Individualizing Pressure Ulcer Risk and Prevention Strategies

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Tissue and Cellular Changes Associated with Pressure

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Pressure Ulcers: Superficial & Deep
Skin Deep or Muscle Bound

Mechanical Loading

Bouten CV, Oomens CW, Baaijens FP and Bader DL, Arch Phys Med Rehabil; 2003
Tissue Susceptibility to Pressure

- Muscle > Skin
  
  Hussain, 1953;
  Kosiak, 1961;
  Daniel, 1982;
  Salcido et al., 1994

- Deep ulcers develop at faster rate
  
  (Bliss, 1999)
Cellular Origin for PU Development

Sustained cell deformation

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<th>20% Compression</th>
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<td><strong>74%</strong></td>
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Bouten et al., 2003
Stekelenburg et al., 2006
Rat Muscle Apoptosis in DTI

Siu et al., 2008
Histology of Human Pressure Ulcers

- **Stage I:**
  - Superficial crust
  - Subepidermal separation & necrosis
  - Degeneration of follicular structures

- **Stage II:**
  - Disruption of dermal papillae
  - Densely packed collagen
  - Necrosis of skin appendages
  - Inflammatory cells present

*Review by Edsberg, 2007*

*Arao et al., 1998*
Histology of Human Pressure Ulcers

- Stage IV:
  - Decreased number of fibers
  - Wider straight & wavy fibers
  - Dense collagen & fat deposits
  - Decreased Vascularity
  - Thicker fiber bundles

Review by Edsberg, 2007
Effects of 50 mmHg static pressure on skin

- Minimal alteration of epidermal structures
- Minimal alteration of dermal structures

Edsberg et al., 2001
Epidermal changes:
• Flattened epidermis
• Fragmented keratin
• Reduced rete ridges

Effects of 170 mmHg static pressure on skin

Edsberg et al., 2001
Effects of 170 mmHg static pressure on skin

Dermal changes:

- Compression of connective tissue layer
- Reduction in diameter of blood capillaries
- Change in elastic fiber alignment

Edsberg et al., 2001
Dynamic Pressure Application (110- to 170-mmHg)

- Surface topography of skin maintained
- Minimal alteration of epidermis or dermis
- Elastin fiber arrangement more closely matched controls than static treatment
- Changes noted in epidermal ridges and fiber bundle orientation in the dermis

Edsberg et al., 2001
Internal Pressure Simulator
Histological differences between black and white LE skin

White skin

Black skin
Stress-Strain Data for White (1) and Black (3) skin sample

Sample 1

Sample 3

<table>
<thead>
<tr>
<th>Stress (Mpa)</th>
<th>Control</th>
<th>Dynamic</th>
<th>Static</th>
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Strain

0 0.1 0.2 0.3 0.4 0.5 0.6 0.7

0 0.1 0.2 0.3 0.4 0.5 0.6 0.7
BLOOD FLOW AND TISSUE DEFORMATION RESPONSES TO LOADING

Sharon Eve Sonenblum
Georgia Institute of Technology
Pressure Ulcer Etiology

1. Impaired lymphatic flow
2. Ischaemia of soft tissues
3. Tissue deformation

(Bouten 2003)
Pressure Ulcer Etiology

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(Bouten 2003)
Pressure Ulcer Etiology

1. Impaired lymphatic flow
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3. Tissue deformation

(Bouten 2003)
Impaired blood flow increases pressure ulcer risk

• Decreased superficial blood flow during surgery
  – Sanada 1997

• Increased blood flow recovery time in response to cold stimulus (older adults)
  – van Marum 2002

• Longer blood flow recovery time following loading (elderly)
  – Meijer, Germs et al. 1994
Holy Grail of Seating:
The Interface Pressure Threshold
Holy Grail of Seating: The Interface Pressure Threshold
Holy Grail of Seating: The Interface Pressure Threshold
What we’ve learned since I was born...

• Pressure to occlude blood flow varies
  – Studies cite 42 – 120 mmHg

• Depends on study design
  – Indentor shape and size
  – Duration of loading
  – Static vs. dynamic

Bader 1990
What we’ve learned since I was born...

