Reliability of the in vivo Test Protocol for Measuring Biomechanical Properties of Buttock Soft Tissue

Jue Wang, M.S.
David M. Brienza, Ph.D.
Gina Bertocci, Ph.D.
Vikram Chib
Patricia Karg, M.S.
Ying-wei Yuan, Ph.D.

Seating and Soft Tissue Biomechanics Laboratory
University of Pittsburgh

A Research Slide Lecture
from the website of Wheelchair University
(http://www.wheelchairnet.org/)
Wheelchair University is a project of the
Rehabilitation Engineering Research Center (RERC) on Wheeled Mobility

Rehabilitation Science and Technology Department
University of Pittsburgh
5044 Forbes Tower
University of Pittsburgh
Pittsburgh, PA 15260

Abstract

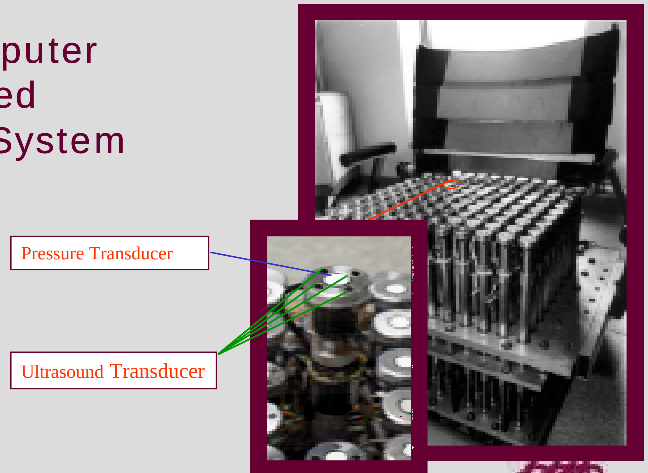
- In vivo indentation properties of buttock soft tissue were evaluated using the Computer Automated Seating System (CASS) and quasi-linear viscoelastic (QLV) modeling. Two non-disabled subjects, age 20 & 23, were tested. R2 for curve fitting of the QLV model parameter to experimental data were greater the 0.97. The ratios of standard deviation to mean for all four QLV parameters were less than 27%. The time dependent relaxation material parameter, α, from parameter wer larger than 0.72. The results demonstrated the reliability and repeatability of our in vivo buttock soft tissue assessment process using the CASS and associated protocol.

Citation

- Wang, J., Brienza,D. M., Bertocci, G., Chib, V., Karg, P., Yuan, Y. (2000). Reliability of the in vivo test protocol for measuring biomechanical properties of buttock soft tissue. The Proceeding the Annual RESNA Conference. June 28-July 2, Orlando, FL, p. 366-368.

Introduction (1)

- The Computer Automated Seating System (CASS)

