Simulations of tissue loads in the seated buttocks on an air-cell-based cushion in bariatric/diabetic wheelchair users

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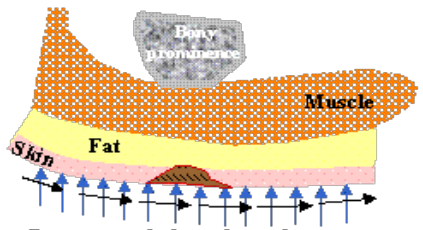
Pressure ulcers

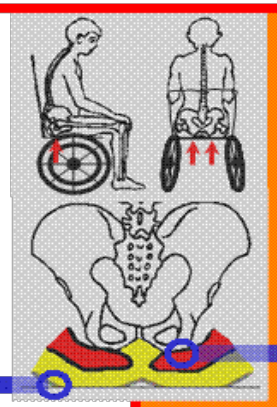
Category 1: Changes in skin

Category 4:
full thickness skin loss; fat and muscle damage; bone is exposed

Distinct mechanisms of deep versus superficial pressure ulcers

Superficial Pressure Ulcers





Extrinsic — Moisture and heat → Friction properties

Intrinsic — Impaired moto-sensory capacities → Friction properties

Intrinsic — Poor nutrition → Friction properties

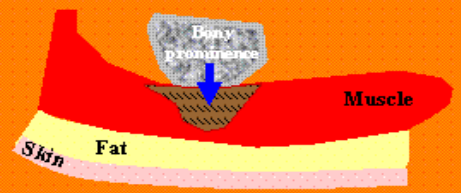
Intrinsic — Infection → Friction properties

Friction properties → **Superficial pressure ulcers**

Superficial pressure ulcers at the buttocks

Deep Tissue Injury (DTI)

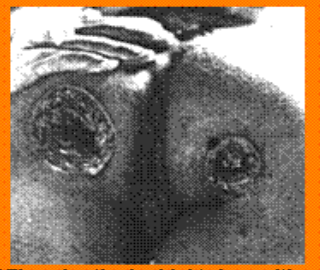
(Black et al., 2005)



Extrinsic — Posture, Time at posture
Stiffness of the support

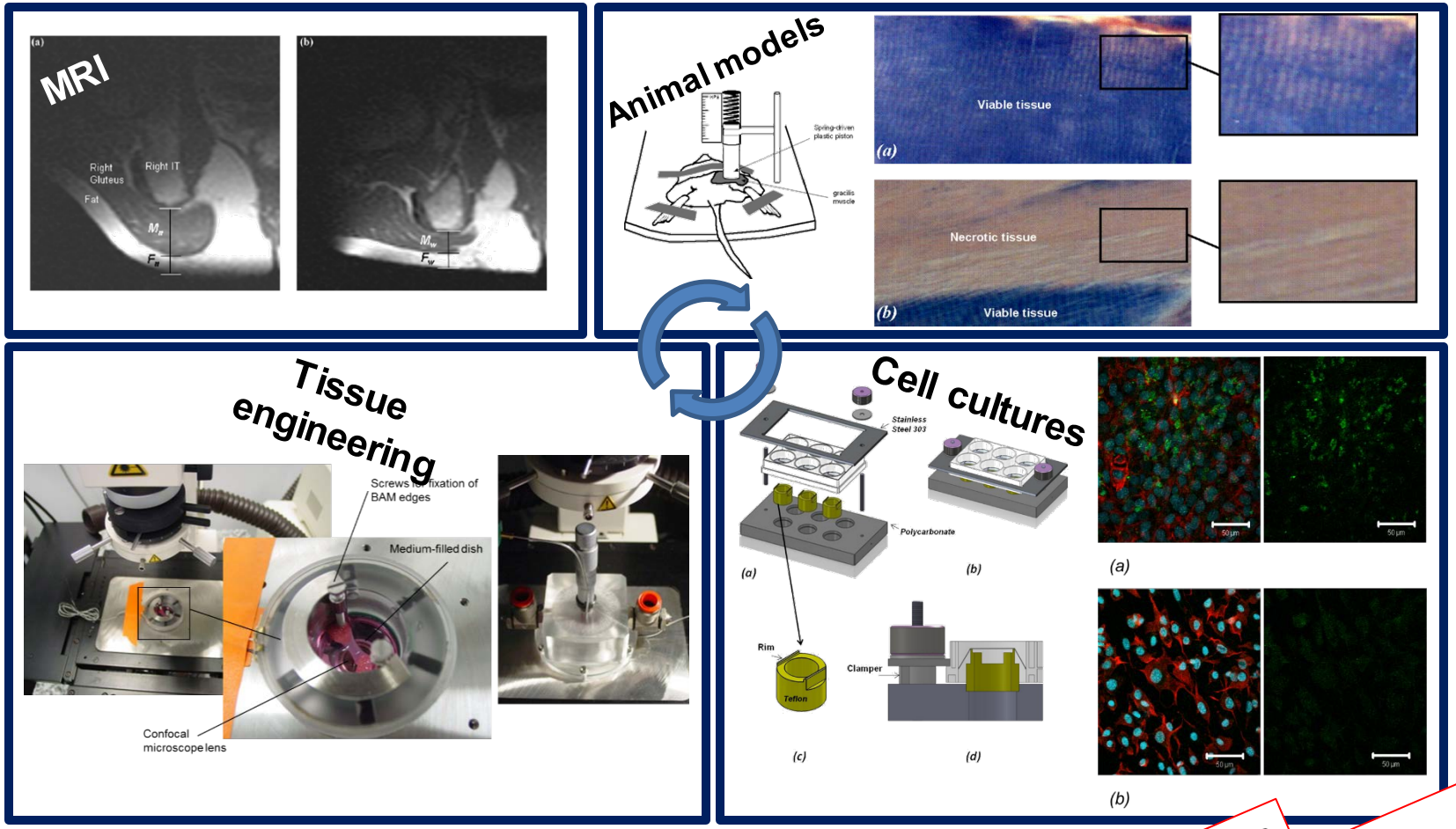
Intrinsic — Impaired moto-sensory capacities → Muscle atrophy

