Modeling the risk at pressure ulcers

During patient repositioning in bed

Delft University of Technology

Thyrza Jagt 1509489

June 11, 2014

Table of Contents

Topic and Goal

- Bedbound patients
- Repositioning in bed
- Risk of pressure ulcers

Goal

Create model from two existing models to asses a patients risk of pressure ulcers

Pressure Ulcers (or 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.

Different categories according to EPUAP

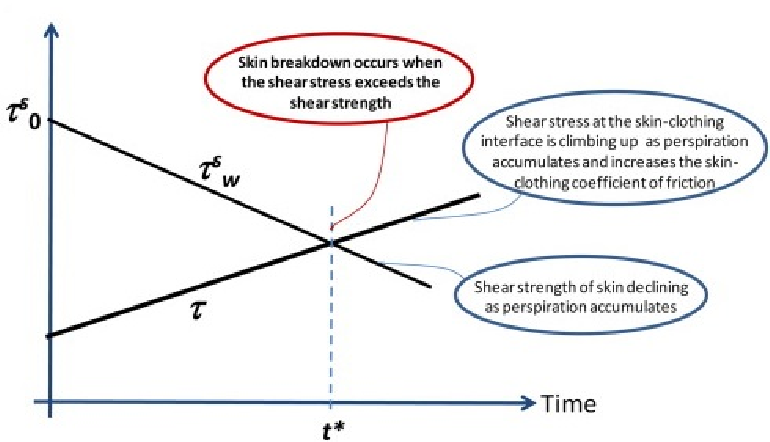
Category/Stage I : Non-blanchable erythema
Category/Stage II : Partial thickness
Category/Stage III: Full thickness skin loss
Category/Stage IV: Full thickness tissue loss

In this thesis we work with Superficial Pressure Ulcers (SPUs)
→ Grade I and II Pressure Ulcers (PUs) ([3, 8])

Two existing models

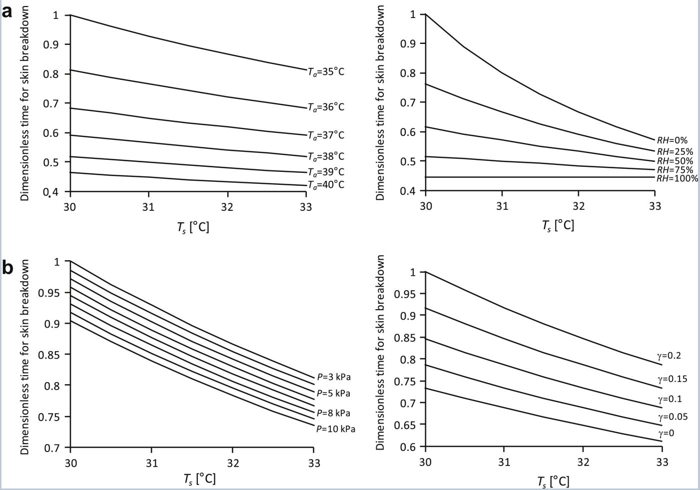
1. "How do microclimate factors affect the risk for superficial pressure ulcers: A mathematical modeling study" *by Amit Gefen* [3]
2. "Modeling the effects of moisture-related skin-support friction on the risk for superficial pressure ulcers during patient repositioning in bed" *by Eliav Shaked and Amit Gefen* [8]

How do microclimate factors affect the risk for superficial pressure ulcers?

