Modeling interaction between micro-climate factors and moisture-related skin-support friction during patient repositioning in bed

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Topic and Goal

Risk of pressure ulcers

- Bedbound patients
- Repositioning in bed
- Effects of microclimate factors

Goal

To create a combined model from two models created by Amit Gefen, in which a patients risk of pressure ulcers can be assessed when considering not only the contact between the body and the bed, but also including the effects of microclimate factors.

Pressure Ulcers (a.k.a. bedsores or pressure sores)

European Pressure Ulcer Advisory Panel: EPUAP

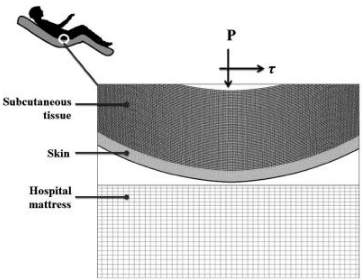
> *"A pressure ulcer is localized injury to the skin and/or underlying tissue usually over a bony prominence, as a result of pressure, or pressure in combination with shear. A number of contributing or confounding factors are also associated with pressure ulcers; the significance of these factors is yet to be elucidated." – http://www.epuap.org*

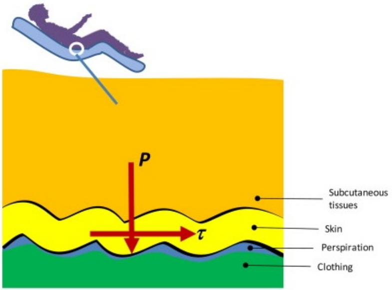
Can occur after application of

- a large pressure for a short period of time,
- or a small pressure for a long period of time.

The basis

1. "Modeling the effects of moisture-related skin-support friction on the risk for superficial pressure ulcers during patient repositioning in bed" *by Eliav Shaked and Amit Gefen* [4]
2. "How do microclimate factors affect the risk for superficial pressure ulcers: A mathematical modeling study" *by Amit Gefen* [2]





Modeling the effects of moisture-related skin-support friction on the risk for superficial pressure ulcers during patient repositioning in bed

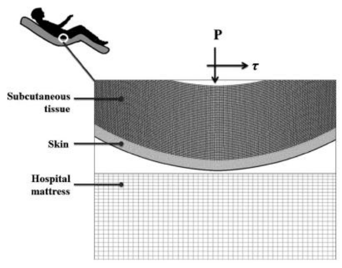


Figure: Source: [4].

- Body exists of skin and subcutaneous tissue
- Body comes into contact with the bed
- Body is repositioned: moved across the bed

How do microclimate factors affect the risk for superficial pressure ulcers: A mathematical modeling study

$$\frac{\Delta V(t)}{V} = \left[\alpha \frac{T_a - 30\,^{\circ}\mathrm{C}}{T_a^{\max} - T_s^{\min}} - \beta \frac{T_a - T_s}{T_a^{\max} - T_s^{\min}} (1 - RH) - \gamma\right] \cdot t$$

- Patient produces sweat
  - Dependent on ambient and skin temperature

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$$\mu = 0.5 \frac{\Delta V(t)}{V} + 0.4$$

- Patient produces sweat
  - Dependent on ambient and skin temperature
- Coefficient of friction changes due to sweat production

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$$\mu = 0.5 \frac{\Delta V(t)}{V} + 0.4$$

$$\tau = \left(0.5 \frac{\Delta V(t)}{V} + 0.4\right) \cdot P$$

- Patient produces sweat
  - Dependent on ambient and skin temperature
- Coefficient of friction changes due to sweat production
  - Stress levels increase

How do microclimate factors affect the risk for superficial pressure ulcers: A mathematical modeling study

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$$\tau = \left(0.5\frac{\Delta V(t)}{V} + 0.4\right) \cdot P$$

$$\tau_w^s = \left(1 - 0.8\frac{\Delta V(t)}{V}\right)\tau_0^s$$

- Patient produces sweat
  - Dependent on ambient and skin temperature
- Coefficient of friction changes due to sweat production
  - Stress levels increase
- Strength of the skin decreases due to sweat production

