

$$\frac{\partial u}{\partial t} = m_u - \frac{1}{\rho_o} \nabla_u p_r$$

with

$$m_u = +(\zeta + f)v - \frac{1}{e_1} \frac{\partial B}{\partial y_1} - \frac{1}{e_3} w \frac{\partial u}{\partial y_3} + D_u^v$$

$$\zeta = \frac{1}{e_1 e_2} \left[ \frac{\partial}{\partial y_1} (e_2 v) - \frac{\partial}{\partial y_2} (e_1 u) \right]$$

$$\frac{\partial v}{\partial t} = m_v - \frac{1}{\rho_o} \nabla_v p_r$$

$$m_v = -(\zeta + f)u - \frac{1}{e_2} \frac{\partial B}{\partial y_2} - \frac{1}{e_3} w \frac{\partial v}{\partial y_3} + D_v^u$$

$$B = \frac{p}{\rho_o} + \frac{1}{2} (u^2 + v^2)$$

$$\frac{1}{e_3} \frac{\partial p}{\partial y_3} = -\rho g$$

$$M_u = \frac{1}{H} \int_{-H}^0 m_u e_3 dy_3$$

$$\frac{1}{e_3} \frac{\partial w}{\partial y_3} = -\frac{1}{b} \left[ \frac{\partial}{\partial y_1} (e_2 e_3 u) + \frac{\partial}{\partial y_2} (e_1 e_3 v) \right]$$

$$M_v = \frac{1}{H} \int_{-H}^0 m_v e_3 dy_3$$

barotropic stream function formulation:

$$\nabla_u p_r = \rho_o \left[ M_u + \frac{1}{H e_2} \frac{\partial}{\partial y_2} \left( \frac{\partial \psi}{\partial t} \right) \right]$$

surface pressure formulation:

$$\nabla_u p_r = \frac{1}{e_1} \frac{\partial}{\partial y_1} (p_r)$$

$$\nabla_v p_r = \rho_o \left[ M_v - \frac{1}{H e_1} \frac{\partial}{\partial y_1} \left( \frac{\partial \psi}{\partial t} \right) \right]$$

$$\nabla_v p_r = \frac{1}{e_2} \frac{\partial}{\partial y_2} (p_r)$$

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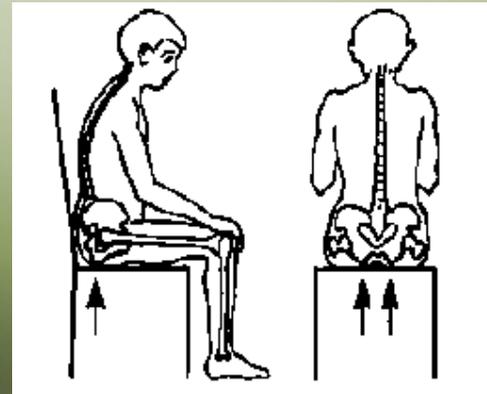
$$\frac{\partial}{\partial y_1} \left[ \frac{e_2}{H e_1} \frac{\partial}{\partial y_1} \left( \frac{\partial \psi}{\partial t} \right) \right] + \frac{\partial}{\partial y_2} \left[ \frac{e_1}{H e_2} \frac{\partial}{\partial y_2} \left( \frac{\partial \psi}{\partial t} \right) \right] = \frac{\partial}{\partial y_1} (e_2 M_v) - \frac{\partial}{\partial y_2} (e_1 M_u)$$

$$\frac{\partial}{\partial y_1} \left[ \frac{H e_2}{e_1} \frac{\partial p_r}{\partial y_1} \right] + \frac{\partial}{\partial y_2} \left[ \frac{H e_1}{e_2} \frac{\partial p_r}{\partial y_2} \right] = \frac{\partial}{\partial y_1} ($$

# *Newton's Third Law*

*For every action there is a equal and opposite reaction.*

- Gravity pulls down
- Cushions and mattresses push up
- Soft tissue gets squeezed in the middle



# *Where does the damage occur?*

- What causes the damage?
  - Stress
  - Strain
  - Heat
  - Ischemia
  - Reperfusion injury
  - Impaired lymphatic flow
  - None of the above
  - All of the above



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## Assessment of mechanical conditions in sub-dermal tissues during sitting: A combined experimental-MRI and finite element approach

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*Strain*

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*Stress*

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# *The argument for strain*

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## Compression-induced deep tissue injury examined with magnetic resonance imaging and histology

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- Large deformation of muscle cells was associated with the location of tissue damage

# *Are pressure ulcers caused by deep tissue damage?*

- Stress alone?
  - Evidence suggests high stress in deeper tissues but ... Why is time a factor?
- Strain alone?
  - Evidence suggests higher strain in deeper tissues but ... Why is time a factor?

# *What about Heat?*

- Pressure (100 mmHg) was applied for 5-hour periods at 4 different temperatures (25°C, 35°C, 40°C, 45°C) on 16 swine
- Pressure damage severity and location after 7 days was found to be related to temperature
  - 25°C - no damage
  - 35°C - deep tissue damage
  - 40°C - deep and superficial damage
  - 45°C - more severe deep and superficial damage

*All the evidence points to*  
***Ischemia***

- Stress and strain occlude blood vessels (i.e. they cause ischemia)
- Heat increases metabolism exacerbates effects of ischemia

# *Do all pressure ulcers result from deep tissue damage?*

- Most do!
  - Ischemia causes pressure ulcers
  - Stress and strain cause ischemia
  - Stress and strain appear to be greatest near bone
  - Histological studies confirm initial deep damage following contact loading

# *What about superficial wounds?*

- Are they pressure ulcers?
- What exactly is a stage I pressure ulcer?