Blood Flow Dynamics in DeBakey Type III Aortic Dissections using Phase Contrast MRI and 4D MRA: Quantification of Inter-Luminal Pressure Differences and Contrast Arrival Times

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Introduction: Aortic dissections (AD) result from blood entering the media creating a true (TL) and a false aortic lumen (FL) [1]. Even after treatment, only one in five patients with DeBakey type III AD survives 3 years [2]. Clearly, a better understanding of TL/FL pressure distributions and flows is fundamental in determining how aortic rupture and organ perfusion evolve, and subsequently, in developing predictive models for treatment outcome. Towards this goal, in a first step, phase contrast magnetic resonance imaging (pcMRI) was used to estimate TL/FL inter-luminal pressure distributions using Bernoulli and Poiseuille equations. In a second step, contrast arrival times in kidney, liver and spleen were quantified after first demonstrating good correlation of pcMRI flow measurements with TL/FL dynamic enhancement from contrast-enhanced 4D magnetic resonance angiography (4D MRA).

Materials and Methods: From 42 patients with type III AD who underwent a dynamic MRI exam [3] at the Acute Aortic Treatment center of the Methodist DeBakey Heart & Vascular center, 10 had both pcMRI and 4D MRA exams (during bolus intravenous Gd-based contrast injection, Time-resolved angiography With Interleaved Stochastic Trajectories,
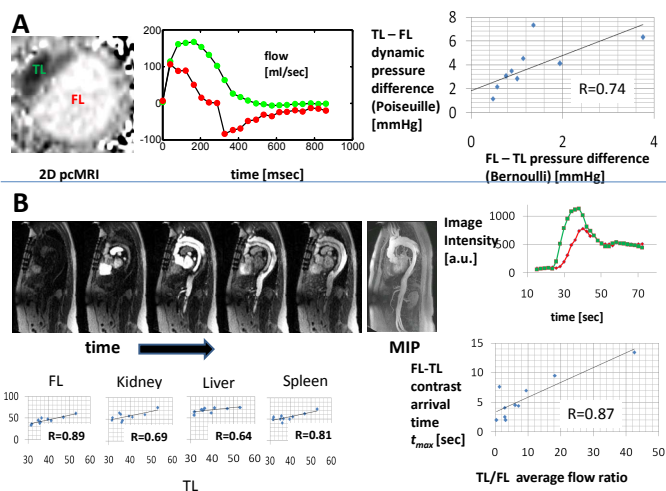

Figure 1: A: *Left:* Transversal pcMRI image and flow curves. *Right:* Correlation between TL and FL pressure differences (Bernoulli) and dynamic pressures (Poiseuille). **B:** *Top left:* 4D MRA demonstrating TL and FL contrast wash-in and maximal intensity projection (MIP). *Top right:* TL and FL wash-in curves. *Bottom left:* Correlation of TL t_{max} with t_{max} for FL, kidney, liver and spleen (values in sec). *Bottom right:* Correlation between FL-TL contrast arrival times and TL/FL average flow ratio.

TWIST, 1.5 mm isotropic voxel resolution, mean temporal resolution 2.4 sec, Siemens Avanto 1.5 T and Verio 3T). TL/FL blood velocities ($v_{t,f}$) and flow rates ($f_{t,f}$) were measured with pcMRI (TR 34 - 42 sec, 5 mm slice thickness, 1.4 mm inplane resolution, 150 VENC). FL/TL inter-luminal pressure differences ($\Delta p = p_f - p_t$) were calculated via the Bernoulli equation: $\frac{1}{2}\rho(v_t^2 - v_f^2) = pdyn_t - pdyn_f = \Delta p = p_f - p_t$, where ρ is the blood density (1050 kg/m^3), $pdyn$ is the dynamic pressure and p is the static pressure. The subscripts $_t$ and $_f$ refer to TL and FL, respectively. Values for the dynamic pressures were also estimated under the assumption of laminar flow by using Poiseuille's equation, with TL and FL flows and cross sections obtained from pcMRI image data. To quantify tissue fluid dynamics, we first demonstrated a good correlation of contrast arrival time (t_{max}) differences in FL and TL (from 4D MRA) with TL/FL volumetric flow ratios (from pcMRI). Then, t_{max} for liver, kidney and spleen tissue were quantified and correlated with t_{max} for TL.

Results: A strong correlation between TL and FL pressure differences calculated with the Bernoulli and the Poiseuille equations was observed (R=0.74, figure 1a). Mean FL-TL static pressure difference derived with the Bernoulli equation was 1.1 mmHg (range: -0.1 to 3.7 mmHg). Mean TL and FL flows were 59.1 (range: 23-107) ml/sec and 11.8 (-8-60) ml/sec, respectively. Mean TL velocity was 16.5 (7-31) cm/sec; mean FL velocity was 2.5 (-1-9) cm/sec. TL/FL mean flow ratios correlated well with FL-TL differences in t_{max}. (R=0.87, figure 1b). TL t_{max} correlated well with t_{max} of FL and of investigated tissues: FL: R=0.89, Kidney: R=0.69, Liver: R=0.64, spleen: R=0.81 (figure 1b). Mean t_{max} values were : TL: 39±7 sec, FL: 44±8 sec, kidneys: 57±10 sec, liver: 68±6 sec, spleen: 54±9 sec.

Conclusion: Values for TL/FL dynamic pressure differences derived from the Bernoulli equation agree with same values calculated with the Poiseuille equation, thus providing a viable approximation for the TL/FL inter-luminal static pressure differences. Dynamic TL/FL enhancement correlated well with TL/FL flow measurements encouraging its use for flow quantification in tissue.

References

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