The Problem with Shear – the Science

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Topics to be Addressed

- Definition of shear at the loaded interface highlighting the distinction between external and internal shear forces.
- How shear interacts with other physical/mechanical parameters e.g. friction and pressure, to influence skin tolerance levels at the loaded interface i.e. its role in the aetiology of PUs.
- Bioengineering strategies and tools to measure shear at the loaded interface.
- The effects of shear on both ex-vivo and human skin models.
Clinical guidelines have multiple recommendations – where is shear?

Thanks to Dr Kath Bogie
Clinical Problem - Pressure Ulcers

First recorded evidence in the Egyptian Section of British Museum – Priestess of Amen

Research area has become an international “Hot Topic”

Incidence is a Quality of Care and Safety Issue

UK chronic wound burden of ~£5 billion pa (Guest et al., 2015)

Over 33% of pressure ulcers that occur in hospitals are related to medical devices (Black et al, 2010)
Pressure ulcers are areas of localized damage to the skin and underlying soft tissue, resulting from sustained pressure (including pressure associated with shear).

PUs are most likely to develop in individuals who are either seriously ill, neurologically compromised or who have impaired mobility.

By adopting a hierarchical approach, there is an increased understanding of both the biomechanical and physiological factors associated with skin health and in the evaluation of preventative strategies.
Different initiation sites and progression of PU damage

Normal Pressure

Skin Fat
Muscle Bone

Deep Tissue Injury “Inside out”

Stage/Category 1-4 Pressure Ulcers “Outside in”

Normal Pressure

Shear Force

Site of initial damage and progression
Pathophysiology of PUs

Tissue response to biomechanical factors

- **Localised ischaemia**
  - Perceived wisdom

- **Impaired fluid flow and lymphatic drainage**
  
  *(Miller and Seale 1981 Lymphology 14, 161-66)*

- **Ischaemic/Reperfusion injuries**
  
  
  - Animal models – related to Pressure Ulcers
    
    *(Peirce et al, 2000; Unal et al., 2001; Saito et al., 2008)*

- **Sustained deformation of cell**
  
  *(Bouten et al, 2001, Gawlitta et al, 2007)*
Extrinsic Factors at the skin-support interface

- **Pressure**
  - localized pressure
  - pressure gradient

- **Shear**
  - Semi-reclined in bed
  - Subject transfer
  - Internal shear

Both factors lead to local shape changes

- **Temperature**
  - $1^\circ C$ rise in temp. increases metabolic demands by 13%

- **Humidity**
  - sweating
  - incontinence

- **Friction**

- **Time**

- **Tissue Viability or status**

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*Reswick & Rogers, 1975*

*Gefen et al., 2006*
Shear and pressure

The presence of shear decreases the tolerance levels of skin caused by normal pressure alone

Dinsdale, 1974
Bennett et al, 1979

Seireg and Chang 1999 Medical Hypotheses 53,141-44
What is Shear?

After Cees Oomens
“Shear” in this case represents a boundary condition = an external force parallel to the surface
Internal Shear

ALL forces on tissue (normal, friction, shear) induce shear strains (deformation) within the soft tissues. Any interaction causing tissue deformation will induce strain.

- In this case, shear represents the local mechanical deformation or strain in an internal region of tissue. 

Reichel, 1958
Danger of shear forces
Mechanism I: Wrinkles

Why are shear forces more dangerous than pressure alone? Because the mechanical load is higher? Probably NOT

Skin wrinkles:
This leads to very high deformations in the skin

Reichel, 1958
Dinsdale, 1974
Mechanism II: Delamination of skin layers

Hagisawa, 2005

Delamination of skin layers
Shear experiment to demonstrate delamination

Lamers et al. (2013) J Mech Beh Biom Mat.

Thanks to Jibbe Soutens
Summary – Damaging effect of shear forces

• In general a mechanical load (pressure and shear) will lead to a heterogeneous strain field inside the tissues
• Highest strains are often found near bony prominences

• High shear forces at the skin surface may result in different damage mechanisms inside the skin and subcutaneous tissues.
  ✓ Wrinkling leads to high strains
  ✓ Delamination
  ✓ Easy to deform skin by shearing due to anisotropy
  ✓ Easy to block blood vessels by shear strain
• It is likely that these high shear forces have a major effect on the tissue layers near the surface

Oomens 2015
A new method to evaluate the effects of shear on the skin


Able-bodied participants

Response of shear (14.5N) superimposed on pressure (3.9kPa) for 15 & 30 mins. on:

Reactive hyperaemic (LDF)

Cytokine upregulation (Sebutape)
Test Design and Results

Cytokine Analysis of Sebutape

Analysis of Laser Doppler Images

- Shear has a significant effect on both inflammatory and reactive hyperaemic responses
Improving the effects of shear on skin viability with wound dressings

De Wert et al. 2016 JMBM

Pressure + Shear
Results – Dressings I-III versus controls

A- IL1-α/TP ratio

B - Blood cell flux

• All foam dressings reduced the effects of pressure in combination with shear
Shear Measurement Systems

- Very few studies describing sensors sensitive to shear at the body support interface

Predia (Molton Corp; Hiroshima, Japan) pressure and shear force sensor shown (a) assembled and with (b) dimensions for pressure sensing area and (c) dimensions for shear sensing area

Monitoring Pressure and Shear at the Stump-Socket Interface

- > 30% of amputees dissatisfied with their socket fit comfort – average socket lifetime of 1 year
- Pressure and shear can cause stump breakdown
- Tissue tolerance levels are reduced in the presence of shear forces
- Research based sensors have been added to the socket and/or stump

Laszczak et al. 2015
Lab-based and Amputee Tests

Amputee: Knee disarticulation, M, 77kg

Stump/socket interface simulator

Laszczak et al., 2016
Solution to Medical Problem – Intelligent Liner with sensors

Stump/socket interfacial pressure & shear monitored when standing and walking.

Product profile

Socket fit diagnosis:
- Too high (danger, adjust socket fit)
- Warning (approaching high level loading)
- Safe loading level
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D4D Devices for Dignity

WOUNDTEC HTC Wound Prevention and Treatment: Healthcare Technology Co-operative

MRC Medical Research Council

http://www.southampton.ac.uk/mdvsn/index.page

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