How do microclimate factors affect the risk for superficial pressure ulcers: A mathematical modeling study

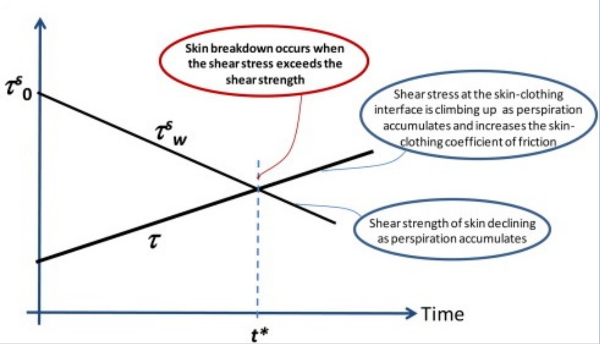

Figure: Skin fails when stress exceeds strength. Source: [2].

The difficulties of the problem

Patient lies in a bed:

- Body is in **contact** with the bed
- Both the body and the mattress will **deform** due to the contact

Deformation

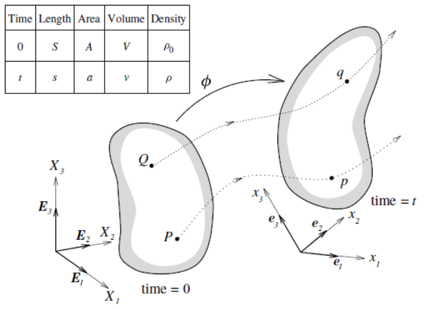

Figure: Many quantities change in the deformation of a body. Source: [1].

- Two configurations: reference and current.
- Need different notation for both configurations.

Contact

1. Contact area is unknown, only conditions are known:
   - Gap function $g(\mathbf{X}, t) = -\mathbf{v}\left(\varphi_t^{(1)}(\mathbf{X}) - \varphi_t^{(2)}(\bar{\mathbf{Y}}(\mathbf{X}))\right) \leq 0.$
   - Contact pressure $\mathbf{t}_N \geq 0$.
   - $\mathbf{t}_N g = 0$.
2. Friction is present: frictional traction force $\mathbf{t}_T \leq \mu \mathbf{t}_N$.

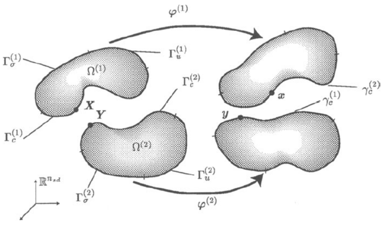

Figure: The two body contact problem. Source: [3].

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Complete problem

Searching for an equilibrium configuration φ
$\rightarrow$ virtual work should be zero for each body i.

$$\delta W^{(i)}(\varphi^{(i)}, \omega^{(i)}) = \underbrace{\int_{\Omega^{(i)}} \nabla\omega^{(i)} : \mathbf{P}^{(i)} \, d\Omega}_{\text{Internal stresses}}$$

$$- \underbrace{\int_{\Omega^{(i)}} \omega^{(i)} \cdot \mathbf{B}^{(i)} \, d\Omega}_{\text{Body forces}} - \underbrace{\int_{\Gamma_\sigma^{(i)}} \omega^{(i)} \cdot \mathbf{T}^{(i)} \, d\Gamma}_{\text{External surface forces}} - \underbrace{\int_{\Gamma_c^{(i)}} \omega^{(i)} \cdot \mathbf{T}^{(i)} \, d\Gamma}_{\text{Contact tractions}} = 0$$