Progressive necrosis ↔ **Deep tissue injury**



DTI under the ischial tuberosities

Sustained deformation is the direct cause of cell and tissue death



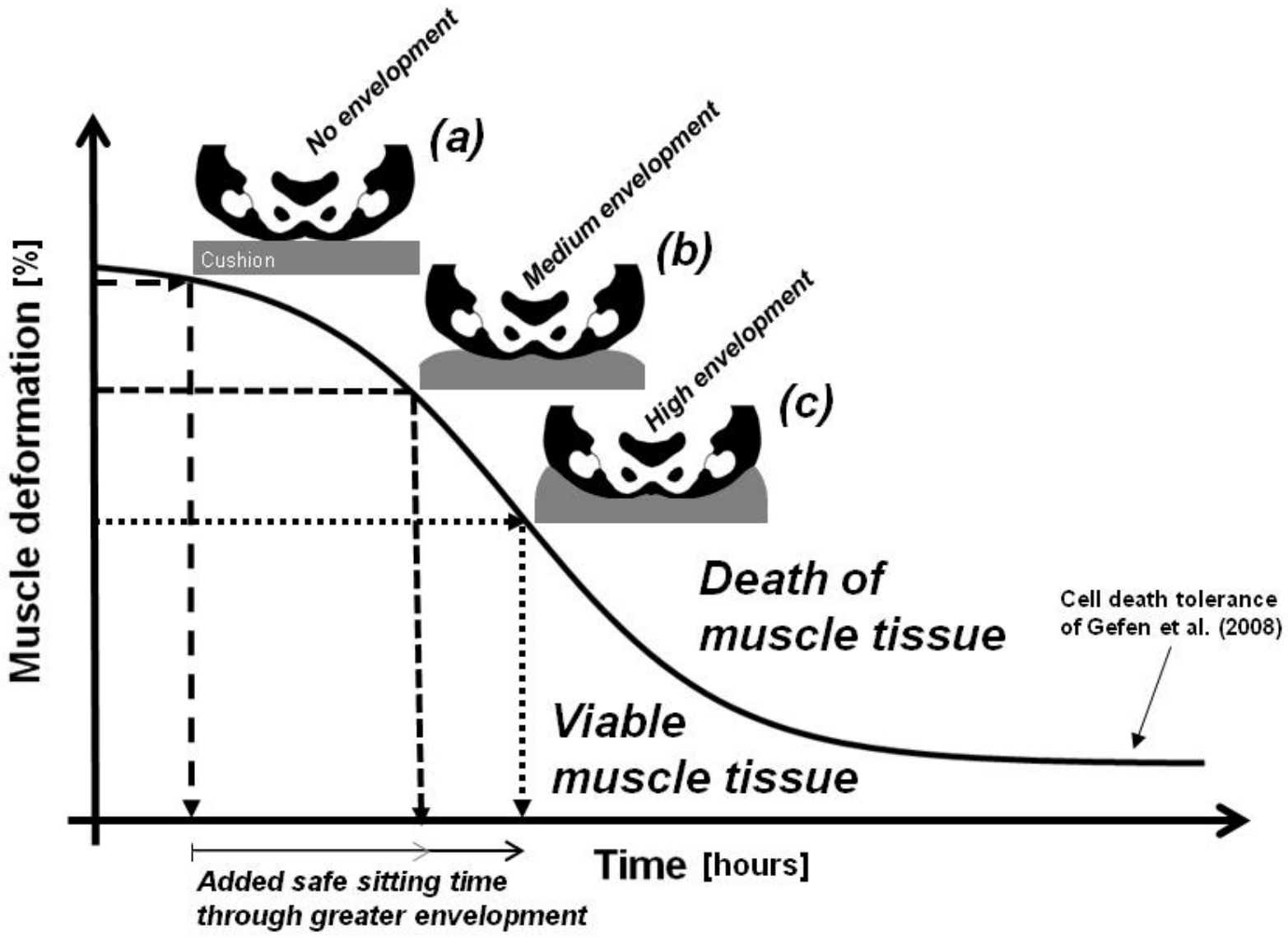
Exposure to deformations kills cells and tissues fast!
Much faster than ischemia

