A computational based analysis of flow mediated dilation: Towards improved endothelial function assessment

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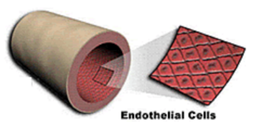
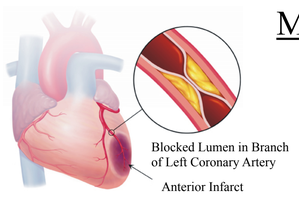
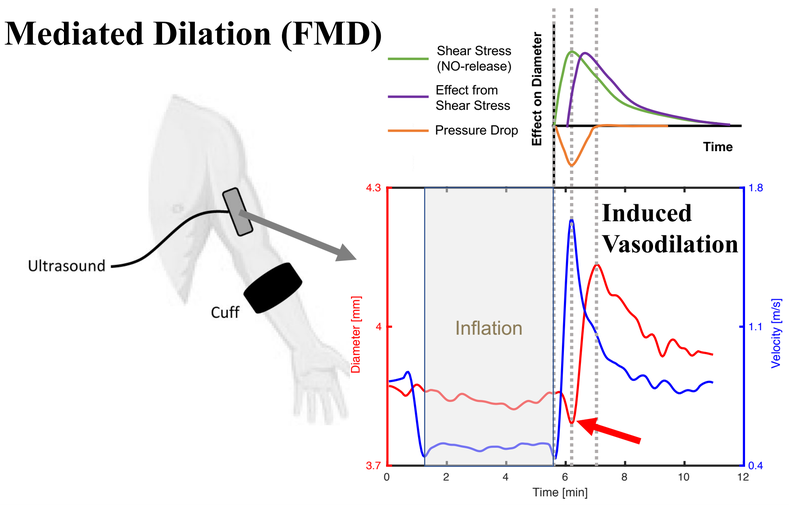
1. Motivation & Objective



Endothelial dysfunction



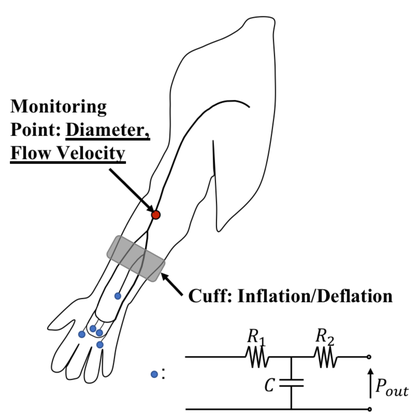
Measurement for Endothelial Function: **Flow Mediated Dilation (FMD)**



- **Current FMD**: assumes vasodilation entirely induced by the increase in wall shear stress (WSS).
- **Issue**: there is evidence of vasodilation being affected by other confounding factors, such as arterial wall stiffness and blood pressure[1].
- **Aim** to investigate the effects of arterial wall stiffness on the results of FMD using computational blood flow modelling.

2. Study Design

Hemodynamic Solver for blood flow (Q), blood pressure (P), and cross-section area (A):



$$\begin{cases} \dfrac{\partial A}{\partial t} + \dfrac{\partial Q}{\partial x} = 0 & \text{Conservation of mass} \\ \dfrac{\partial Q}{\partial t} + \dfrac{\partial}{\partial x}\left(\alpha \dfrac{Q^2}{A}\right) + \dfrac{A}{\rho}\dfrac{\partial P}{\partial x} = \dfrac{f}{\rho} & \text{Conservation of momentum} \end{cases}$$

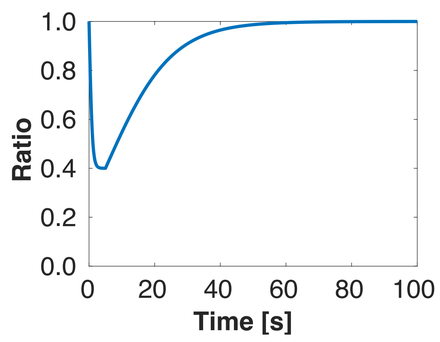
Tube Law:

$$P = P_0 + \frac{\beta(x)}{A_0(x)}\left(\sqrt{A} - \sqrt{A_0(x)}\right) + \frac{\Gamma(x)}{A_0(x)\sqrt{A}}\frac{\partial A}{\partial t}$$

$$\beta(x) = \frac{3}{4}\sqrt{\pi}E(x)h(x)$$

FMD Model:

i) Prescribed change of peripheral resistance (Trigger of FMD):



ii) The relationship between WSS (τ) & Young's modulus (E)[2] (Endothelial function) :

$$E(t) = E_{base}(1 + \delta E)$$

$$\frac{d\delta E(t)}{dt} = \frac{1}{C_d}\left(\alpha_\tau \tau_{cum}(t) - \delta E(t)\right)$$

