0 was estimated using the QA-method. For the in vivo experiments mice between 25g and 30g were anesthetized with 1.5 vol.% isoflurane. ECG triggering and respiratory gating was applied for all MR measurements. By using an interleaved acquisition scheme a temporal resolution of 1ms could be achieved. MR experiments were performed on a Bruker Avance 750 spectrometer. Imaging parameters were: TE 2.1 ms, FOV 25×25 mm^2, slice-thickness 1.0 mm, resolution 98×98 μm^2 total measurement time: approx. 10 min.

Results: The arterial pulse pressure was examined in four C57Bl/6 mice at the abdominal aorta. Figure 1 and 2 show representative results of the PWV measurements using the QA-method [1]. Figure 3 shows the measured flow pulse and the calculated pressure pulse. Mean arterial pulse pressure was measured to be (29.4 ± 8.7) mmHg. Due to the complex impedance a significant phase shift between both pulse shapes is visible. The peak flow precedes the peak pressure. By measuring at two adjacent locations and subtracting the results the pulse waves could be divided into a forward traveling wave and a backward traveling wave thus taking primary wave reflections into account.

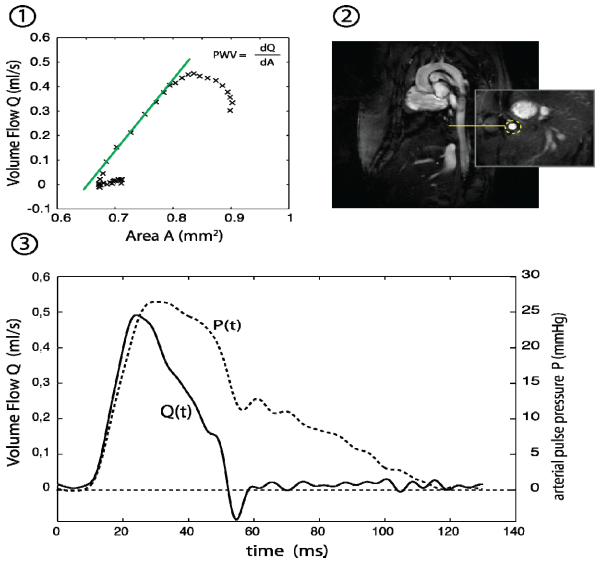

Fig.1,2: **QA method**: PWV-calculation as the slope of the flow-area relation during early systole.
Fig. 3 : **Pressure pulse (P(t))** calculated from the flow pulse (Q(t)) by using the complex impedance.

Conclusion:

In this study, we have demonstrated the feasibility of high field MR microscopy to quantify noninvasively the arterial pressure pulse in the murine abdominal aorta. The present results are in good agreement with results from the literature obtained by invasive methods looking at the systematic arterial pressure (SAP) and the diastolic arterial pressure (DAP) [4].

References:
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