Up to 6 – 8 hours

Minutes to hours

Conclusion: support surfaces and devices for prevention should minimize internal tissue deformations and loads, not (just) interface (skin) pressures!

Adequate envelopment minimizes tissue deformations



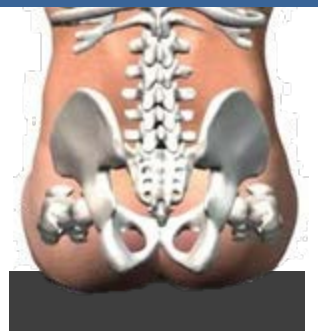
Gefen, *Ostomy Wound Management* 2014

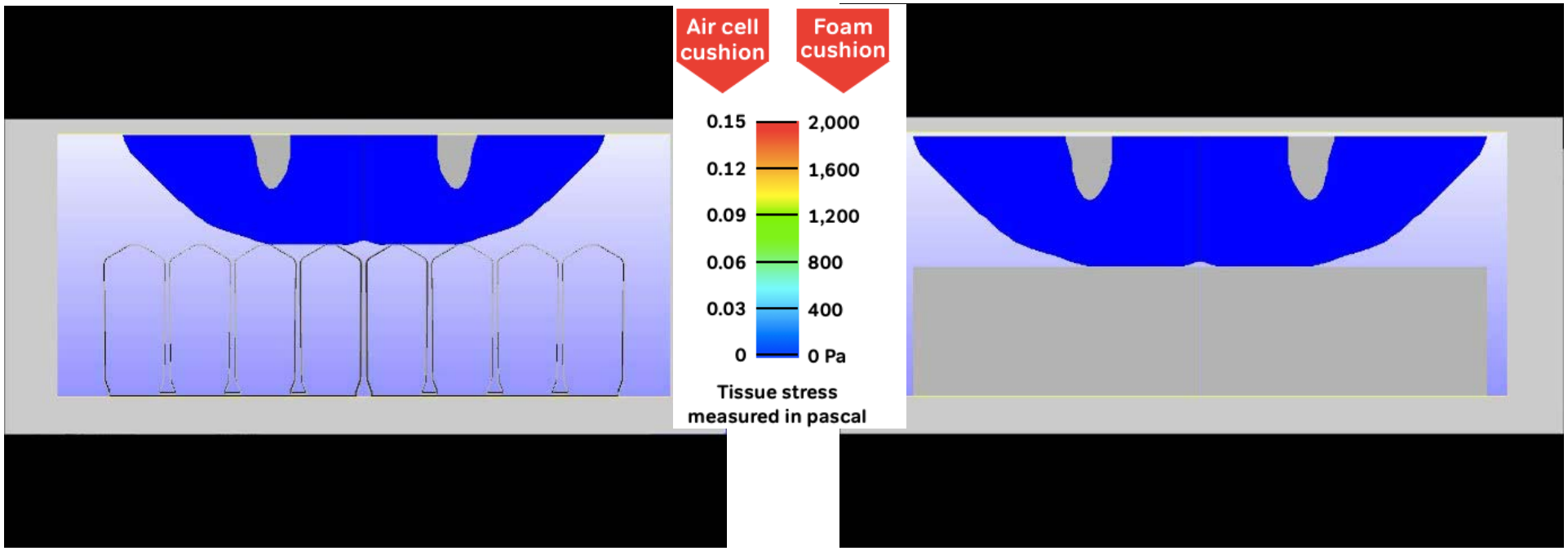
Example: Greater envelopment substantially reduces localized tissue loads during wheelchair sitting

Air-cell-based (ACB) cushion

Flat foam cushion

stiffness= 10 kPa





Levy et al. *Journal of Tissue Viability* 2014

Goal

Integrate previous modeling concepts
with pathoanatomical and biomechanical tissue changes that result from obesity and diabetes…

