Non-invasive Estimation of Pressure Gradients in Pulsatile Flow using Ultrasound

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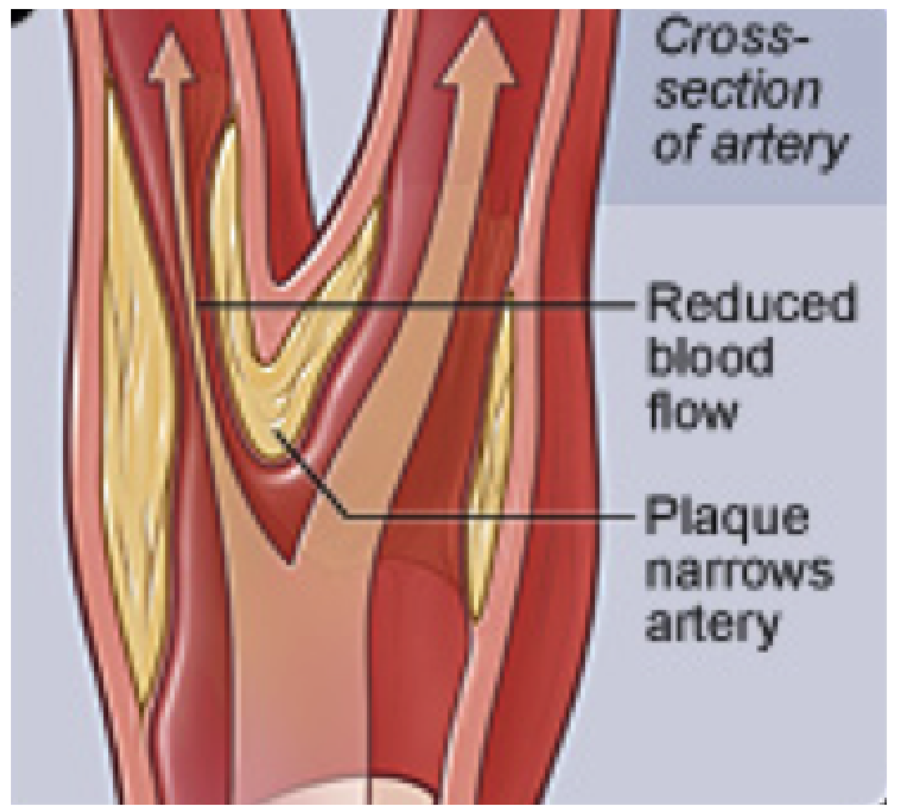
Background



Carotid artery suffering from atherosclerosis.

Objective:
Show that pressure gradients can be measured non-invasively.

Background:
Pressure gradients in hemodynamics provides important information for diagnosing various cardiovascular diseases. The gradients are used to study how flow changes, caused by for instance plaque formation, affect the risk of embolism.

Current measures:
Today's measure of pressure gradients is an invasive procedure done by catheters under the guidance of X-ray.

Long-term aim:
The idea of estimating pressure gradients non-invasively, is to replace catheterization thereby minimizing the risks that are associated with invasive procedure.

