Arterial stenosis stemming from vibration-altered Wall Shear Stress: A way to prevent vibration-induced vascular risk?

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Talk outline

General framework / Goal

Strategy: multiscale approach

Acute effects

Chronic effects
Hand-Arm Vibration general issues and goal

Hand-Arm Vibration in France

- Workers exposed: **2.2 M**
  - 8% > 20 h/week

- 200 occupational diseases/year
  - 8.5M€/year

- >¾ using rotating hand-held machines
  - $f > 50$ Hz

Regular exposure, high level => vascular, sensory-neuronal, musculoskeletal disorders

A need to protect the workers: ISO 5349 standard +

Pathophysiological effects of vibration $> 50$ Hz underestimated

Improving the vibration exposure assessment

Better protect workers against Vibration White Finger
A two-scale approach

From working conditions to pathological effects

Working conditions
- Mechanical effects
  - Acute
- Physiological effects
  - Acute
- Pathological effects
  - White fingers

A two-step process

Model A
- Biomechanics
  - Vibration
- Physiology
  - Vibration-altered WSS

Model B
- Pathology
  - Arterial stenosis
- Physiology
  - Vibration-altered WSS

Noël et al., Vibration, 5(2), 2022
Wall Shear Stress assessment

**Settings**
- 8 frequencies: 31 - 400 Hz @ 40 m/s² rms unweighted
- 6 amplitudes: 1 - 40 m/s² @125 Hz
- 24 (20 ♂, 4 ♀) healthy subjects
- Exposure at 23°C (±0.5°C):
  - Without
    - 10 s
    - 2 min
  - With
    - 10 s
    - 2 min
  - Back
    - 10 s
    - 2 min

**Method**
- Segmentation image processing
- Womersley pulsatile fluid flow model

**Hardware**
- Ultrasound probe
- Ultrasound system
- Finger support
- Arm support
- Ultrasound system
- Handle
- Shaker
- Chipping hammer

Noël and Settembre, *Journal of Biomechanics*, Volume 131, 2022
Wall Shear Stress: effect of frequency

For each frequency => WSS drops
WSS drop is frequency independent

Rest  Vibration
2.9 Pa   1.2 Pa

n.s. No Significance
*  p < 0.05
** p < 0.01
*** p < 0.001
>*** p < 0.0001
Wall Shear Stress: effect of vibration level

- **WSS drop** depends on vibration acceleration
- **Normalized_WSS** = \(-\beta_1 \log_2(AccelerationRMS) + \beta_2(Age) - \beta_3(HandMass) + \beta_0, \beta_i > 0\)
Haemodynamic oscillations in fingers arteries

Noël and Settembre, Computer in Biology and Medicine, under review
Mechanobiological modelling of arterial stenosis
Modelling the intimal hyperplasia mechanisms

- **Intimal hyperplasia**: abnormal proliferation/migration of smooth muscles cells

Coupling ABM-FEM: Agent-Based Model - Finite Element Method

- WSS promotes the secretion of growth factors by endothelial cells

Reda et al., Biomechanics and Modeling in Mechanobiology, 21, 1457–1481, 2022
Modelling arterial stenosis: exposure

- Vibration exposure: 4 hours per day - 40 m/s² rms non weighted for 10 years

- Non exposed: WSS = 3 Pa
- Vibration: WSS = 1 Pa

- ABM
- FEM

WSS = 1 Pa

10 years
Modelling arterial stenosis: results

30% of stenosis after 10 years of exposure to vibration 4 h per day
Conclusion

All models are wrong, but some are useful.

George E. P. Box
Perspective: predictability chart for arterial stenosis i.e. pathology

Degree of stenosis (%) computed according to the years of the working life and the daily exposure time to a vibration @ 40 m/s² rms unweighted.

- **No risk**
- **Risk**
- **Forbidden**

Variables:
- **Years of work [year]**
- **Daily exposure to vibration [hour]**
- **Stenosis [%]**

\[\text{Degree of stenosis} = \text{years of working life} \times \text{daily exposure time to vibration @ 40 m/s}^2 \text{ rms unweighted}\]
Our job: making yours safer

Thanks for your attention