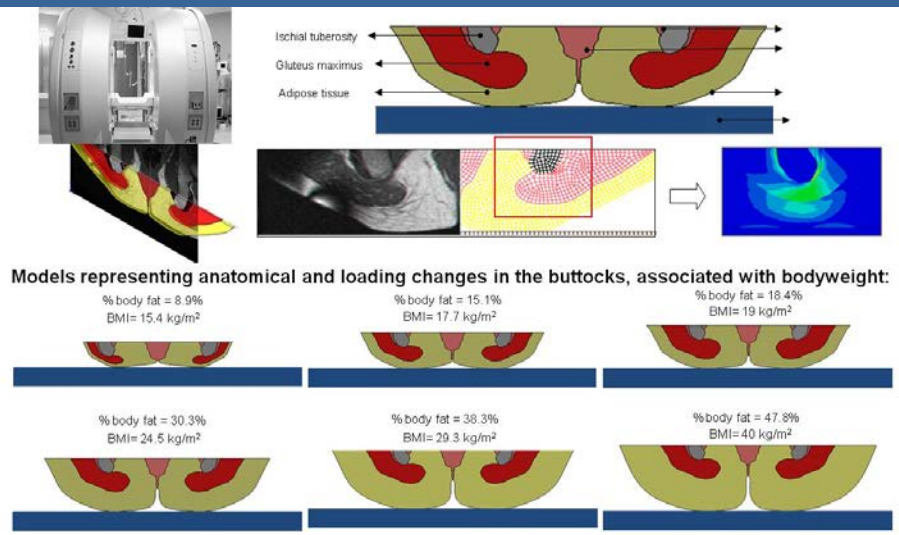
…to determine how a support surface might reduce this risk.

Modeling tissue loads on foam cushions

- Sopher & Gefen (2010) used FE models to investigate how BMI variations influence tissue loads on flat foam cushions

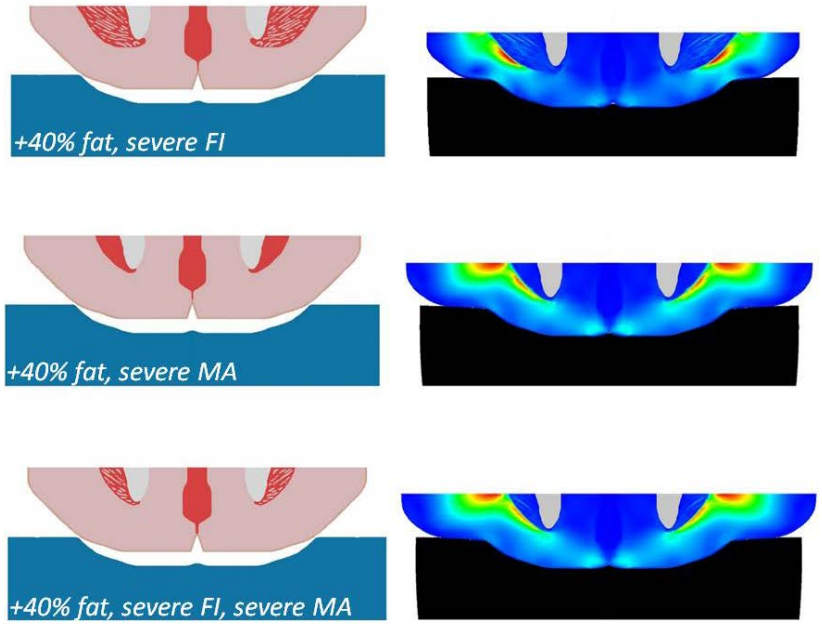
- Shoham & Gefen (2015) used the same method to explore how fat mass affects tissue loads on contoured foam cushions

- Both studies reported a **considerable increase** in muscle strains/stresses with increased levels of BMI or fat mass