Governing Equation and Method

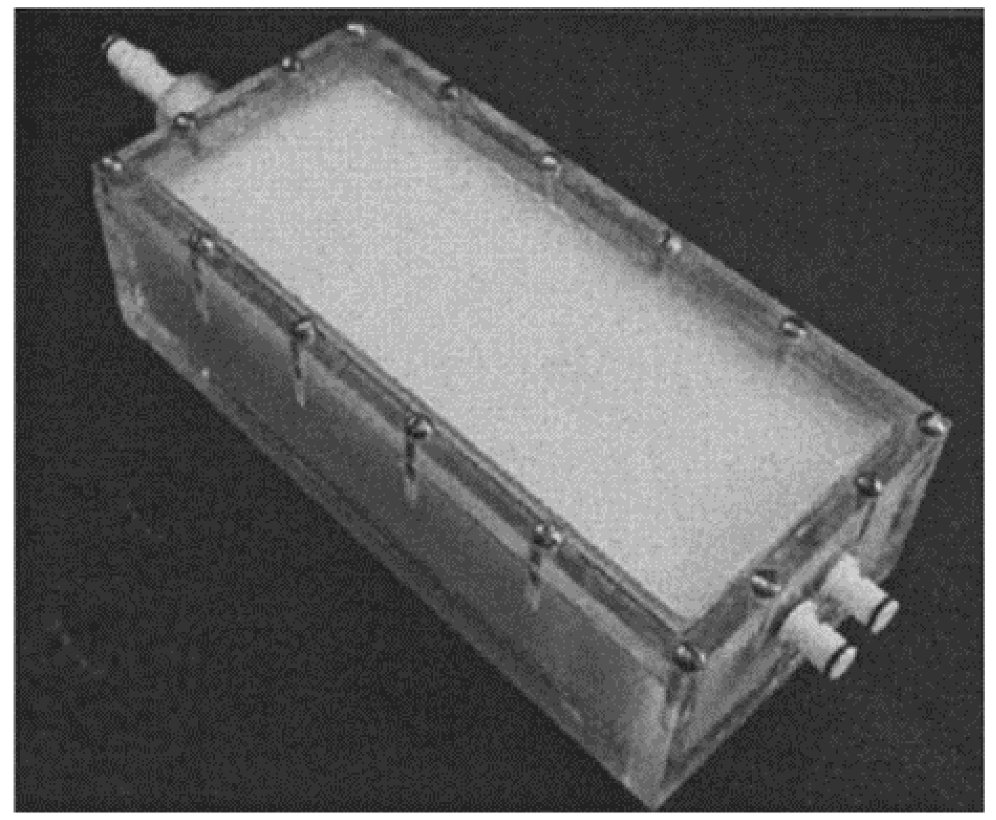
The Navier-Stokes equation for an incompressible fluid

$$\rho\left[\frac{\partial \mathbf{v}}{\partial t}+\mathbf{v}\cdot\nabla\mathbf{v}\right] = -\nabla p + \rho\mathbf{g} + \mu\nabla^2\mathbf{v}. \qquad (1)$$

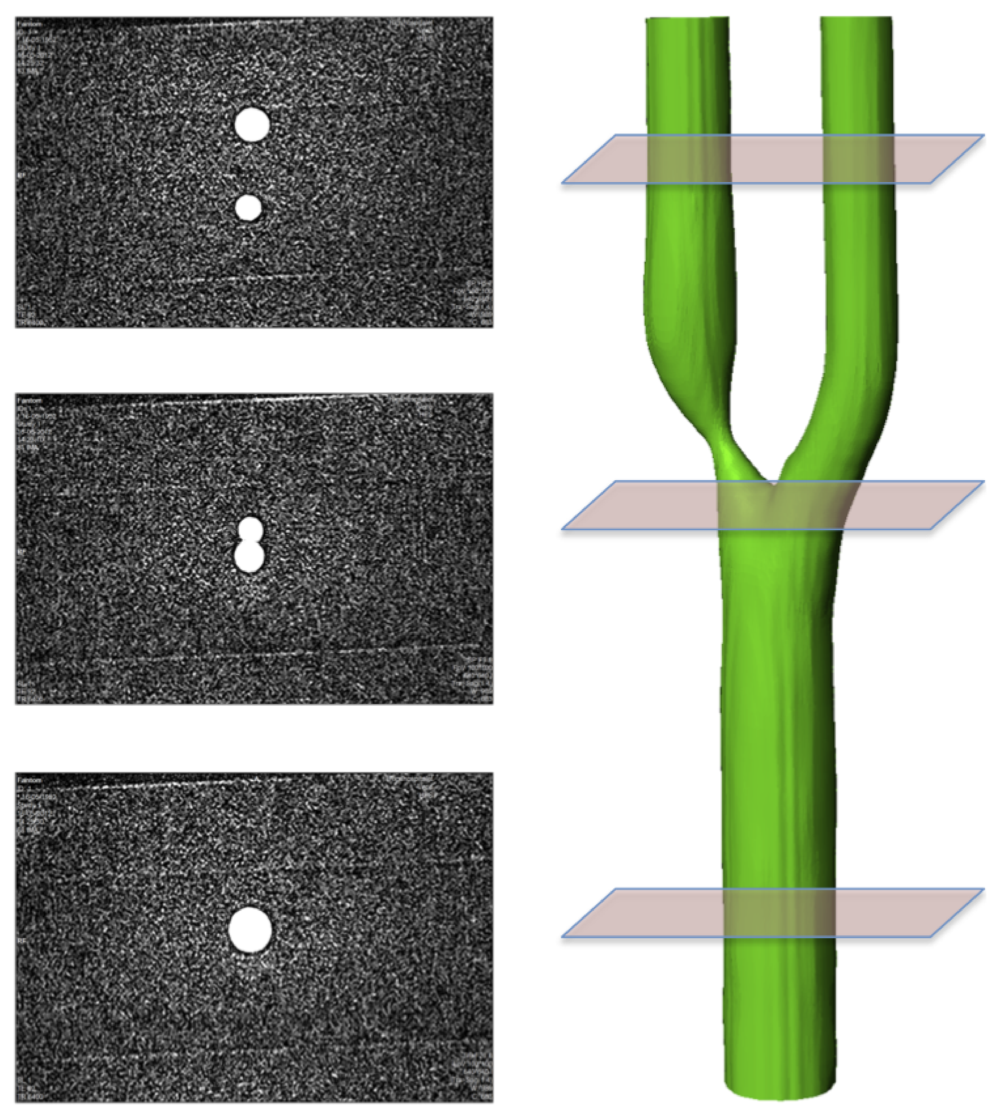
ρ: Density. $\frac{\partial \mathbf{v}}{\partial t}$: Temporal acceleration. $\mathbf{v}\cdot\nabla\mathbf{v}$: Spatial acceleration. ∇p: Pressure gradient. $\mathbf{g}$: Gravity. $\mu\nabla^2\mathbf{v}$: Viscous force. The gravitational forces are negligible as the patient is placed in a supine position, thus;