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Complete problem

$$\delta W^{(i)}(\boldsymbol{\varphi}^{(i)}, \boldsymbol{\omega}^{(i)}) = \int_{\Omega^{(i)}} \nabla\boldsymbol{\omega}^{(i)} : \mathbf{P}^{(i)}\, d\Omega - \int_{\Omega^{(i)}} \boldsymbol{\omega}^{(i)} \cdot \mathbf{B}^{(i)}\, d\Omega - \int_{\Gamma_\sigma^{(i)}} \boldsymbol{\omega}^{(i)} \cdot \mathbf{T}^{(i)}\, d\Gamma - \int_{\Gamma_c^{(i)}} \boldsymbol{\omega}^{(i)} \cdot \mathbf{T}^{(i)}\, d\Gamma = 0$$

The summation of the virtual work over the two bodies should be zero.

$$\begin{aligned} \delta W(\boldsymbol{\varphi}, \boldsymbol{\omega}) &:= \sum_{i=1}^{2} \delta W^{(i)}(\boldsymbol{\varphi}^{(i)}, \boldsymbol{\omega}^{(i)}) \\ &= \underbrace{\sum_{i=1}^{2} \left\{ \int_{\Omega^{(i)}} \nabla\boldsymbol{\omega}^{(i)} : \mathbf{P}^{(i)}\, d\Omega - \int_{\Omega^{(i)}} \boldsymbol{\omega}^{(i)} \cdot \mathbf{B}^{(i)}\, d\Omega - \int_{\Gamma_\sigma^{(i)}} \boldsymbol{\omega}^{(i)} \cdot \mathbf{T}^{(i)}\, d\Gamma \right\}}_{\delta W^{int,ext}(\boldsymbol{\varphi},\boldsymbol{\omega})} \\ &\quad \underbrace{- \sum_{i=1}^{2} \int_{\Gamma_c^{(i)}} \boldsymbol{\omega}^{(i)} \cdot \mathbf{T}^{(i)}\, d\Gamma}_{\delta W^{c}(\boldsymbol{\varphi},\boldsymbol{\omega})} = 0. \end{aligned}$$

Solution Method

Newton-Raphson Method

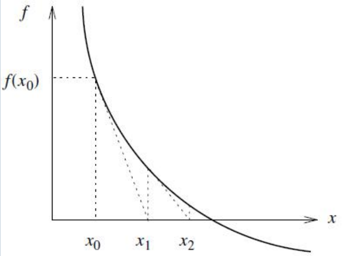


Figure: The Newton-Raphson method for a one-degree-of-freedom problem. Source: [3].

Solving $f(x) = 0$.

- Iterative method
- Initial guess x_0
- Update the guess

Solving $\delta W(\varphi, \omega) = 0$.

- Solve $\delta W(\varphi_k, \omega) = -D\delta W(\varphi_k, \omega)[\mathbf{u}]$, with
- $\varphi_{k+1} = \varphi_k + \mathbf{u}$.

Finite Element Method

- Divide the volumes into elements.
- Solve the problem as a summation over the elements instead of an integral over the volume.

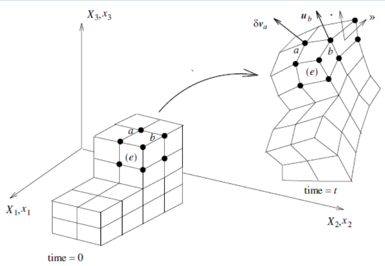
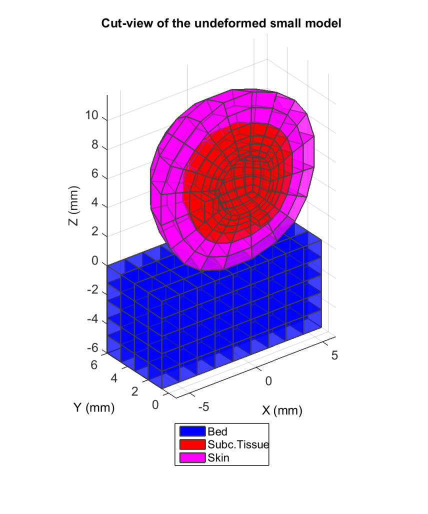


Figure: Discretization of the volume. Source: [1].