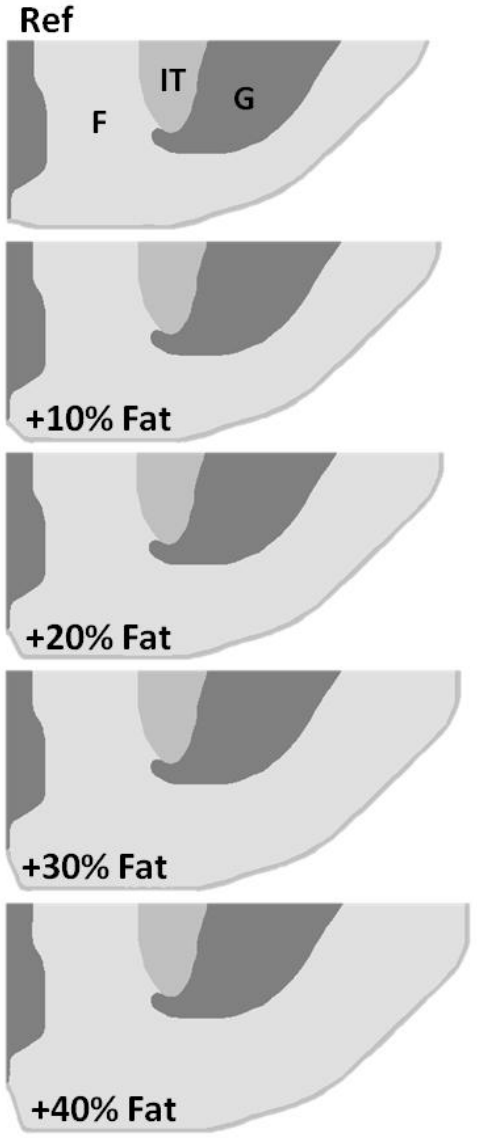
Elsner & Gefen, *J Biomech* 2008

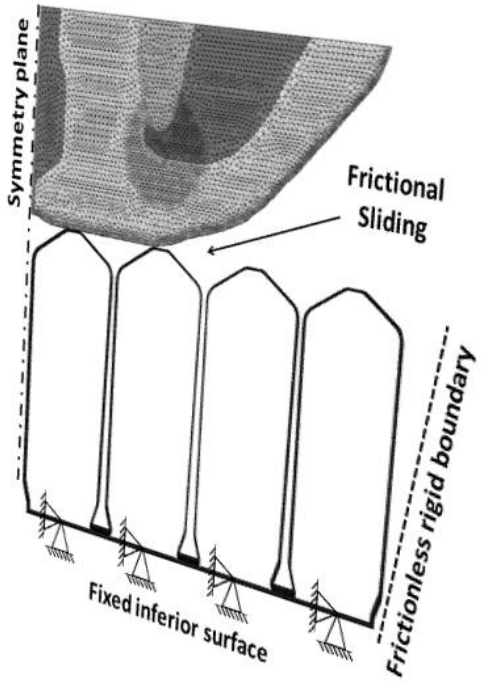
Sopher and Gefen, *J Biomech* 2010

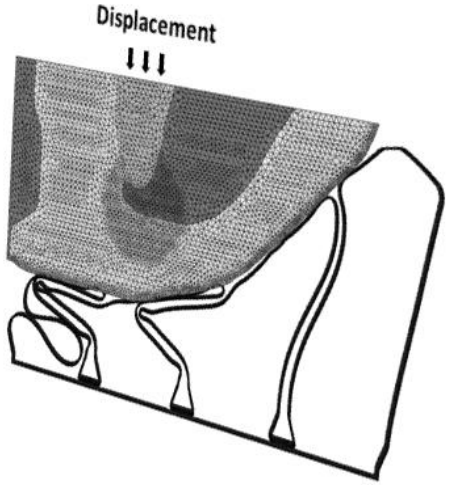


Shoham et al. *Adv Skin Wound Care 2015*

Model variants to simulate weight gain while sitting on an ACB cushion