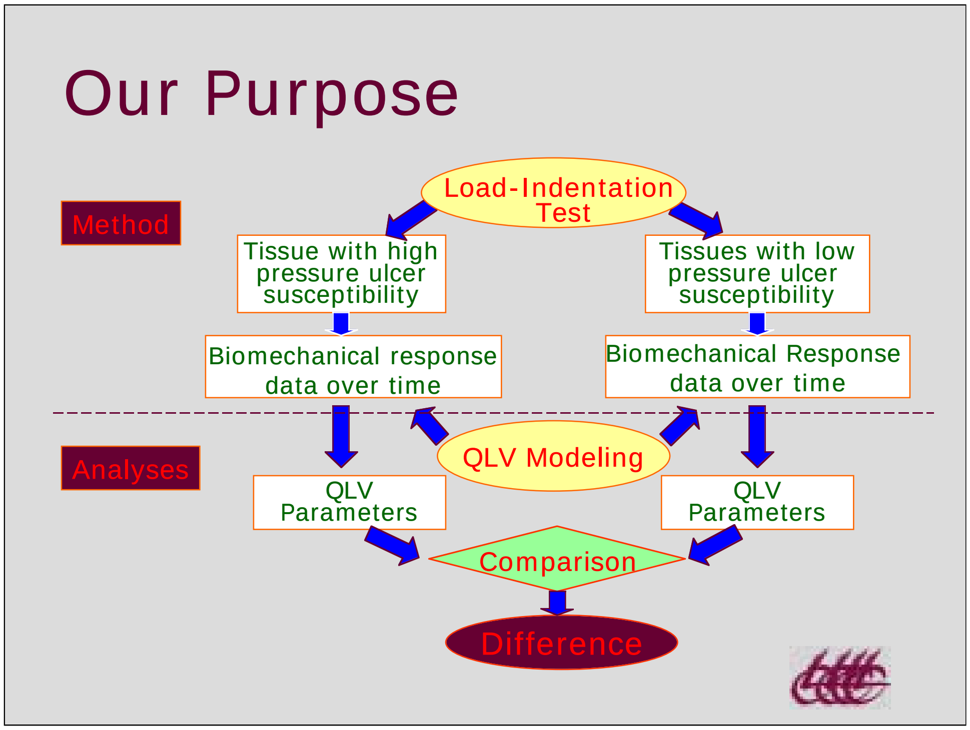


Introduction (2)

- An in vivo test protocol using the quasi-linear viscoelastic (QLV) model to assess the biomechanical properties of buttock soft tissues is being developed.

Objective

- Identify tissue response and biomechanical properties that correlate with a risk for pressure ulcer development


Our Purpose
Method
Load-Indentation Test
Tissue with high pressure ulcer susceptibility
Tissues with low pressure ulcer susceptibility
Biomechanical response data over time
Biomechanical Response data over time
Analyses
QLV Modeling
QLV Parameters
QLV Parameters
Comparison
Difference

Questions

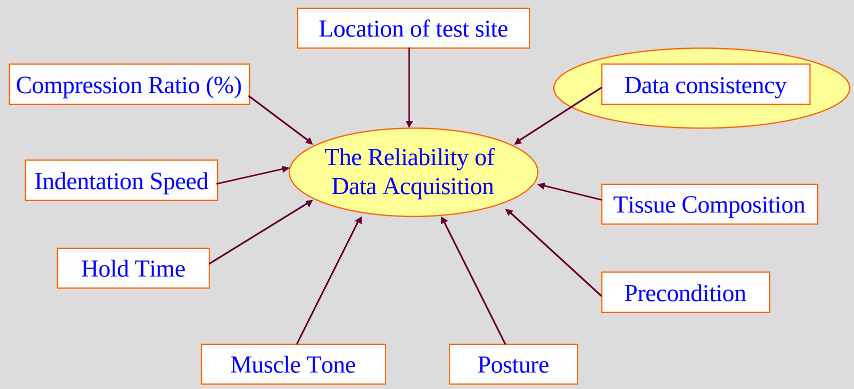
- ✦What is the repeatability of measurement data?
- ✦Is the QLV model appropriate for the response of buttock soft tissue?

Confounding Factors (1)

- The factors affecting the measurement of thickness of soft tissue layers
  - IT, femur bone, and buttock tissues have complex shape or multiple compositions --> miss the echoes from deep tissue interface;
  - The swiveling head of the sensor responds to body tissue changes --> miss the echoes from deep tissue interface;
  - During dynamic loading condition, soft tissue can deform and their density can be changed by compression or expansion --> lost tracking of interface.