$$\frac{d\tau_{cum}(t)}{dt} = \delta\tau - \frac{\ln(2)\,\tau_{cum}}{HL}$$

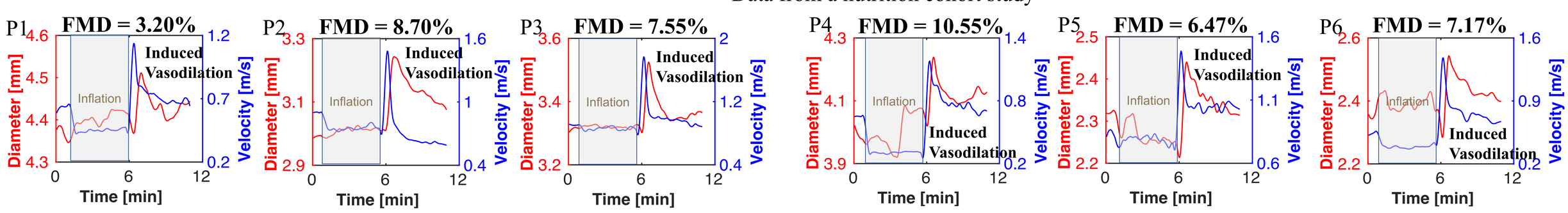
$$\delta\tau(t) = \tau_{base} - \tau(t)$$

$$\tau(t) = \mu\frac{U}{R}(\xi + 2) \qquad \xi = \frac{2-\alpha}{\alpha - 1}$$

3. In-vivo Data

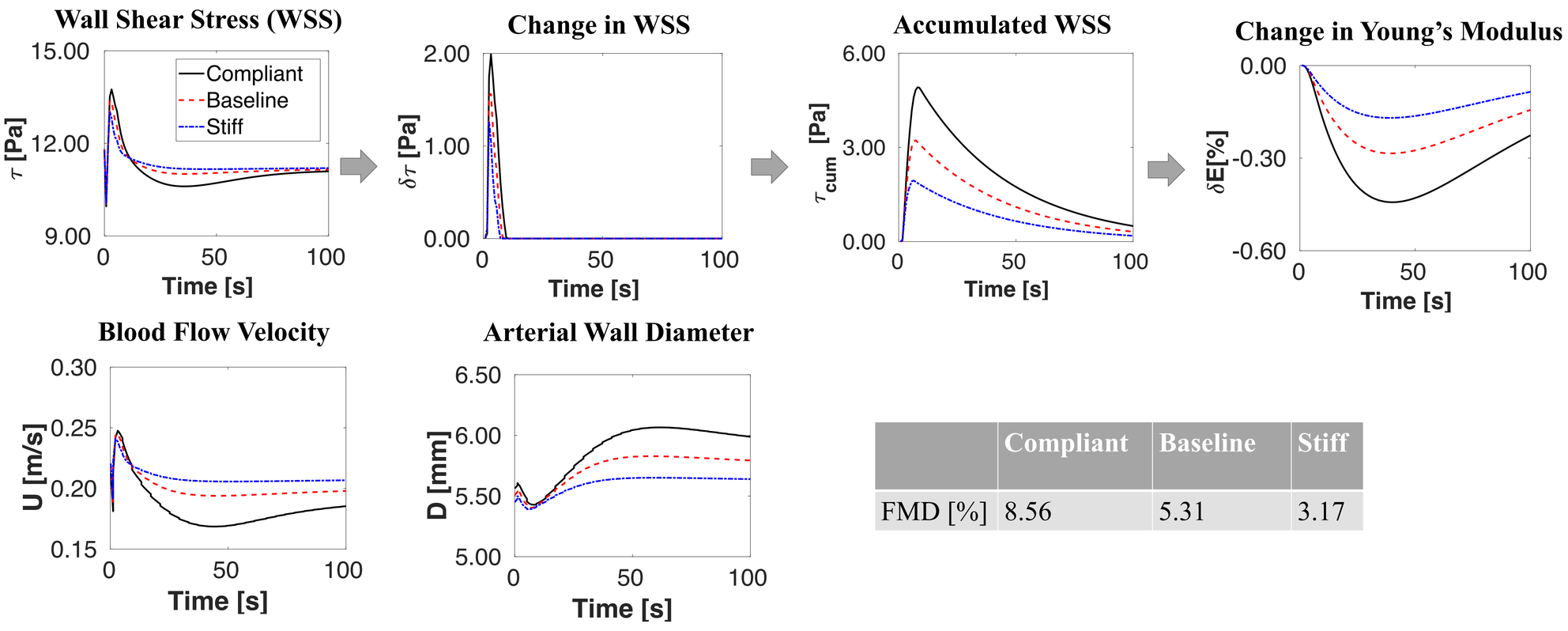
In-vivo data to test the simulated velocity (U) and diameter (D):

Data from a nutrition cohort study[1]



4. In-silico Simulation

Simulated evolution of key physical variables in FMD (displayed as mean over each cardiac cycle in the brachial artery). Results shown at **baseline** and with **stiffer** or more **compliant arteries**:



	Compliant	Baseline	Stiff
FMD [%]	8.56	5.31	3.17

5. Discussion & Conclusion

- We have developed a novel numerical model to simulate the process of FMD.
- In-silico FMD results agree well with in-vivo data: the simulation can capture the surge increase in velocity right after cuff deflation, the diameter drop right after cuff deflation is followed by a diameter increase.
- For the same prescribed endothelial function (relating WSS to Young's modulus variation) and decreased peripheral resistance, FMD increases with decreasing arterial stiffness.

6. Future Plan

- Investigate other confounding factors that may affect the results of FMD using our novel numerical model developed in this study.
- Apply the numerical model to investigate endothelial-dysfunction related diseases (*e.g.* coronary artery disease).
- Obtain a new FMD index that is not affected by confounding factors.

References

1. Jiang, Benyu, *et al.*, *Hypertension* 57 (6) (2011): 1145-1150.
2. Van Brackle , *et al.*, *Journal of Applied Physiology* 122 (5) (2016): 1292-1303.

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