The basic model

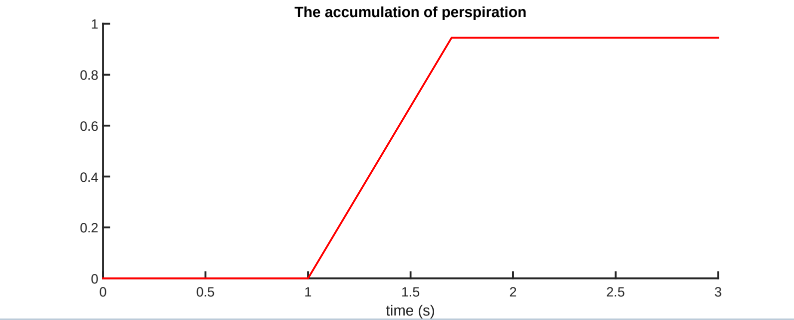


- Body exists of subcutaneous tissue and skin
- Two steps:
  1. Body moves downwards towards the bed
  2. Body is repositioned; moved across the bed

Including Micro-Climate factors

While the body is at rest the effects of the microclimate factors are applied

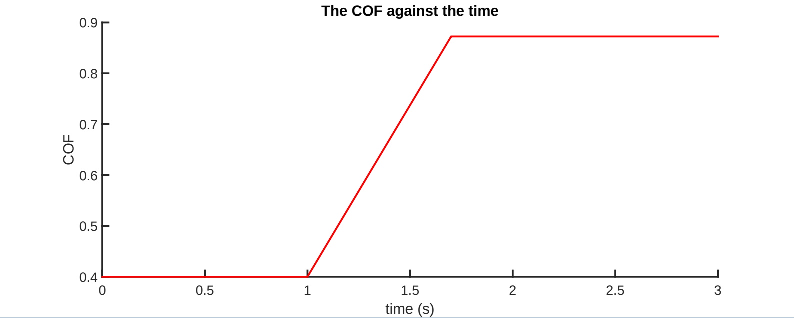
- Perspiration is accumulated



Including Micro-Climate factors

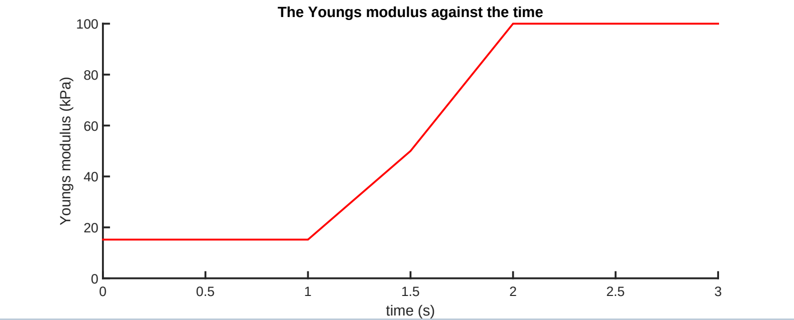
While the body is at rest the effects of the microclimate factors are applied

- Perspiration is accumulated
- The coefficient of friction changes as an effect of the production of perspiration.



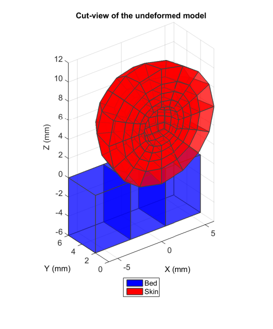
Further improvements

- The Young's modulus (stiffness) of the skin changes



Further improvements

- The Young's modulus (stiffness) of the skin changes
- Additional weight is added