$$\nabla p = -\rho\left[\frac{\partial \mathbf{v}}{\partial t}+\mathbf{v}\cdot\nabla\mathbf{v}\right] + \mu\nabla^2\mathbf{v}. \qquad (2)$$

Equipment used in the experimental setup



Flow phantom mimicking a carotid artery with 70 % atherosclerosis



Magnetic resonance imaging was used for scanning the flow phantom. Image slides were collected and the fluid domain was extracted using segmentation software.

An MRI scanner and an ultrasound scanner were used in the set-up

Visual comparison between the simulated model and the estimated results

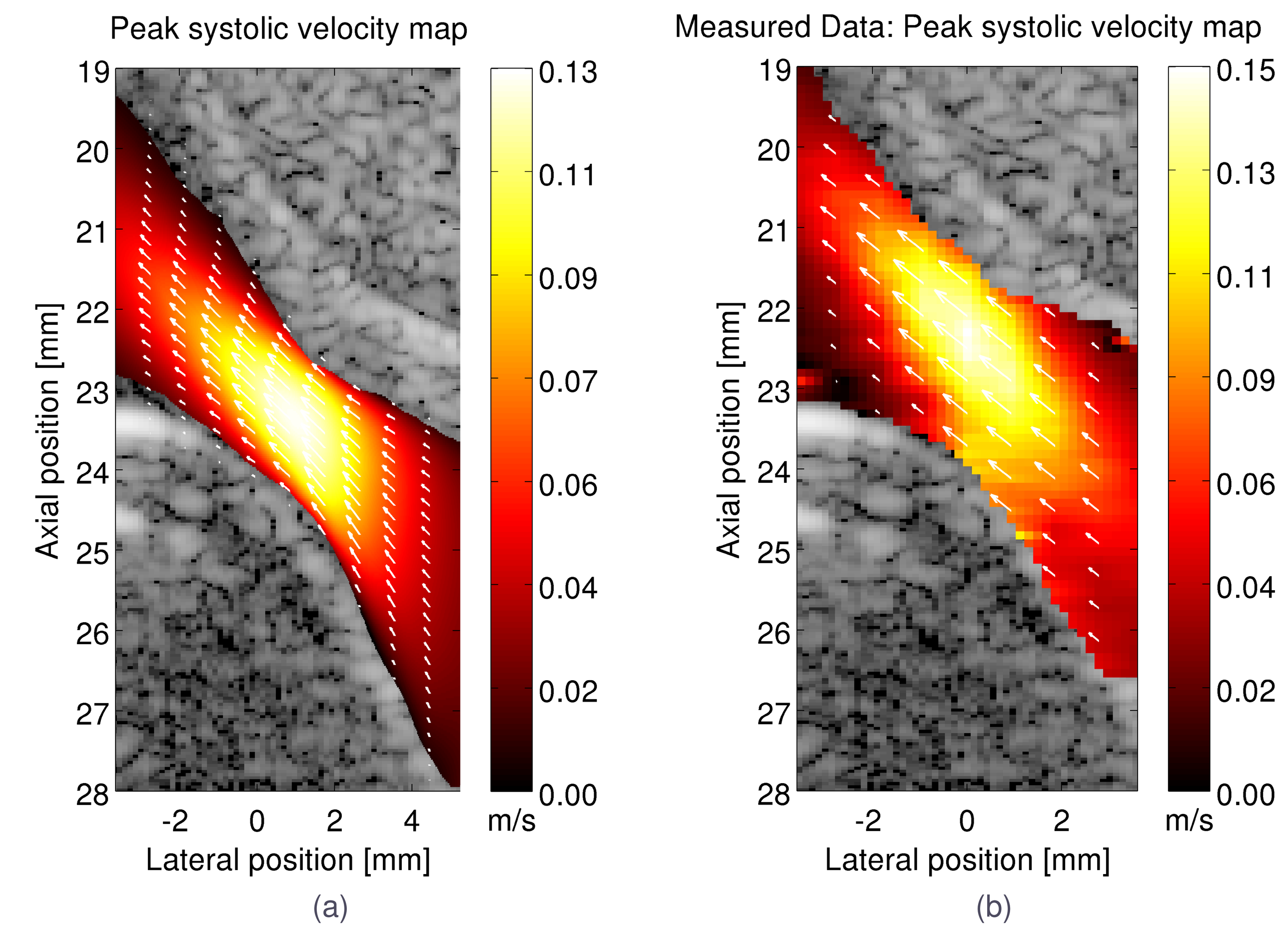


Fig. A shows the simulated velocity field through the center of the constricted vessel, while Fig. B presents the estimated field obtained from ultrasound flow data.