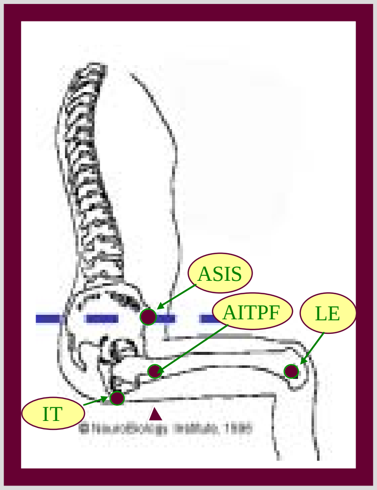
Confounding Factors

The Factors Affecting QLV modeling



Reference: Fung, 1993; Woo, 1981; Sauren, 1983; Zheng, 1996, 1999; Mak, 1994

The Location of Test Site



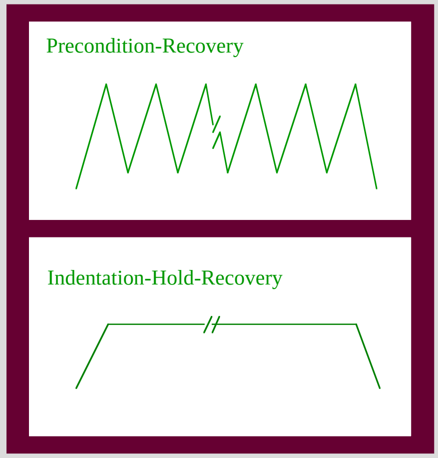
✦ Test Site is 4 cm anterior to IT on the proximal femur (arrow)

Test Protocol

- Preparation
  - Position subject's test site above one of the sensors in the 3 by 3 sensor array in CASS using a special cushion;
  - Adjust the angle between the seat and the back support, footrests, and armrests (comfortable posture)

Data Acquisition

- Preconditioning
  - Move sensor through indentation-recovery cycles for 3 min.at 1 mm/sec.;
  - The indentation range: 20% of initial thickness of bulk soft tissue layer.
- Indentation Test
  - Move the sensor through a indentation-hold-recovery cycle;
  - Hold Time: 5 min.;
  - Indentation-recovery speed: 1 mm/sec.



Soft tissue Modeling

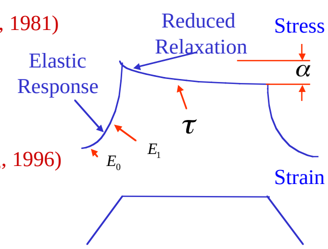
- Viscoelastic properties of soft tissues are modeled in terms of reduced relaxation function, G(t), and elastic response, $P^{(e)}(u)$, of buttock soft tissue in QLV model.

$$P(t) = \int_{-\infty}^{t} G(t-\xi)\frac{\partial P^{(e)}(u(\xi))}{\partial u(\xi)}\frac{\partial u(\xi)}{\partial \xi}d\tau$$ (Fung, 1981)

$$G(t) = 1 - \alpha + \alpha e^{-t/\tau}$$ (Zheng, 1996)

$$P^{(e)}(u) = \frac{2ah}{1-v^2}uk(h,u)E^{(e)}(u)$$ (Zheng, 1996)

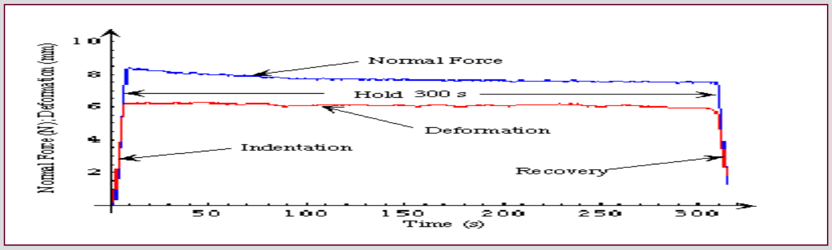
$$E^{(e)}(u) = E_0 + E_1 u(t)$$ (Zheng, 1996)



Notes: a is the radius of the indentor, h is the initial thickness of the tissue layer, v is Poisson's ratio, k(h,u) is a scaling factor (v, a/(h(1-u)), u(t) is relative indentation (w/h), α is the reduced relaxation parameter, τ is the time constant, E_0 is the initial modulus, and E_1 is the nonlinear modulus.