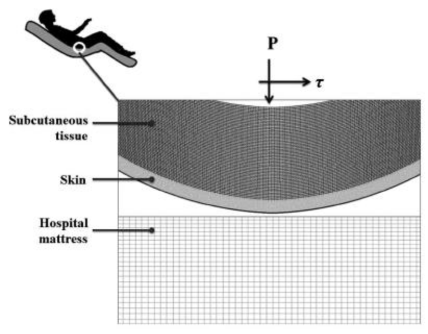


- Shear stress τ
  - depends on the coefficient of friction μ
  - depends on the pressure P to the skin
  - μ depends on accumulation of sweat $\frac{\Delta V(t)}{V}$ (Volume accumulated over time period t within available space V)
  - $\tau = \mu P = \left[0.5\frac{\Delta V(t)}{V} + 0.4\right] P$
- Shear strength of skin τ_w^s
  - depends on accumulation of sweat $\frac{\Delta V(t)}{V}$
  - depends on the shear stress of dry skin τ_0^s
  - $\tau_w^s = \left[1 - 0.8\frac{\Delta V(t)}{V}\right] \tau_0^s$
- Skin breakdown
  - occurs when $\tau = \tau_w^s$
  - use this to calculate the critical time t^*

Results - was able to mimic the calculations in Matlab



Modeling the effects of moisture-related skin-support friction



- Hooke's law within the bodies
- Pressure from above
- Movement across the bed
- Coulombs law of friction
- Finite Element Method

- Sliding with friction
- Plane Stress analysis
- Skin and subcutaneous tissues: linearly elastic isotropic nearly incompressible materials.
- A pressure boundary condition on the top edge of the model,to simulate the load over the ROI
- Pressure under the bony prominence equals 130kPa (body force)
- The hospital mattress was constrained of any movement on the sides and the bottom.
- Displacement was applied to the top edge of the model in a standard lateral turning,
  - 10cm horizontal sliding along the mattress and
  - 1 cm toward (i.e., immersion into) the mattress.

Results

In the article they describe relations between

- Maximal effective stress and applied shear stress
- Maximal stress (effective and shear) and COF
- Elastic modulus of the skin and the maximal effective stress

And they give an example of the distribution of effective stress over time.

Have not been able to fully mimic their calculations.
→ I only implemented with Hooks law, no contact model yet
→ They used FE software (ADINA)
→ I have emailed the authors with some questions, no reply yet

Overall idea of contact problems

Normal contact problem:

Two (elastic) bodies are being pressed together by a normal force.

Tangential contact problem:

A tangential force acts upon the bodies apart from the normal force.

Three components of contact problems:

1. **Deformation** due to the the load that presses the bodies together
2. **Relative Motion** such as being at rest, approaching each other, sliding and rolling over each other.
3. **Compression, adhesion** in the direction perpendicular to the area, and **friction and micro-slip** in the tangential directions.

Contact conditions

This last component can be described using conditions called the contact conditions.

- For the gap e_n between the two bodies:

$$e_n \geq 0 \begin{cases} = & \text{contact} \\ > & \text{separation} \end{cases}$$

- For the normal stress p_n

$$p_n \geq 0 \begin{cases} = & \text{separation} \\ > & \text{contact (compression)} \end{cases}$$

Note that: $e_n p_n = 0$.

Tangential contact problems

In tangential contact problems (tangential force present):
local friction law.
For example Coulomb's law:

$$F_x \leq \mu F_N \begin{cases} = & \text{complete sliding} \\ < & \text{sticking} \end{cases}$$

TU Delft

Different contact models

- Hertz theory of elasticity
- JKR, DMT, Bradley
- Tangential contact problems
    - The Cattaneo problem
    - Coulomb's law of friction
    - Influence of temperature and fluids

TU Delft

The Hertzian theory

- A normal contact problem between a rigid sphere and an elastic half-space
- All adhesive forces are neglected
- Assumes a pressure distribution
- Originally three results:
  1. the contact radius was determined,
  2. the maximum pressure was determined and
  3. the normal force of the contact was determined.
- Expanded for other bodies

Adhesive contact models

JKR, DMT, Bradley

- Based on the Hertzian theory
- Include adhesive forces
- All valid for different scenarios (1976, Tabor)
- DMT-Theory and JKR-Theory are both special cases of the general problem

Bradleys model is correct for absolutely rigid bodies,

The JKR-Theory is valid for large, flexible spheres, and

The DMT-Theory is valid for small, rigid spheres.