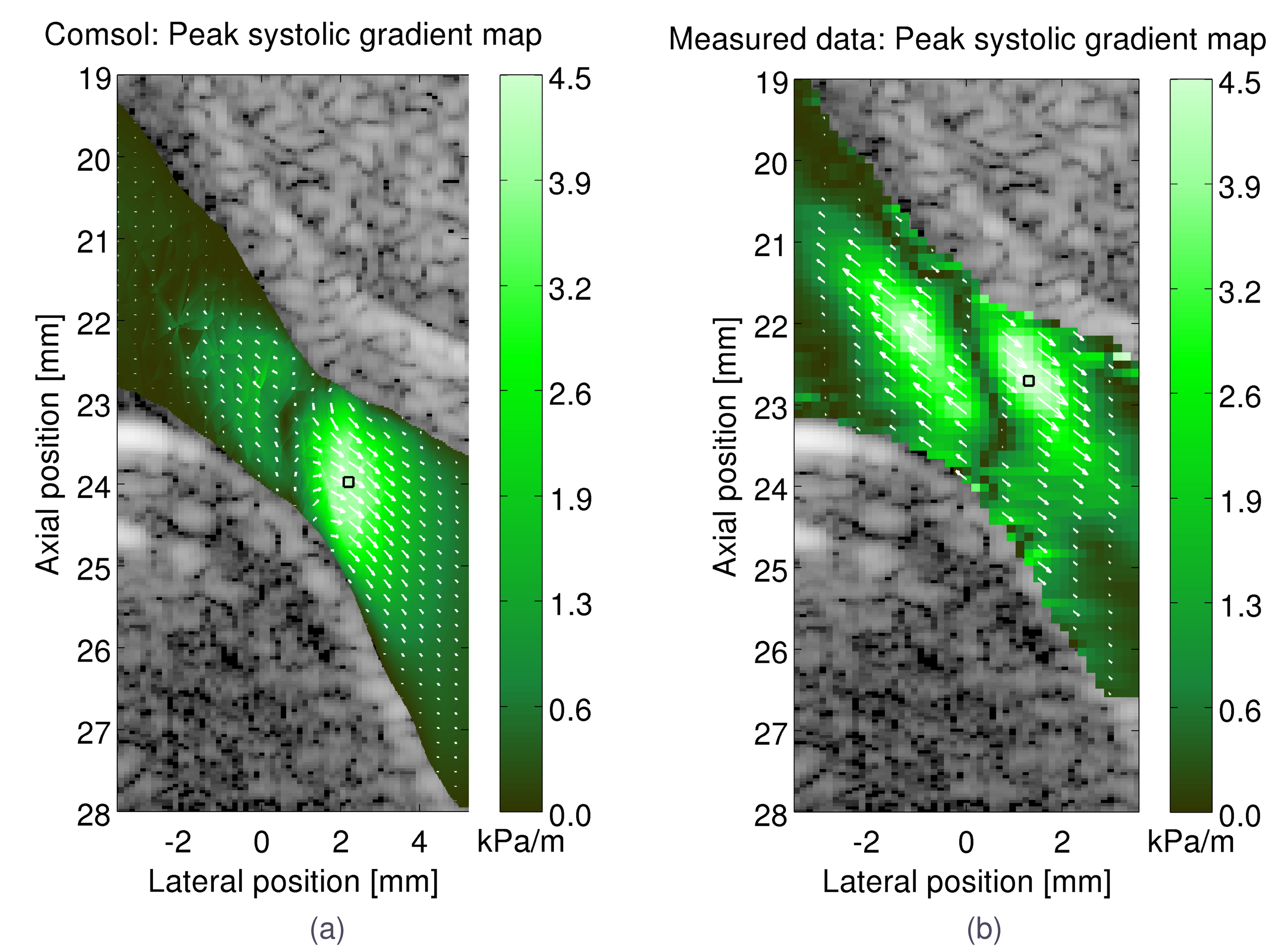
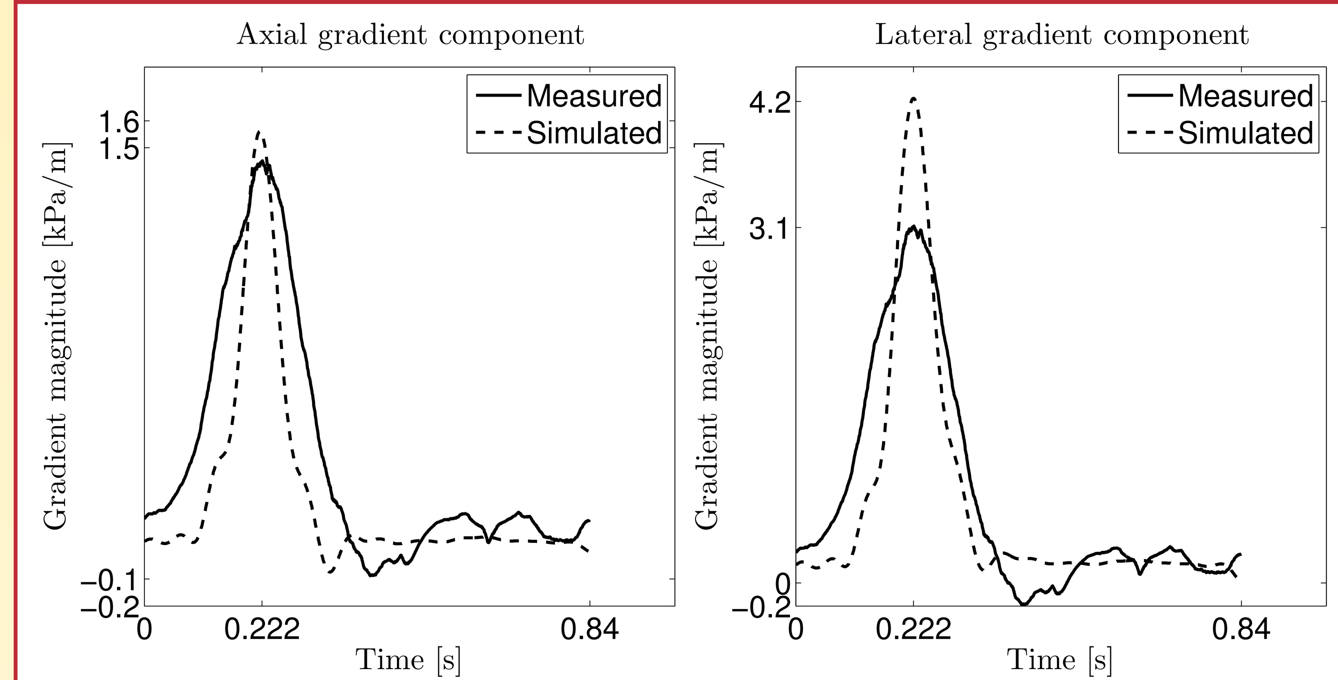


Fig. A shows the simulated pressure gradient field through the center of the constricted vessel and Fig. B presents the estimated pressure field. The estimated pressure field is estimated from the velocities shown in the top Fig. B. using (2).

