

Continuous Non-Invasive Blood-Pressure Measurements

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MMSG Southampton, September 2007

Overview: Finapres and Tonometer

Finapres

- Finger cuff exerts pressure around finger
- Sensor measures light transmission through finger
- Pressure varied to keep light intensity constant
- Light intensity selected to achieve maximum amplitude of pressure variations

Colin Tonometer

- Systolic and diastolic pressures measured using cuff on upper arm.
- Pressure transducers held firmly against radial artery in wrist.
- Signal from transducers calibrated with known pressures at systole and diastole to give continuous pressure reading.

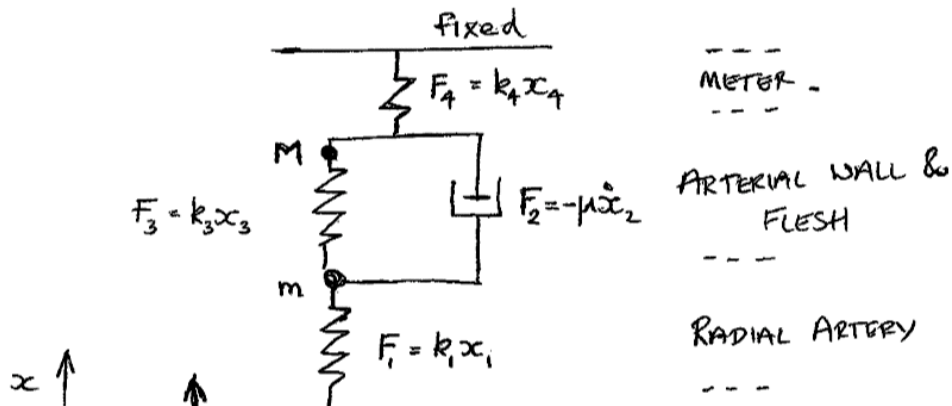
The Problem

- Under normal resting conditions, the two devices appear to give similar readings for the blood pressure.
- But in two different experiments, both devices are used to record blood pressure and consistently give different readings.
- How accurately is each device measuring the blood pressure?
- Either the pressure really is different between the wrist and the finger, or something is affecting at least one of the two devices.

Possible Explanations

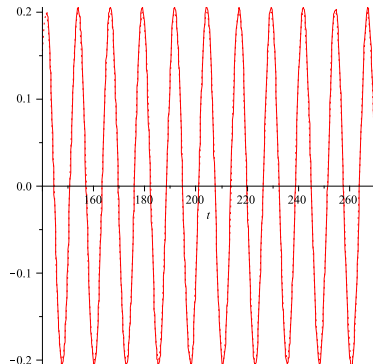
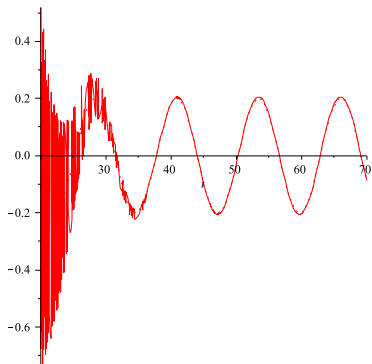
- Not much distance between wrist and finger tip, and arteries there are quite large. Hence there is normally little pressure difference between the two locations.
- Believe that some sort of physiological change occurs as a result of the stress conditions to affect at least one of the readings.
- Tonometer is close to a direct pressure measurement . . .
- . . . so think about the Finapres on the finger.
- Could vasoconstriction of finger arteries cause the differences?
 - Either by directly causing a pressure difference
 - Or by altering the Finapres reading

Tonometer Models I: Spring Model



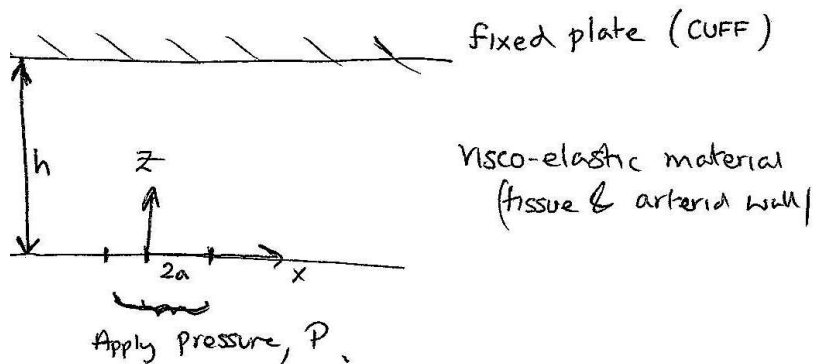
Prescribed oscillatory forcing of bottom spring

Tonometer Models I: Spring Model



Initial transients die away to leave steady oscillations

Tonometer Models II: Elastic Solid Model



$$\sigma_{ij} = \left(\lambda e_{kk} \delta_{ij} + 2\mu e_{ij} \right) + \left(-\frac{2}{3} \mu^* \frac{\partial e_{kk}}{\partial t} \delta_{ij} + 2\mu^* \frac{\partial e_{ij}}{\partial t} \right)$$

$$e_{ij} = \frac{1}{2} \left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \right)$$

$$\rho \frac{\partial^2 \mathbf{u}}{\partial t^2} = \nabla \cdot \boldsymbol{\sigma}$$

Finapres Model: Derivation

Assume Poiseuille flow in a circular tube.