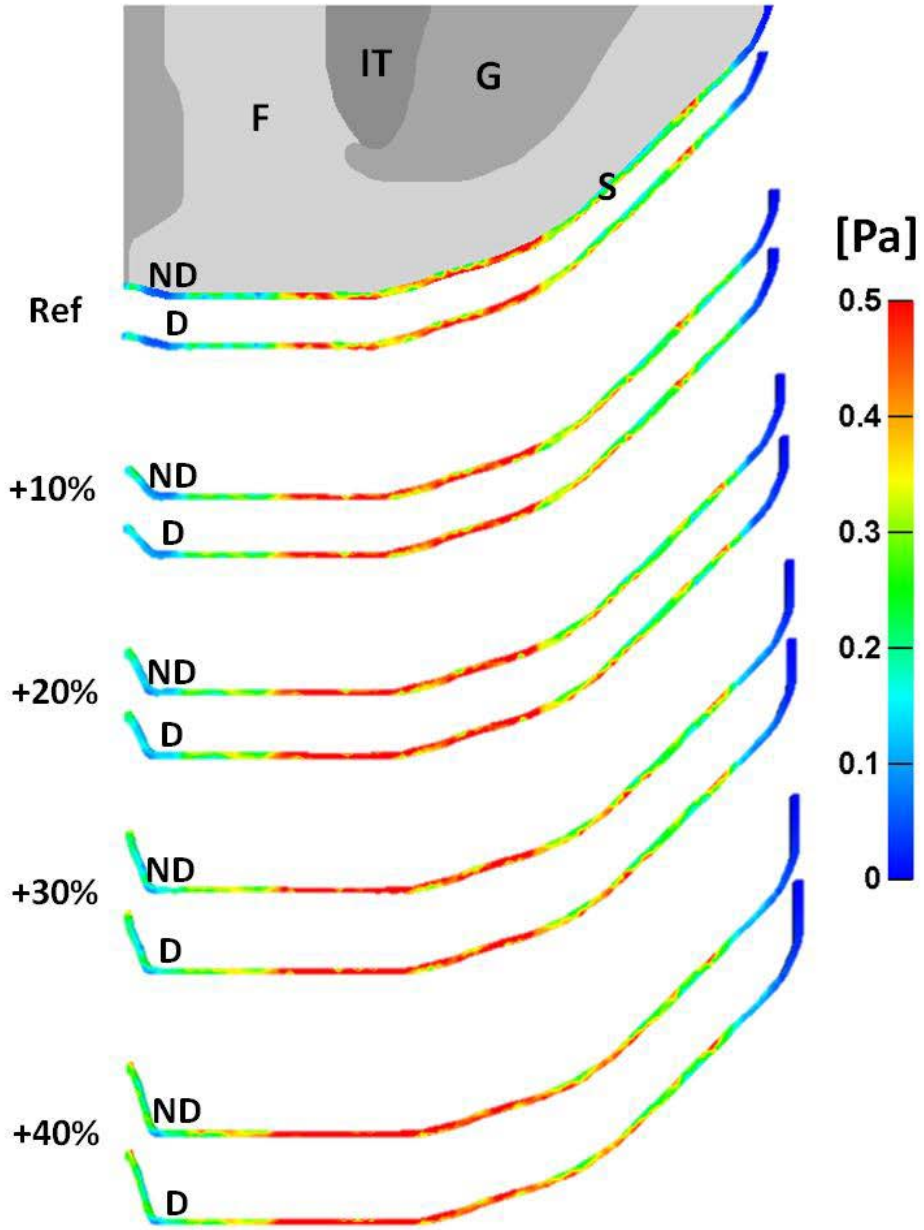




Skin tissue stresses in diabesity models

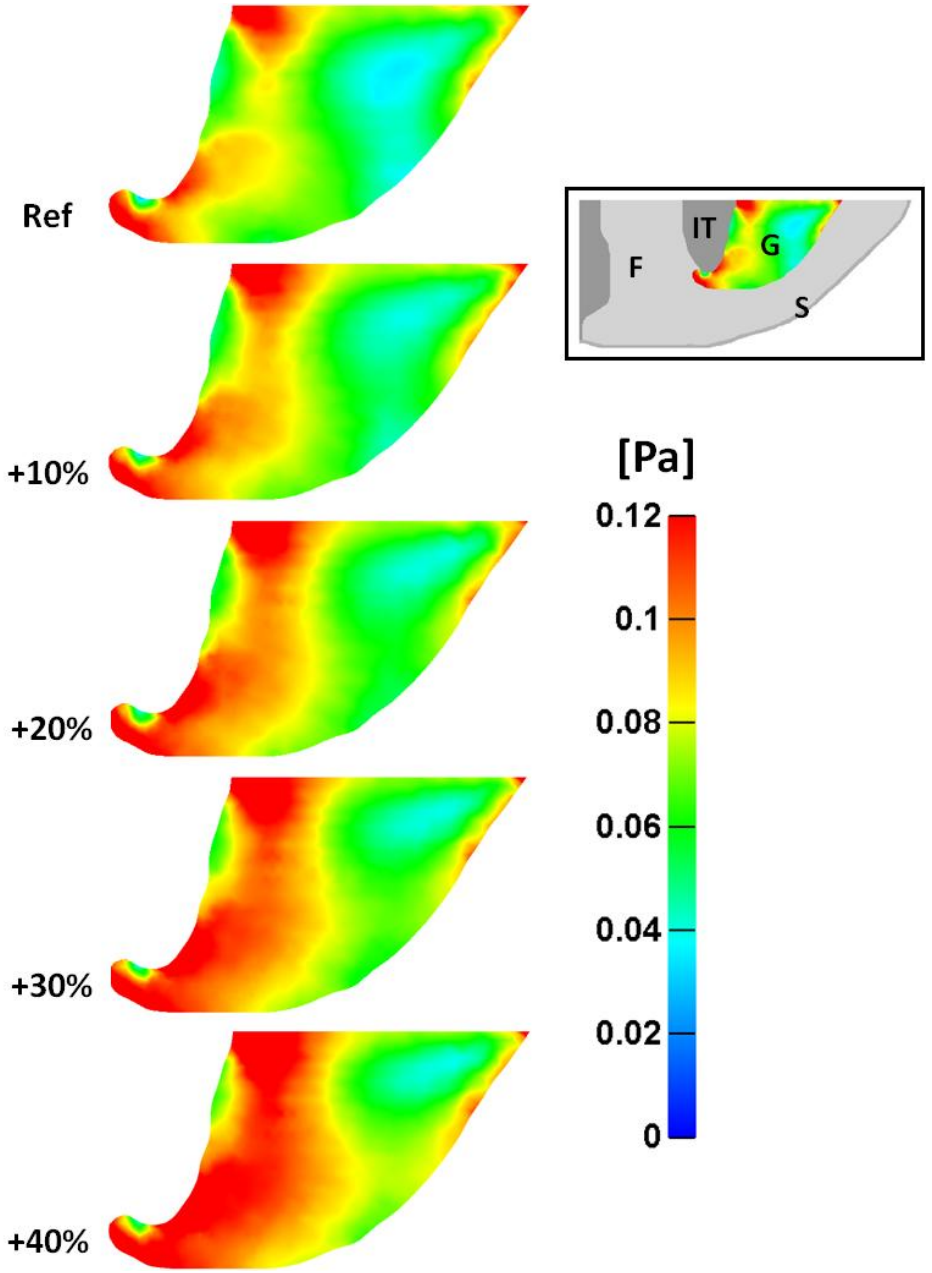
Diabetic skin and fat tissues were considered as **being 40% stiffer** than non-diabetic tissues according to the literature