• There is a critical pressure to occlude blood flow, but this threshold varies widely within and across individuals.
  – Anatomy (bony structures underneath)
  – Individual characteristics
  – Amount of deformation and shear
    • more deformation → more occlusion (Bergstrand 2009)
Intrinsic Risk Factors That Impact Blood Flow

- Diagnosis (SCI or Other)
- Male Gender
- Nutrition
- Smoking Status
- Cardiovascular Disease
- Vasodilators
- Lymphocytopenia

Blood Flow Example
Blood Flow Example

N=34 men, <40 years old with chronic SCI
(Sonenblum and Sprigle 2012)
Blood Flow Example

Lymphocytopenia:
- Higher flow during unloaded sitting
- Slow decay from hyperaemic response
- Lower normalized pressure at LOW load
Pressure Ulcer Etiology

1. Impaired lymphatic flow
2. Ischaemia of soft tissues
3. Tissue deformation

(Bouten 2003)
Tissue Deformation

• What does strain look like inside the seated buttocks?
  – Finite Element Modeling (FEM)
  – Magnetic Resonance Imaging (MRI)
• Internal response varies according to tissue properties
• Tissue properties vary across individuals
• Intrinsic risk factors impact tissue properties
What does stress and strain look like inside the seated buttocks (FEM)?

- Finite element models to date
  - Based on MRI in one coronal plane.
  - Bulk deformation within coronal plane are matched to the human
  - Assumes no anterior/posterior deformation
  - Estimate material properties
- Peak Strains
  - 100-200% in the muscle
  - 50-90% in the fat

Finite Element Model Example
(Coronal Plane)

Compression

Tension

BMI = 25.5 kg/m²

Elsner 2008
MRI of the Seated Buttocks
(Coronal Plane)
MRI of the Seated Buttocks (Coronal Plane)

Unloaded vs. Loaded

- Apex of the IT
- Femoral head
- IT
- Muscle
- Fat

Lateral
Medial
MRI of the Seated Buttocks

(Coronal Plane)

Apex of the IT

3cm posterior to apex of IT
MRI of the Seated Buttocks (Coronal Plane)

Unloaded

Loaded

Apex of the IT

3cm posterior to apex of IT

femoral head

IT

Muscle

Fat

Bifurcating blood vessel

Medial

Muscle
MRI of the Seated Buttocks

(Coronal Plane)

 Apex of the IT

3cm posterior to apex of IT
MRI of the Seated Buttocks (Coronal Plane)

Apex of the IT

3cm posterior to apex of IT
MRI of the Seated Buttocks
(Sagittal Plane)
3D Rendering of the Gluteus & Hamstring

Unloaded

Loaded
Internal response varies according to tissue properties

- Parameter analyses from finite element models
  - ↓ in muscle stiffness ↑ muscle strain
  - ↓ fat stiffness ↑ increases fat strain
  - Unclear if changes in fat stiffness impact muscle strain
  - ↓ tissue thickness ↑ strain
  - ↓ radius of curvature of the ischial tuberosities ↑ strain

Intrinsic risk factors impact tissue properties

- **SCI**
  - “Small deformation stiffness” larger in able-bodied (0.33 N/mm) than SCI (0.23 N/mm) (Makhsous, 2008)
  - Muscle atrophy and reduced muscle thickness (Castro, Apple et al. 1999; Linder-Ganz, Shabshin et al. 2008; Makhsous, Venkatasubramanian et al. 2008)

- **BMI**
  - Increased BMI decreases skin stiffness (Smalls, Randall Wickett et al. 2006)

- Decreased tissue stiffness in young men with SCI (Sonenblum 2012)
  - High BMI, history of PU, Incomplete injury

- How quickly the tissue ‘bottoms out’ under load
  - 10 years older → increase of 5% of maximum displacement at 4.2 N
  - Smoking → increase 4% of maximum displacement at 4.2 N
Now What?