$$\text{FINAPRESS CUFF, } P_{\text{ext}} = \sigma(t)$$

$$P = 1 - E_{\text{cost}}$$

$$P = P_L$$

$x=0$ ————— ARTERY ————— $x=L$

$$\text{FINAPRESS CUFF, } P_{\text{ext}} = \sigma(t)$$

$$\frac{\partial A}{\partial t} + \frac{\partial}{\partial x} (\bar{u}A) = 0$$

Conservation of mass

$$\bar{u} = -\frac{A}{8\pi\mu} \frac{\partial p}{\partial x}$$

Viscous pressure drop

$$A = A_0 + k(p - \sigma)$$

Tube law

$$\frac{\partial q}{\partial t} = \mathcal{R} \frac{\partial}{\partial x} \left((\mathcal{K} q + 1)^2 \frac{\partial q}{\partial x} \right)$$

$$\int_0^1 q \, dx = \mathcal{V} \quad (\text{constant light intensity})$$

with

$$\mathcal{K} = \frac{kP_0}{A_0} \quad \mathcal{R} = \frac{A_0^2}{8\pi\mu kL^2\omega} \quad \mathcal{V} = \frac{1}{P_0k} \left(\frac{V}{L} - A_0 \right)$$

and $q(x, t) := p(x, t) - \sigma(t)$ is the transmural pressure.

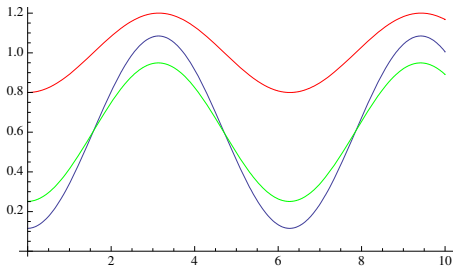
The boundary conditions are:

$$q = 1 - \epsilon \cos t - \sigma(t) \quad \text{at } x = 0,$$

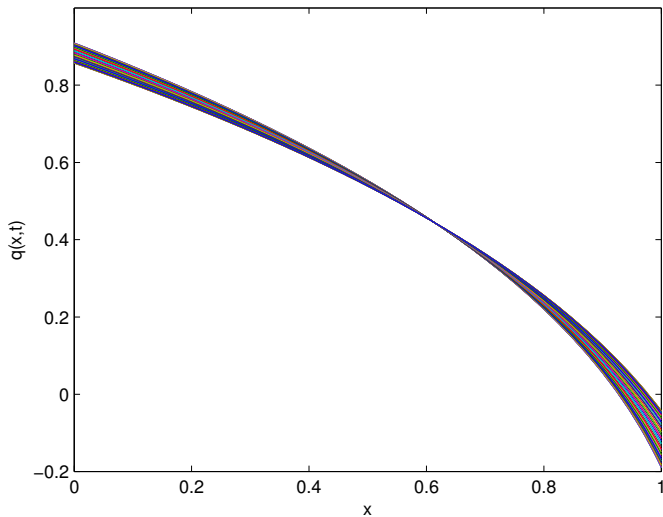
$$q = p_L - \sigma(t) \quad \text{at } x = 1.$$

Finapress Model: Analytical Solution

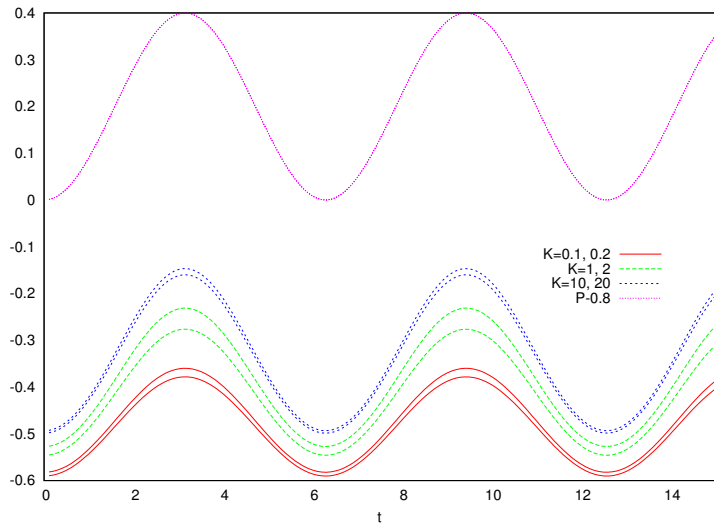
- Complicated system, so look at some limits analytically.
- Solution for case of small amplitude oscillations about steady state. (Involves Bessel functions like $\xi^{1/6} J_{3/4}(C(1+i)\xi^{2/3})$ and difficult to apply boundary conditions!)
- Special case of above with $\mathcal{K} = 0$ results in linear diffusion equation.



Finapress Model: Numerical Solution of Full Model



Finapress Model: Numerical Solution of Full Model



Tonometer Spring Model

- Transducer spring signal matches arterial pressure variations after initial transients die away.
- Measurements are not sensitive to change in arterial stiffness (stiffness of a spring) because the stiffness of the arterial wall \ll the stiffness of the meter.

Finapres Artery Model

- Limit cases ($\kappa = 0$ and $|q| \ll 1$) approached analytically.
- Numerical solutions found.

Finapres

- Incorporate vein model, capillaries, and matching / jump conditions.
- Use experimental data to estimate parameters
- Investigate influence of vessel and cuff parameters on the error with current numerical model

Colin Tonometer

- Solve the visco-elastic model
- Derive a model analogous to the 'Finapres model'

Experimental Data

- Examine more closely.
- Can key features can be explained by models?