

## REAL-TIME SUBJECT-SPECIFIC FINITE ELEMENT MODEL OF THE BUTTOCK DURING WHEELCHAIR SITTING: A TOOL TO EVALUATE THE MECHANICAL CONDITIONS FOR DEEP PRESSURE SORES

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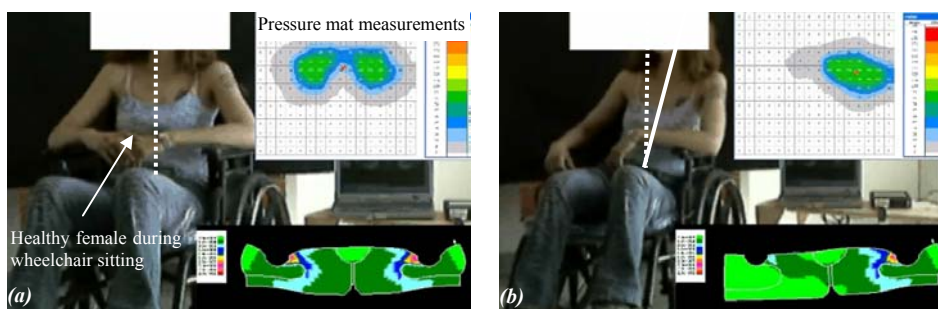
Deep pressure sores (DPS) in sub-dermal tissues of the buttocks are a life-threatening and costly complication in wheelchair bound patients. Excessive mechanical strains and stresses in the gluteus muscle under the ischial tuberosities (IT) are associated with DPS onset [1]. In this study, we developed a subject-specific finite element (FE) modeling method that allows visualization and analysis of deep tissue strains/stresses during wheelchair sitting in real-time, based on continuously measured sitting contact pressures.

**The subject-specific FE model.** A two-dimensional (2D), plane stress FE model of the IT and enveloping soft tissues was developed based on a cross-sectional MRI anatomy. The IT-gluteus interface was set as "no-slip", and sitting pressures, sampled at 10 Hz using a pressure mat (Tactilus, Sensor Products Co.), were fed into the model as real-time contact force boundary conditions (Figure). The FE system of equations is solved using the *LU decomposition* method. Briefly, this method provides the optimal time for solution in case that only the vector of boundary conditions is changing between multiple solutions [2]. To verify our real-time FE code for numerical accuracy, we compared its calculations with those of commercial FE software (Nastran 2004) and found differences that were smaller than 5 kPa. In order to validate our model results, strain and stress distributions were compared to human measurements resulted from MRI scanning (4 subjects) and stress distributions were compared with physical phantom measurements, respectively.

**Healthy subject studies.** Real-time, subject-specific FE models of the ischium region were built for four healthy subjects based on their MR images. Subjects were asked to sit in a wheelchair in a neutral position and watch a movie for 90 minutes (Figure). Based on continuous contact force measurements acquired using the pressure mat, real-time FE analysis of deep tissue strains and stresses in the buttocks was obtained for each subject (Figure). Specifically, we monitored peak principal compressive strains and peak principal compressive, shear and von Mises stresses in the right and left gluteus muscles.

For the four subjects, cross-correlation coefficients between deformed muscle contours calculated from MRI or using real-time FE did not drop below 0.8. The mean error between contours was smaller than 10%, and the standard deviation was kept below 5%. The internal stresses calculated using real-time FE were in very good agreement with internal stresses measured by the phantom ( $p>0.98$ ). Mean value of the predictive error of the real-time FE model was found to be  $4 \pm 4$  kPa (N=44 experiments). Our healthy subject studies showed maximal principal compressive strains of  $72 \pm 5\%$  and  $68 \pm 7\%$  under the right and left IT, respectively. Principal compressive, shear and von Mises stresses were found to be  $34 \pm 3$  kPa,  $14 \pm 1$  kPa and  $31 \pm 4$  kPa under the right IT, and  $32 \pm 4$  kPa,  $13 \pm 2$  kPa and  $30 \pm 2$  kPa under the left IT, respectively. Maximal continuous exposure to pressure was  $24 \pm 17$  min and  $13 \pm 8$  min for right and left sides, respectively.

We conclude that real-time FE is a valid method for monitoring gluteal strain/stress distributions under the IT, and are expecting that this method will make a substantial contribution in preventing severe DPS among chronic wheelchair users.



Real-time predictions of gluteal strains and stresses during wheelchair sitting using our subject-specific FE model and system: symmetrical sitting (a), and tilting to the left (b)

1. Linder Ganz & Gefen. Mechanical compression-induced pressure sores in rat hindlimb: muscle stiffness, histology, and computational models. *J Appl. Physiol.* 96:2034-2049, 2004.
2. Yarnitzky, G., Yizhar, Z., and Gefen, A., 2005, "Real-time subject-specific monitoring of internal deformations and stresses in the soft tissues of the foot: A new approach in gait analysis," *J Biomech, In Press*.