- Which intrinsic risk factors can be changed?
- Interventions to extrinsic risk factors to increase blood flow and decrease deformation
  - Cushion surface
  - Position changes and pressure relief
  - Dynamic loading
- Blood flow or tissue deformation as an outcome measure

Goosens 2007; Jan 2010; Makhsous 2007; Mayrovitz 1999; Sonenblum 2011; Thorfinn 2009; van Geffen 2010
DEMOGRAPHIC, PHYSIOLOGICAL AND BEHAVIORAL RISK FACTORS

Stephen Sprigle
Georgia Institute of Technology
Risk Assessment

• Systematic collection of information that links a person to a level of risk
• One aim is to identify modifiable risk factors

• Pressure ulcer risk assessment is well established
  – In the US the Braden Scale is most often used
    • Celebrating its 25th anniversary this year
Risk Assessment - Braden Scale

- **SENSORY PERCEPTION**
  - ability to respond meaningfully to pressure-related discomfort

- **MOISTURE**
  - degree to which skin is exposed to moisture

- **ACTIVITY**
  - degree of physical activity

- **MOBILITY**
  - ability to change and control body position

- **NUTRITION**
  - usual food intake pattern

- **FRICITION & SHEAR**
Relating Demographic, Physiological & Behavioral Variables to PU Occurrence

• Observational cohort study
  – Typically retrospective
• May use
  – Existing data sets
    • databases, medical records, etc
  – Self-report
    • Interviews & surveys
Let’s look at a few

- Hospital in-patients
- Long-term care residents
- Surgery patients
- Persons with SCI
Pressure Ulcer Risk Factors Among Hospitalized Patients
(Allman, 1995)

• 286 patients
• age 55 years or more
• expected to be confined to bed or chair >= 5 days
• No PU on admission
• *Sources of data*: prospective via medical records, investigator evaluation, lab and other reports
PU Risk factors - Hospitalized Patients
(Allman, 1995)

• Previous pressure ulcer
• Lymphopenia
  – lymphocyte counts less than 1.50x10^9/L
• Immobility
• Dry skin
• Nutrition
  • Depleted triceps skinfold measure
• Decreased body weight
  – lowest quartile of baseline weight (<58 kg)
Pressure Ulcer Development in Long-Term Care
(Horn, et, al 2004)

• 1524 residents of 95 LTC facilities
• Each followed for up to 12 weeks
• Source of data: Medical records, Minimum Data Set
Pressure Ulcer Development in Long-Term Care
(Horn, et al 2004)

> 500 variables collected

- Demographics & medical history
  - Braden Scale scores
  - severity of illness using the Comprehensive Severity Index
  - nutritional status
  - cognitive ability
  - incontinence status
  - mobility

- Treatment characteristics
  - nutritional interventions
  - pressure management strategies
  - Incontinence interventions
  - medication use
  - use of a high calorie/high-protein nutritional supplement

- Facility characteristics
  - staffing patterns
  - use of a skin care team
  - outside consultant wound care specialist
Pressure Ulcer Development in Long-Term Care Residents (Horn, et al 2004)

*Characteristics that predisposed residents to developing a new PU included*

- history of a PU
- requiring assistance with 7+ ADLs
- oral eating problems
- weight loss
- use of a catheter for 14+ days
Patient-specific characteristics in surgical patients

- 3225 patients over 2 yr period
- Source of data: electronic medical record

Patient-specific risk factors
- Age
- BMI
- Diabetes
- Use of vasopressors
- Number of surgeries
- Braden Score

Gender- only non-significant patient characteristic
Pressure ulcer risk assessment scale for individuals with SCI
(Salzberg, 1996 & 1998)

• 219 spinal cord-injured patients evaluated
• 6 year duration of study
• 80% had a history of 1+ pressure ulcers
• Source of data: retrospective data collected during annual examinations
Pressure ulcer risk assessment scale for individuals with SCI
(Salzberg, 1996)

- restricted activity level
- degree of immobility
- complete SCI
- urinary incontinence
- autonomic dysreflexia
- advanced age
- comorbidities of cardiac, pulmonary, and renal disease
- impaired cognitive function
- Diabetes
- Cigarette smoking
- residence in a nursing home or hospital
- Hypoalbuminemia
- anemia

