A biomechanical model designed for real-time monitoring of internal mechanical loads in soft tissues of the seated buttocks based on pressure mat measurements

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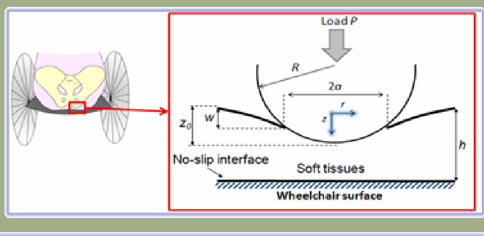
1 Background & Aim

- Spinal cord injury patients are under daily risk for developing **deep tissue injury** (DTI)
- DTI is a severe pressure ulcer that initiates at the proximity of the ischial tuberosity (IT) bones



We aimed to formulate a patient-specific biomechanical model that can continuously monitor internal tissue stresses in real-time

2 Biomechanical Model

- We adopted a solution of an axisymmetric contact problem of a finite-thickness, transversely isotropic elastic layer (soft tissue) and a rigid spherical indenter (IT).
- The stress components for the von Mises stress for a non-slip contact model are:

$$\sigma_{rr} = -c_{13}\frac{a^2 - r^2}{2Rh};\sigma_{zz} = -c_{33}\frac{a^2 - r^2}{2Rh};\sigma_{rz} = -\frac{c_{44}r}{Rh}(h - z)$$

where $a = \sqrt[4]{4RhP/\pi c_{33}}$ and C_{ij} are the elastic constants of the soft tissues.

- The stress components for the von Mises stress for a free-slip contact model are:

$$\sigma_{rr} = -\frac{(c_{11} - c_{12})c_{13}}{8c_{11}Rh}(2a^2 - r^2);\sigma_{rz} = 0;\sigma_{zz} = -\frac{c_{11}c_{33} - c_{13}^2}{2c_{11}Rh}(a^2 - r^2)$$

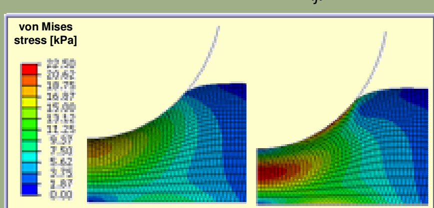
where $a = \sqrt[4]{4Pc_{11}Rh/\pi(c_{11}c_{33} - c_{13}^2)}$

- We accounted for friction between the soft tissues and the IT using β proportional to the IT-soft tissue friction coefficient:

$$\sigma_{VM}(t,r,z) = \beta\left(\sigma_v^{no-slip}(t,r,z)\right) + (1-\beta)\left(\sigma_v^{free-slip}(t,r,z)\right)$$

3 Biomechanical Model

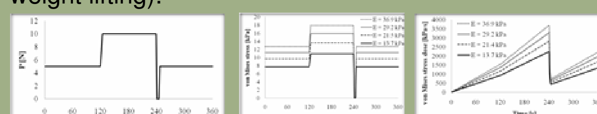
- We utilized finite element (FE) analyses to account for large deformations and obtain a geometry function, $\alpha = A\left(\frac{R}{h}\right)^B$, which multiplies the constitutive parameters , C_{ij}.



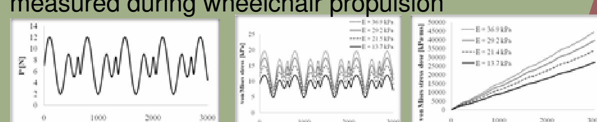
- Sensitivity analyses of anatomy and tissue mechanical properties, showed that the mechanical properties (elastic modulus, Poisson's ratio) of the soft tissue are the most influential factors in this modeling.

4 Simulations & Patient Studies

- We calculated peak internal von Mises stresses , as well as the internal stress dose (ISD), as the numerical time integral of the peak internal von Mises stress in the soft tissue.
- We simulated static bilateral sitting (including shifting and weight lifting):



- We simulated dynamic sitting according to force patterns measured during wheelchair propulsion

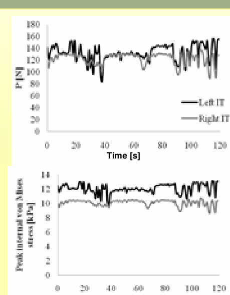


- The present algorithm was tested with sitting pressure data recorded from 5 paraplegic patients.
- A stress asymmetry index (SAI) was calculated:

$$SAI(t) = \log\left(\frac{\sigma_{VM}^{left\ IT}}{\sigma_{VM}^{right\ IT}}\right)$$

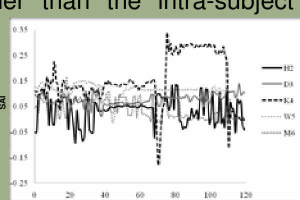
5 Results

- An example of the measured loads and internal stresses for one patient:
- Measured loads were similar under the left and right IT during the 40-65s timeframe.
- Contrarily, internal von Mises soft tissue stresses at that time were evaluated to be higher under the left IT – probably produced by a sharper left IT indenting a thinner soft tissue layer at that side.



- Inter-subject variability was higher than the intra-subject variability.

Patient ID	Side	Maximal peak stress [kPa]	Average of peak stresses [kPa]	COV [%]
H2	Left	40.8	34.9 (4.1)	11.7
H2	Right	34.5	31.9 (1.3)	4.1
D3	Left	13.7	12.1 (0.7)	5.4
D3	Right	10.7	10.1 (0.4)	4
K4	Left	38	12.4 (4.7)	37.9
K4	Right	26.3	12.2 (4.1)	33.6
W5	Left	52.9	50.3 (2.3)	4.6
W5	Right	41.1	38.5 (1.1)	2.9
M6	Left	44.5	42.6 (1.2)	2.8
M6	Right	43.2	39 (2.8)	7.2
Average stress [kPa]:		34.6 (13.7)	28.4 (15.2)	
COV [%]:		39.5	53.4	



6 Discussion & Conclusion

- We believe that this method holds a high potential for clinical applications, bridging between sophisticated modeling efforts at the research lab and clinical needs.
- As a next step, we hope to translate it to a medical device ready for large-scale human studies, with the aims of screening patients at risk for DTI based on high ISD or SAI values, and also, for training patients by means of biofeedback to avoid DTI.