Research at Center for Fast Ultrasound Imaging (CFU)
Part 1: Vector Flow Imaging
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Front-line research in Ultrasound

- Part 1:
  - How can we measure the true blood velocity in the clinic?
  - Can we measure pressure non-invasively

- Part 2:
  - Can measure 3-D flow fast?
  - Can we break the speed-accuracy trade-off?
  - Can we see brain function and epileptic attack?
  - Can we resolve structures below the resolution limit?

Part 1 now, Part 2 after the break

Modern color flow mapping

Conventional velocity estimation system

- Low frame rate (approx. 20 Hz)
- Angle dependent velocity estimation

- Velocity changes direction in the image
- Determination is dependent on angle between beam and flow:
  \[ V_r = |v| \cos(\text{angle}) \]
- At 45 degrees: 71% of velocity
- At 60 degrees: 50% of velocity
- At 80 degrees: 17% (!) of velocity
- At 90 degrees 0%
Sensitivity to Angle

At 70° a 5° angle error gives a velocity error of more than +/-20%.

Complicated flow in bifurcation

- What is the magnitude of the flow?
- What directions does it have?
- Is it normal?
- Not possible to use one correction factor
- Angle between beam and flow changes as a function of place and time
- Full velocity vector is needed

Normal velocity measurement:
Sound field oscillates in ultrasound direction

New vector velocity:
Sound field also oscillates across beam
Simple generation

Source
Source

Ultrasound propagation direction

Oscillation across

Transverse distance

Generation for a transducer

Generation for a transducer

\[ \lambda_x = \frac{2z\lambda_z}{D} \]

- \( z \) – depth
- \( D \) – distance between peaks
- \( \lambda_z \) – axial wavelength
- \( \lambda_x \) – Lateral oscillation period

RASMUS

- Remotely Accessible
- Software programmable
- Multi-channel
- Ultrasound System

- Can be used for synthetic aperture, real-time, in-vivo data acquisition

- Made solely for research purposes
In-vivo vector velocity for carotid artery and jugular vein

Velocity in carotid bifurcation

Complicated flow in bifurcation

Commercial implementation: BK Medical ProFocus scanner
FDA approved January, 2012
Scanning of the carotid artery

Vein-artery connection for kidney hemodialysis patient

Anatomy of vein-artery graft

Systolic flow for aortic valve stenosis Before and after valve replacement
**Vector Concentration**

The vector concentration in the carotid artery during a heart cycle.

![Image](image1)


**Diagnostic value of pressure gradients**

![Image](image2)

**Hansen et al. Ultrasonic Imaging, Vol. 35, No. 4, 2013**
Estimating pressure gradients from Navier-Stokes equation

\[
\rho \frac{\partial v}{\partial t} + v \cdot \nabla v = -\nabla p + \rho g + \mu \nabla^2 v
\]

\[
m \cdot a = F
\]

The TO method can estimate both spatial and temporal acceleration

In-vivo scanning of carotid artery

Non-invasive mapping of pressure in-vivo...
Pressure Gradient Estimation

Median pressure drop over 13 cardiac cycles

- Systolic: ∆P = 129 Pa (75%)
- Diastolic: ∆P = 55 Pa (25%)
- Median: ∆P = 67 Pa (10%)
- Standard Dev. ∆P = 24.6 Pa (14%)

Vector Flow Imaging

- Vector velocity can be measured fast and in all directions
  - Velocity magnitude correctly identified
  - No angle correction – correct magnitude and direction for all times and places
  - Disturbed and turbulent flow can be correctly visualized in 3-D
  - Pressure gradients can be estimated