Validation of Intravascular Pressure Gradients Derived from Four-Dimensional Flow-Sensitive Magnetic Resonance: In Vitro Intraluminal Catheter Comparison Using an Elastic Phantom

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Target Audience: Physicists, cardiologists, radiologists and technologists interested in MR flow quantification and haemodynamic imaging

Purpose

In vitro comparison of the non-invasive measurements of relative pressure gradients using 4D (time-resolved) MR imaging with an intravascular pressure catheter in a bespoke elastic vascular phantom [1-3]. In literature, comparison of 4D pressure difference mapping in the human aorta with ultrasound derived volumetric flow showed moderate underestimation while the use of a phantom on the other hand has given the investigators a better correlation [2, 3]. Using the Navier-Stokes equation, relative pressure gradients can be derived from 4D MRI flow assessment of velocity vectors fields relative to a specific reference point within the phantom. The liquid-filled catheter is a hydraulic system with equally distributed rheological forces [4]. Being a 2nd-order biosensor with a sinusoidal dynamic response, the catheter-sensor is the most accurate gold standard and accepted method in pressure diagnostics [4].

Methods

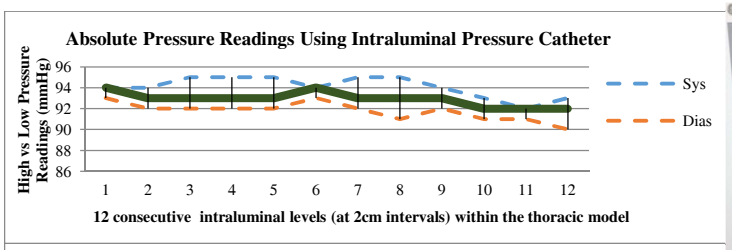
A whole-body bespoke (aneurysmal) elastic (silicon) vascular phantom is used in this experiment, consisting of a head, cardiac and abdominal models (Elastrat, Geneva, Switzerland). Once assembled, steady flow of a slippery blood-analogue is circulating for 15-30min (to ensure bubble-free circuit) into the phantom using a non-pulsatile pump. A percutaneous introducer (40F) is attached to the external iliac artery of the connected abdominal model and used for the insertion of an 8F/150cm intraluminal pressure catheter (Medi-tech, Boston Scientific, MA) through a standard 5F sheath and sliding over a 6F Terumo glidewire (Terumo Medical Corp., NJ). The distal end of the catheter is connected to a liquid-filled pressurized system attached (zero-calibrated) to an intra-arterial sensor (dome) of an MRI compatible intensive care unit (ITU) monitor. Multiple pressure (absolute) samplings with zero-level calibration prior to each reading can be taken. Maximum, minimum and average pressures (eq. to systolic, diastolic, mean arterial pressure MAP in pulsatile system) are recorded by the intra-arterial pressure monitoring setting of the ITU monitor. The whole phantom setup is then placed in the scanner to obtain several acquisitions of the non-invasive 4D flow MRI sequence (license agreement with M. Alley [5], Stanford University, CA, installed on 3 Tesla, GE Discovery 750, 32Ch Torso Coil, ET=1.46, RT=3.81, spatial resolution=1.79, FA 15 degrees, voxel size 1.56x1.56x2mm, matrix 256x256x16, scanning time 10min). Switching off the cardiac monitor with emulation of regular ECG pulse (80bpm) has triggered 4D flow scanning. Acquired data is rendered and phase-offset (errors) corrected then post-processed using GT Flow v2.14 software (GyroTools, Zürich, Switzerland) [6].

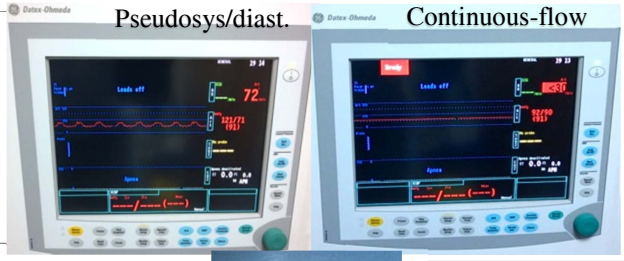
Results & Discussion

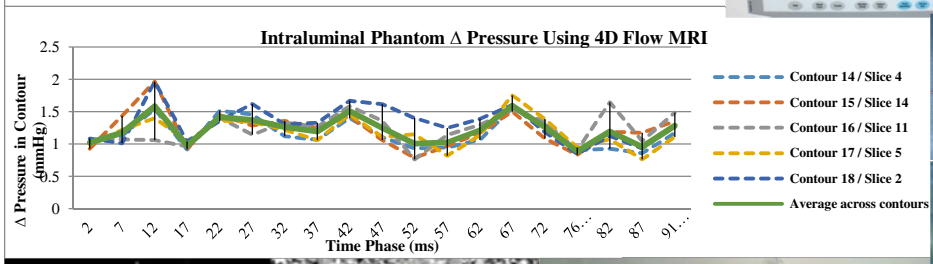
Outside the scanner, a dynamic 2nd order system response of the catheter-phantom setup is first demonstrated by manually eliciting a pseudo-pulsatile (pseudo-systolic & diastolic) rhythm (cardiac model massage) causing an observed sinusoidal pressure gradient. In a steady (continuous-flow) condition, 24 intravascular pressure catheter readings (12 points, 2cm interval, 2x repeats) are collected within the cardiac model. The intraluminal pressure range is recorded (max. 91- min. 94, ΔP= 2-3mmHg). Post-processing of the 4D flow MRI data of the imaged cardiac model shows a derived relative pressure gradient range from 1.4 – 2.9 mmHg (average 1.7 mmHg, SD 0.09), assessed by 2 observers at 5 different contours each within a separate slice.

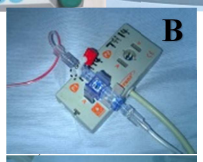
Conclusions

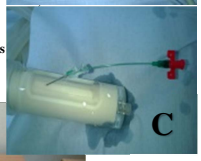
Experiment demonstrates the concordant potential in 4D flow MRI to derive non-invasively intravascular pressure gradients in continuous flow dynamics. A pulsatile version of the experiment is planned to be synchronized during a 4D flow MR imaging session.



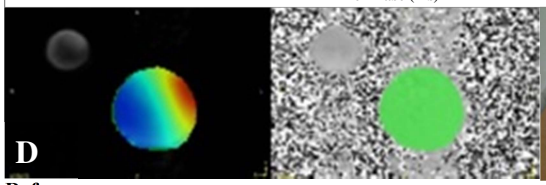


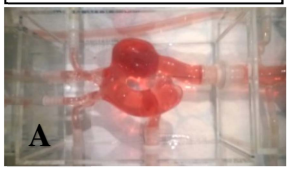






A) Cardiac vascular model
B) Pressure-sensor (dome)
C) Introducer & sheath/wire
D) 4D PC MRI & coloured generated pressure maps
E) Assembled whole phantom





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