Results (1)

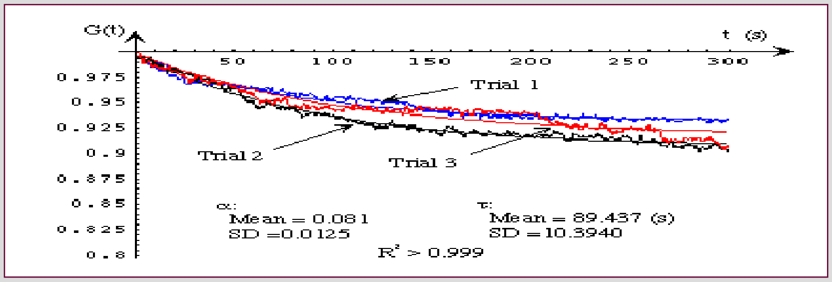
Loading Response in time domain



- Simultaneous measurement of force, sensor tilt angle, and tissue deformation

Results (2)

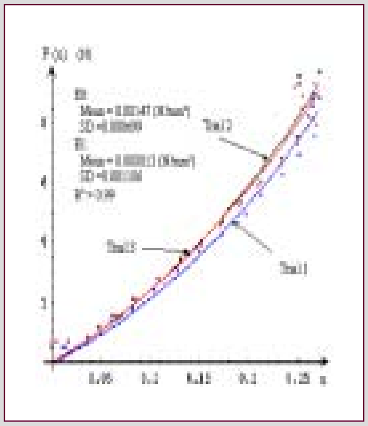
Curve fitting reduced relaxation function



- Reduced relaxation properties for three successive trials
  - Consistent data from three trials suggested repeatability of the system performance and the test protocol under dynamic loading conditions.

Results (3)

Curve fitting elastic response



- Elastic Response for three successive trials
  - Visco-elastic property of soft tissues affects the repeatability of the data, especially in in vivo measurement.
  - Using pseudo-elasticity method, after precondition, the repeatability of the data for three trials was improved.

Results (4)

	Subject 1				Subject 2			
Parameters	Alpha	Tou (s)	E_0 (N/mm^2)	E_1 (N/mm^2)	Alpha	Tou (s)	E_0 (N/mm^2)	E_1 (N/mm^2)
Mean	0.081	89.44	0,00375	0.04777	0.087	64.06	0,00815	0.00801
SD/Mean%	15.47	11.62	12.81	15.13	22.64	26.77	6.08	16.26
R^2 for curve fitting	> 0.93		> 0.87		>0.92		> 0.97	
ICC_{Alpha}: -----	ICC_{Tou}: 0.726		ICC_{E0}: 0.9675		ICC_{E1}: 0.9212			

- Comparison of QLV parameters between two subjects
  - Standard deviations/ Mean for four QLV parameters were less than 27%;
  - Good curving fitting, R squares were greater than 0.87;
  - The mean of the data for time-dependent material parameter, as were close;
  - The intraclass correlation coefficient (ICC) for other three QLV parameters were larger than 0.72.

Discussion (1)

- In our initial tests, the results for early reduced relaxation showed 14 times error between QLV parameters for repeated tests. (The data cannot be used for comparison)
- The current test protocol greatly improves the consistency of results (Standard deviations/ Mean for four QLV parameters were less than 27%).

Discussion (2)

- Our tests showed that the protocol with less than 14 N load and in 10-30% deformation are in accord with the physiological range and the QLV modeling condition.

Discussion (3)

- There are more complex factors which affect the consistency of data in in vivo test;
- Preconditioning improved the consistency of the sampling data.

Conclusion

- The test protocol for using CASS and QLV modeling provided consistent data to determine the in vivo biomechanical properties of buttock soft tissues.

Acknowledgement

✦ This study was funded by Paralyzed Veterans of America, Spinal Cord Research Foundation, and the NIDRR RERC on Wheeled Mobility grant #H133E990001