Standard deviation and bias of estimator

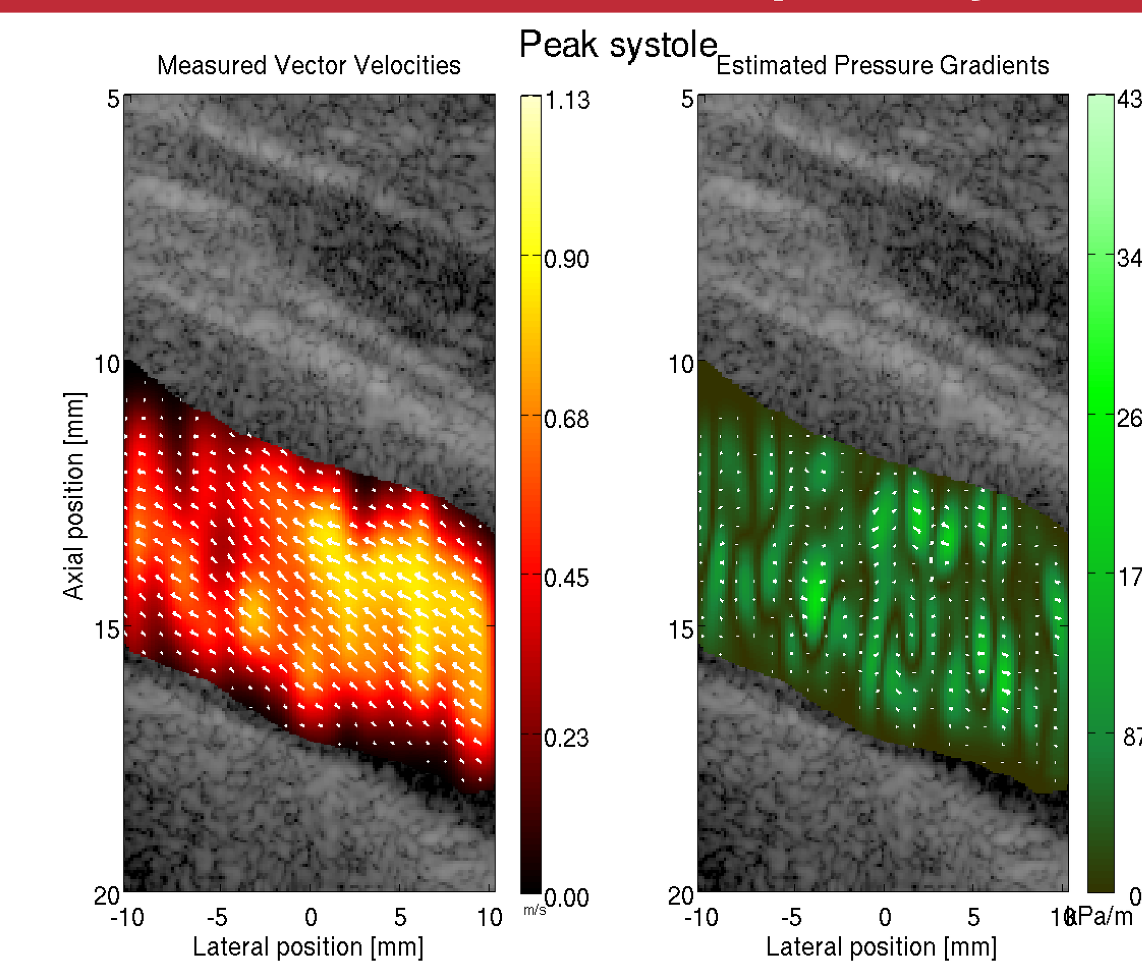
The standard deviation and bias of the estimator is calculated to 13 % and 10 % relative to the peak estimated gradient, respectively.

Single point comparison over the pulse



The graphs show the magnitude of the axial and lateral gradient component. The plotted data is taken from the peak pressure value in the upstreams region, also marked by the dark square seen on the pressure plots.

In-vivo measurement at peak systole



Vector velocity flow and pressure gradients measured on a common carotid artery at peak systole.

Conclusion

Pressure gradients can be derived non-invasively using vector velocity ultrasound data.