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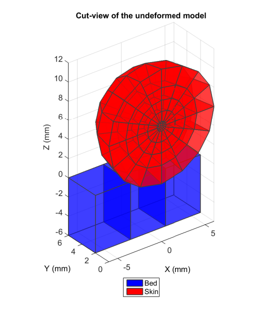
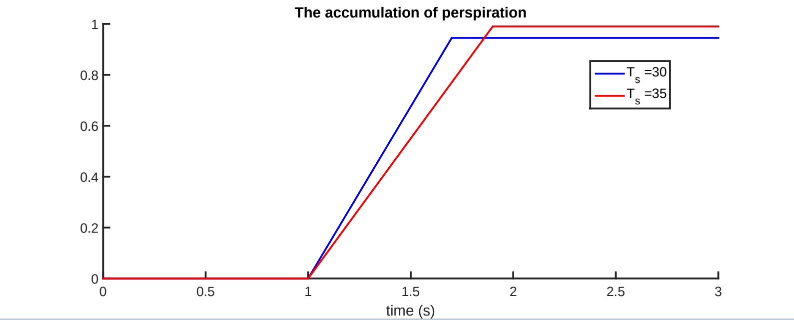


Further improvements

- The Young's modulus (stiffness) of the skin changes
- Additional weight is added
- A different value of the skin temperature is used



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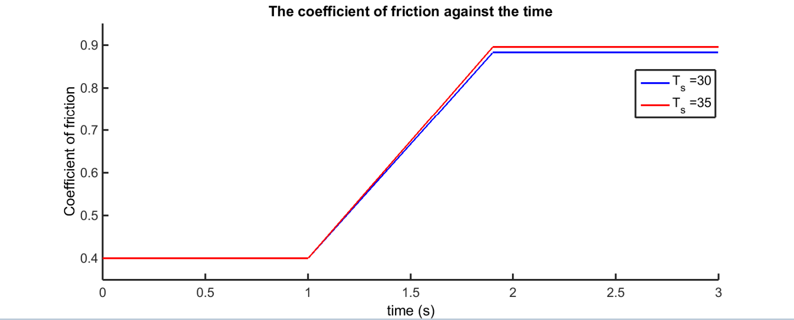

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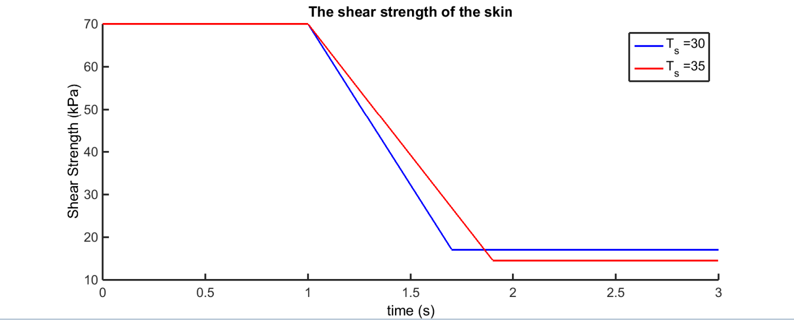
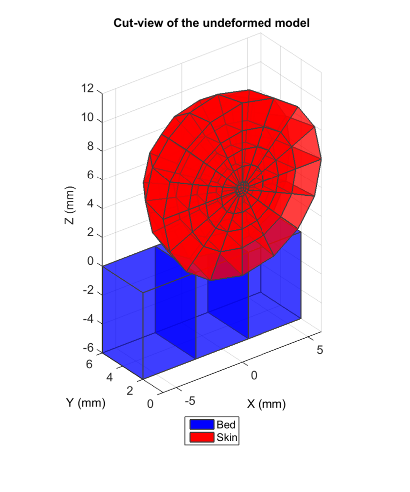


The final model



- Body exists of only skin
- Three steps:
  1. Body is subject to gravity and hence moves downwards
  2. The body is at rest and the effects of the microclimate factors are applied
  3. Body is moved across the bed

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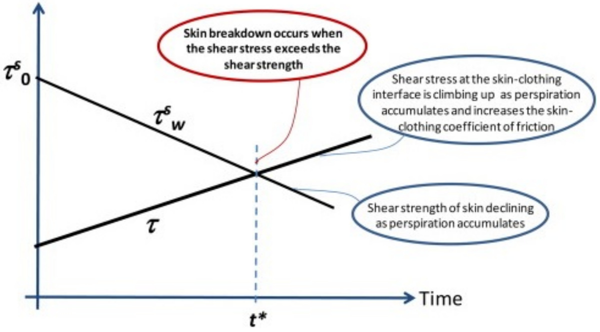
Results