Tangential contact problems

The Cattaneo problem

- Contact between an elastic sphere and an elastic plane (half-space)
- Sphere is pressed onto the plane (normal force)
- Then shifted over the plane's surface (tangential force)

- Start with normal force $\rightarrow$ Hertzian normal pressure
- Then tangential force pushes: center of the sphere moves
- sliding/sticking occurs $\rightarrow$ need new distribution
- New distribution is a combination of two Hertzian distributions

TU Delft

Coulombs law of friction

$$F_f \leq \mu F_N$$

- F_f: frictional force
- F_N: normal force
- μ: coefficient of friction

Coefficient of friction can depend on:

- contact time
- normal force
- sliding speed
- surface roughness
- temperature

Influences of temperature and fluids

In both articles: COF dependent on sweat accumulation.
Sweat accumulation: dependent on temperature

In the first article: very simple model for sweat accumulation

$$\frac{\Delta V(t)}{V} = \int_0^t (\dot{S} - \dot{E} - \dot{D})dt' \tag{1}$$

$\dot{S}$: rate of production of perspiration
$\dot{D}$: rate of drainage of perspiration via the contact materials
$\dot{E}$: rate of evaporation of perspiration.

Signorini problem

Problem with ambiguous boundary conditions

- Contact between elastic sphere and a rigid frictionless plane
- Goal: find the displacement vector of the body which is only subject to its body and surface forces.
- Contact area is not known
- Subject to two systems of inequalities which denote respectively
  - the area of support (contact area)
  - the area of separation
- Do not know which point satisfies which system

Choosing a model

Not as easy as just picking a model
We:

- have normal force and a tangential force
  $\rightarrow$ need tangential contact model
- want to check the effect of sweat (fluid)
- work with a human body $\rightarrow$ exists of different layers (skin, subc. tissue)
- now the body is modeled as part of a circle
  $\rightarrow$ skin surface has radius of curvature equal to 180mm
  $\rightarrow$ can we just assume a contact area?
  $\rightarrow$ Signorini problem

What's next?

- Hopefully Eliav Shaked will answer my email
  - Maybe he knows which contact model they used
  - My guess: the combination of the Hertzian distributions (Cattaneo)
- Implement the model using Matlab or other software
  - Start with using the contact model used in the Cattaneo problem
  - See if the contact model can be improved or should be replaced by another model
- Right now the body is implemented as part of a circle. Should this be changed?
  - Can we guess the contact area?
  - Should we 'use' Signorini?
- Combining the two models
  - Use the FEM to calculate the shear stress
  - Find the critical time for different parameter values

Sources

[1] Dietrich Braess. *Finite elements. Theory, fast solvers, and applications in solid mechanics*. Cambridge University Press, Cambridge, UK, 2001.

[2] EPUAP. European pressure ulcer advisory panel.

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

[4] A. Segal J. van Kan and F. Vermolen. *Numerical Methods in Scientific Computing*. VSSD, Delft, the Netherlands, 2008.

[5] K.L. Johnson. *Cotact mechanics*. Cambridge University Press, 1985.

[6] Amar Khennane. *Introduction to Finite Element Analysis Using MATLAB® and Abaqus*. CRC Press, 2013.

[7] Valentin L. Popov. *Contact Mechanics and Friction. Physical Principles and Applications*. Springer, Heidelberg, Germany, 2010.

[8] 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.

[9] S. Timoshenko and J.N. Goodier. *Theory of Elasticity*. McGraw-Hill Book Company, Inc., 1951.

[10] E.A.H. Vollebregt. A new solver for the elastic normal contact problem using conjugate gradients, deflation, and an fft-based preconditioner. *Journal of Computational Physics*, 257:333–351, 2014.

[11] Wikipedia. Signorini problem, 2014.