The locally increased soft tissue stiffness in skin and fat imposes the risk of elevated tissue stresses, while also subjecting nearby tissue segments to an increased risk of deformation-inflicted injury

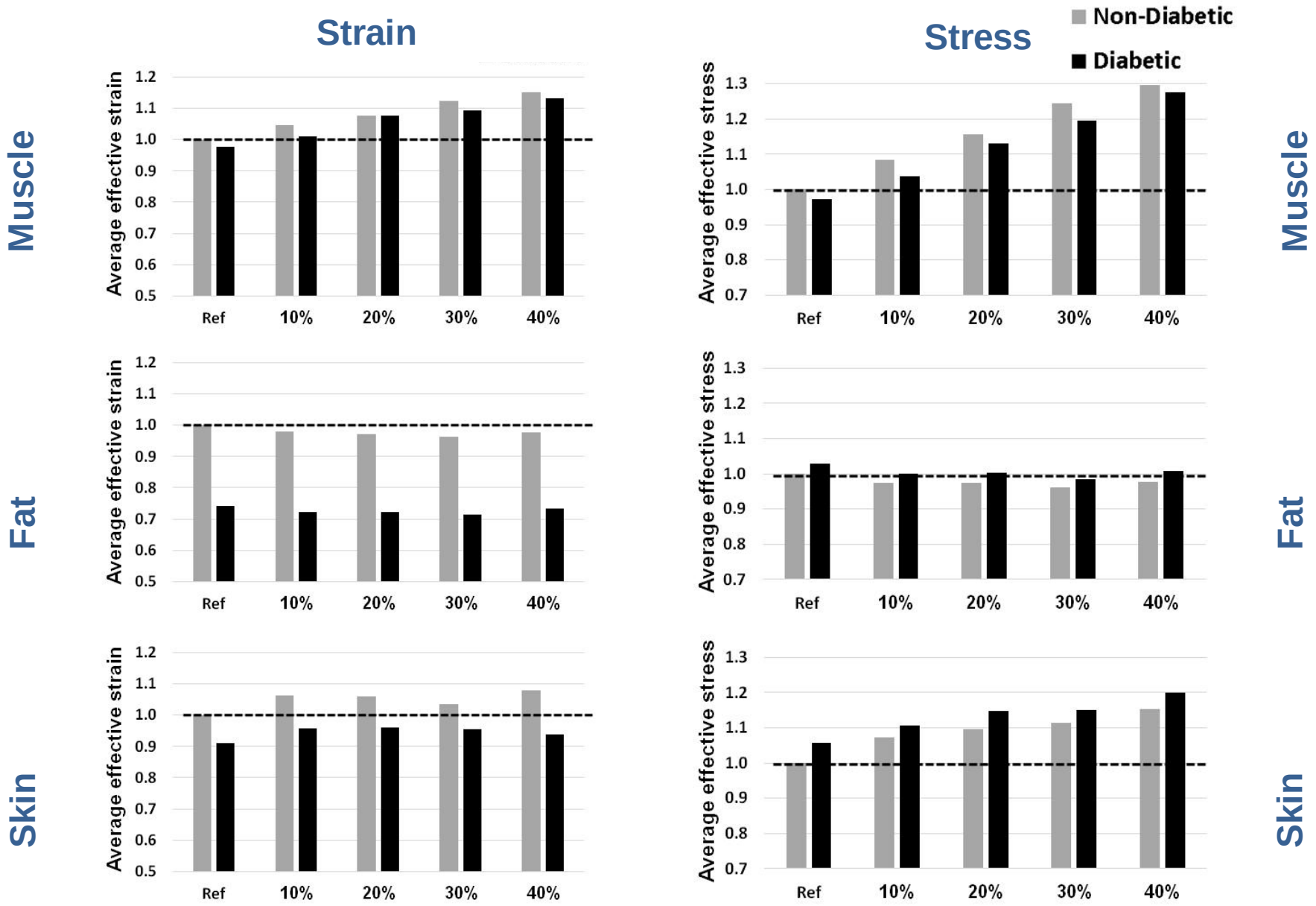


Muscle tissue stresses in weight-gain models

Volumetric exposure to elevated gluteal muscle tissue stresses increases as bodyweight rises



Diabesity: The combined effect of obesity and diabetes



ACB cushions keep the effective average strain/stress values from exceeding a +20% increase for up to +20% increase in fat mass (equivalent to BMI of 30)

Key Finding

Tissue **stresses in the "worst case"** diabetic, obese simulation seated **on an ACB cushion, were a fraction of the stresses** reported in the literature **for "best case",** non-obese, non-diabetic simulated subjects **on foam.**

Through immersion and envelopment, this risk of diabesity was substantially reduced by the ACB cushion.

Discussion and Wrap-Up

- Previous research demonstrated that strains and stresses in weight-bearing tissues of the buttocks significantly increase with rise in body or fat masses

- However, **the ACB cushion was able to dramatically counter this pathophysiological risk factor of diabesity.**

- The **ACB** cushion's **adaptability** and **adjustability** allow it to conform to a variety of anatomies and pathophysiological changes, including this often overlooked **risk factor of diabesity.**

Publication

FEATURE

A Computer Modeling Study to Evaluate the Potential Effect of Air Cell-based Cushions on the Tissues of Bariatric and Diabetic Patients

Ayelet Levy, MSc; Kara Kopplin, BSc; and Amit Gefen, PhD

Abstract
Sitting-acquired pressure ulcers (PUs) are a potentially life-endangering complication for wheelchair users who are obese and have diabetes mellitus. The increased body weight and diabetes-related alterations in weight-bearing tissue properties have been identified in the literature to increase the risk for PUs and deep tissue injuries (DTIs). A computer modeling study was conducted to evaluate the biomechanical effect of an air cell-based (ACB) cushion on tissues with increased fat mass and diabetes, which causes altered stiffness properties in connective tissues with respect to healthy tissues. Specifically, 10 finite element (FE) computer simulations were developed with the strain and stress distributions and localized magnitudes considered as measures of the theoretical risk for PUs and DTIs to