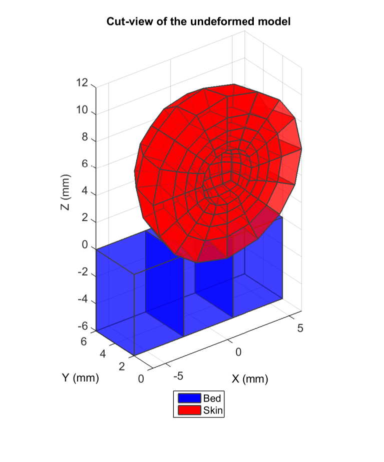
Skin breakdown: skin 'fails' if stress exceeds strength

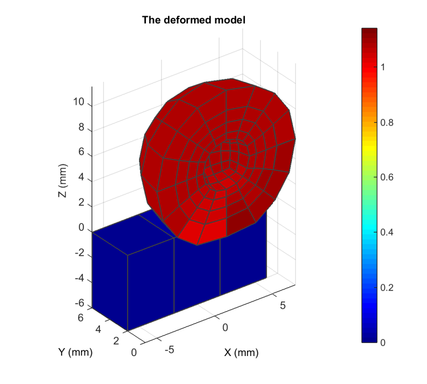
- Look at the strength of the skin
- Look at the stress levels of the skin