≈ 75% sensitivity and specificity
Recurrent pressure ulcer patterns in SCI
Krause & Broderick, 2004

- 633 subjects- injured 5+ yrs reported on PU hx
- Source of data: interviews and self-report
Recurrent pressure ulcer patterns in SCI
Krause & Broderick, Arch Phys Med Rehabil; Vol 85, August 2004

- 34% reported no PUs since SCI onset
- 36% reported having PUs immediately after injury with few if any after that point.
- 17% reported getting PUs every couple of years
- 9% reported getting PUs at least once a year
- 4% reported having PUs on an almost constant basis, often requiring hospitalization.
Which were related to recurrence?

Protective factors

• Employed
• Healthy lifestyle
• Eat healthy diet
• Eat vegetables
• Self-reported fitness
• Exercise compared with others
• Planned exercise

SCI-specific protective factors

• Regular skin checks
• Regular weight shifts
• Drink extra water
• Turn regularly in bed

Risk Factors

• Smoking
  – Currently smoking
  – Smoke 100 cigarettes

• Alcohol
  • CAGE (last 12mo)
  • CAGE (ever)
  • 5 drinks on 1 occasion

• Prescription medication use
  – Treatment for depression
  – Treatment for sleep
  – Treatment for pain
  – Treatment for spasticity

CAGE: questionnaire about alcohol use & opinions
Which were related to recurrence?

**Protective factors**
- Employed
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*SCI-specific protective factors*
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**Risk Factors**
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- CAGE (ever)
- 5 drinks on 1 occasion
- Prescription medication use
  - Treatment for depression
  - Treatment for sleep
  - Treatment for pain
  - Treatment for spasticity
Predictive and protective factors identified by multiple studies using multiple cohorts (remembering not all factors were measured by all)

- Diabetes (Salzburg, Tschannen)
- Moisture/incontinence (Salzburg, Horn)
- Mobility & Activity (Salzburg, Horn, Allman, Krause)
- Eating poorly - loss of weight
  - (Salzburg, Horn, Allman, Tschannen, Krause)
- Age (Salzburg, Tschannen)
- Smoking (Salzburg, Krause)

These 6 factors have also been identified in other studies as well
Which factors impact physiology and biomechanics of tissue?

- Diabetes
- Moisture/incontinence
- Mobility & Activity
- Eating poorly- loss of weight
- Age
- Smoking

So, the reason why we measure Patient-specific factors is because we cannot readily measure physiology or biomechanics of tissue.
Which show up on Braden Scale?

• Diabetes
• Moisture/incontinence
• Mobility
• Eating poorly- loss of weight
• Age
• Smoking
So, why has the Braden Scale been so successful?

- PU formation is obviously complex
- More complex risk models have been developed
- The Scale does not inform specific interventions

My belief:

**Parsimony** did not hinder real world validity
Can (and should) a PU Risk Assessment Scale be developed for Wheelchair Users?

• Must cross diagnoses
• Must accommodate different environments & amounts of wheelchair use
• Must assess value of myriad variables versus the complexity & accuracy of measurement
  – Tissue stiffness and thickness
  – Tissue response to load
  – Blood work (e.g., lymphocytopenia; hypoalbuminemia, anemia)
  – Self reported behaviors
• Do EMR’s permit more complex risk assessment tools?
Download our presentation...

For a full reference list

www.mobilityrerc.gatech.edu
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- Invacare
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- The Roho Group
- Sunrise Medical

[Logos of the sponsors]
References (p1)

- Horn S, et. al The National Pressure Ulcer Long-Term Care Study: Pressure Ulcer Development in Long-Term Care Residents. JAGS 52:359–367, 2004
References (p2)

• Loerakker, S., L. R. Solis, et al. (2012). "How does muscle stiffness affect the internal deformations within the soft tissue layers of the buttocks under constant loading?" Comput Methods Biomech Biomed Engin.
References (p3)

References (p4)