assess the effects of fat mass and pathological tissue properties on the effective strains and stresses in the soft tissues of buttocks during sitting on an ACB cushion. The FE modeling captured the anatomy of a seated buttocks acquired in an open magnetic resonance imaging examination of an individual with a spinal cord injury. The ACB cushion facilitated a moderate increase in muscle strains (up to 15%) and stresses (up to 30%), and likewise a moderate increase in size of the affected tissue areas with the increase in fat mass, for both diabetic and nondiabetic conditions. These simulation results suggest wheelchair users who are obese and have diabetes may benefit from using an ACB to minimize the increased mechanical strains and stresses in the weight-bearing soft tissues in the buttocks that result from these conditions. Clinical studies to increase understanding about the risk factors of both obesity and diabetes mellitus for the development of PUs and DTIs, as well as robust preclinical comparative studies, may provide much-needed evidence to help clinicians make informed PU prevention and wheelchair cushion decisions for this patient population and other wheelchair-bound individuals.

Keywords: wheelchair, support surfaces, obesity, diabetes, finite element modeling

Index: *Ostomy Wound Management* 2016;62(1):22–30

Potential Conflicts of Interest: This research project is supported by a grant from ROHO, Inc, Belleville, IL aimed at developing computational models for evaluating the effects of cushioning materials and designs on buttocks tissues during weight bearing. Dr. Gefen is the Chair of ROHO's Scientific Advisory Board. Ms. Kopplin is employed by ROHO, Inc.

In the medical literature and clinical guidelines,[1] pressure ulcers (PUs) are defined as localized injury to the skin and/or underlying tissues that develop as a result of excessive and sustained pressure and/or shear, usually under a weight-bearing bony prominence. After more than a decade of rigorous research work, it is now well established that severe PUs are caused primarily due to exposure to sustained large tissue deformations over critical time periods that compromise the integrity and homeostasis of cells and the viability of tissues.[1-6]

PUs are categorized with respect to either their depth or the types of tissues involved. Superficial (skin) PUs are commonly associated with frictional forces, shear loads, and

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