Results basic model

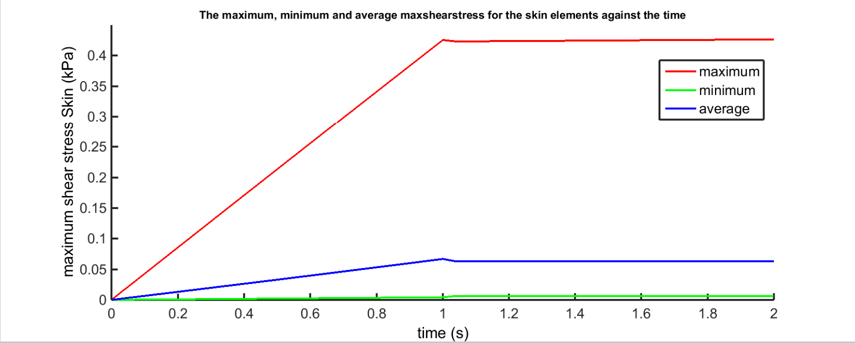
The Basic model





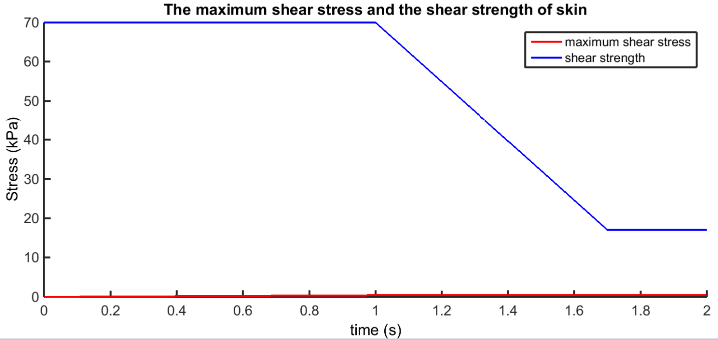
Results basic model

The maximum, minimum and average stress



Results basic model

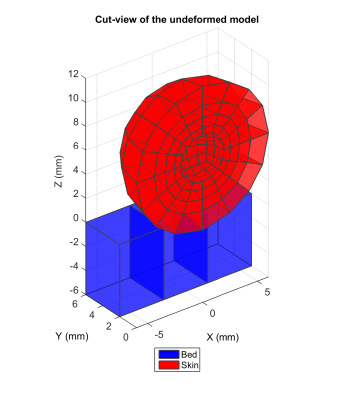
The stress compared to the strength

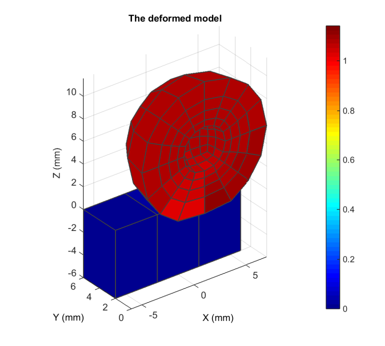


Results model with microclimate factors

The Microclimate model

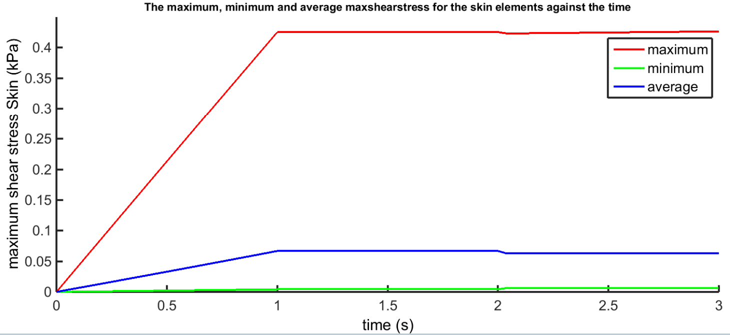
Coefficient of friction is time dependent





Results microclimate model

The maximum, minimum and average stress



Results microclimate model

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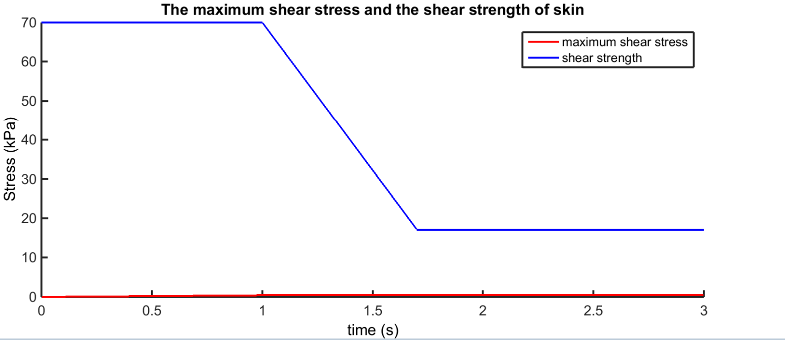

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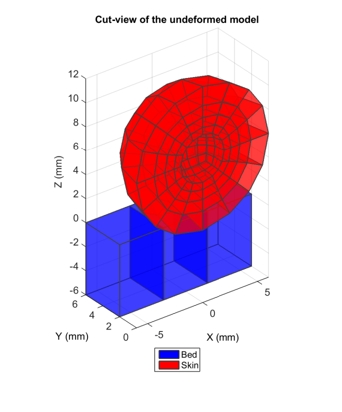
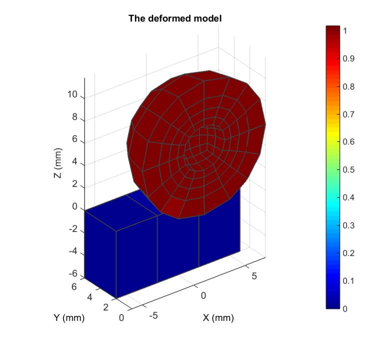
Results changing stiffness

Changing the stiffness

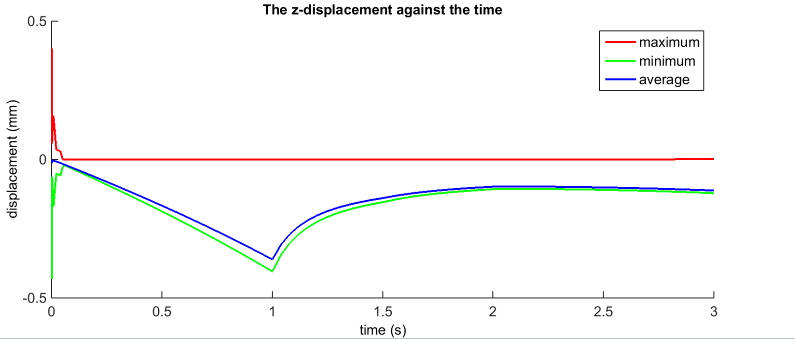
Both the COF and the stiffness of the skin change in time.





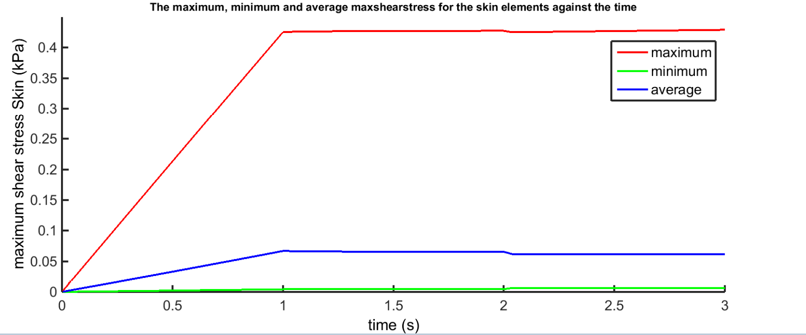
Results changing stiffness

The movement in the z-direction



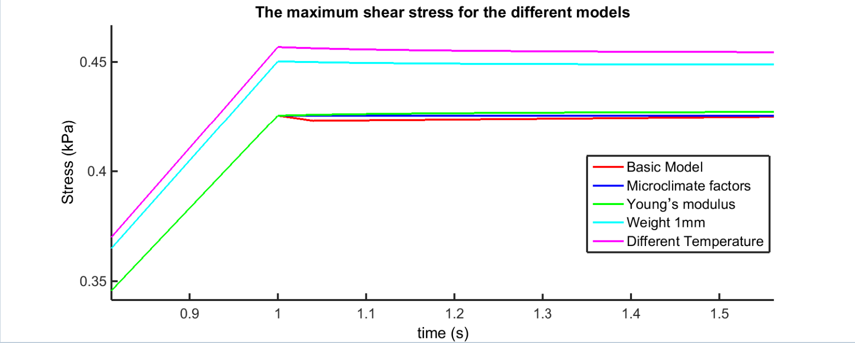
Results changing stiffness

The maximum, minimum and average stress



Overall Results

The stress levels of the different models



Conclusions

- The two models are combined : a model now exists including the effect of the microclimate factors
- Stress increases:
    - Microclimate factors (changing friction)
    - Changing stiffness
    - Adding of weight
    - Increasing skin temperature
- No skin failure is noted
- Improvements are still necessary

Remarks and Recommendations

- The model should be increased.
- The geometry of human body should be improved.
- It should be noted that the different body parts of the patient are connected.
- Constants such as the temperature should be time-dependent.
- More timesteps could be added to see what happens when the patient is at rest for a longer period of time.
- More realistic values for the changing stiffness should be used.

Once improved the model can be used for special cases.

- An unresponsive patient lies on top of a tube.
- A patient whose head or legs need to be elevated.

Sources

[1] Javier Bonet and Richard D. Wood. *Nonlinear Continuum Mechanics for Finite Element Analysis*. Cambridge University Press, Cambridge, United Kingdom, 1997.

[2] Amit Gefen. How do microclimate factors affect the risk for superficial pressure ulcers: A mathematical modeling study. *Journal of tissueviability*, 20:81–88, 2011.

[3] Tod A. Laursen. *Computational Contact and Impact Mechanics*. Springer, Durham,USA, 2002.

[4] Eliav Shaked and Amit Gefen. Modeling the effects of moisture-related skin-support friction on the risk for superficial pressure ulcers during patient repositioning in bed. *frontiers in bioengineering and biotechnology*, 1, 2013.