ABSTRACT: A prosthetic socket design and fitting procedure for trans-tibial amputees is an iterative process requiring several visits to a highly skilled prosthetist. Computational modeling can be used to model the socket stump interaction and can assist this iterative fitting process. Dynamic Roentgen Stereophotogrammetric Analysis data was used as boundary conditions to accurately model bone-stump-socket interaction in a trans-tibial amputee finite element model. Large relative motion between fibula and tibia was accounted for in the analysis. The socket reaction forces were calculated using non-linear finite element analysis. We found that socket is subjected to non-zero pressures in all three directions of motion. The stress distribution in the soft tissues was assessed based on the accurate dynamic kinematic DRSA data. The simulation revealed that both location and magnitude of maximum normal and shear stresses is changing with time.

METHODS: The DRSA method is capable of assessing kinematics and strain of deformable materials (hard and soft tissue) with translational and rotational accuracy of less than ±0.1 mm and 0.8 degrees respectively for very high speeds of motion, up to 1000 Frames/s [1]. A patient with trans-tibial Elevated Vacuum socket participated in the study (IRB approved). The preliminary Finite Element Models (FEM) resulted from reconstructing solid models from Computed Tomography (CT) volumetric data that included the socket, the silicone liner, and the residual stump [2] (soft tissues, fibula, and tibia bones). The socket is modeled with homogeneous isotropic linear elastic material (Modulus of Elasticity of 1.1 GPa and Poisson’s ratio of 0.38). Both bones – fibula and tibia are much stiffer than the soft tissue and, therefore, assumed to be rigid. The soft tissues are considered to be homogeneous isotropic and compressible. We also assume that there is no slip between bones and soft tissues.

RESULTS: The results of motion tracking of the fibula and tibia markers over time showed that the bones move independently from each other in all three directions. The shear stresses in the soft tissues are depicted in Figure 2. Simulation revealed that both location and magnitude of maximum normal and shear stresses is changing in time.

CONCLUSIONS: The DRSA data was used to accurately describe bone-stump-socket interaction during the motion. Large relative motion between fibula and tibia was detected. This behavior can be attributed to bone and soft tissue structural instability below the knee joint. It was found that socket experiences non-zero pressures in all three directions of motion. Simulation revealed that both location and magnitude of maximum normal and shear stresses is changing with time. In the future, kinematics from more markers will be used to improve the model. Another future challenge is to distinguish between muscle, fat and skin tissues in the FE model.

SIGNIFICANCE: There is currently no method available to directly measure in-vivo stress within the residual stump in the amputee extremity. FEM, if validated appropriately, is the best available tool for predicting in-vivo computed forces and moments. Appropriate calibration of the FE models with experimentally measured high accuracy DRSA kinematics allows us to iteratively refine patient specific material properties and eventually estimate stress fields within the tissue.

ACKNOWLEDGEMENTS: NIH SBIR grant #: 1R44HD068150-01 and EC 7th Framework Marie Curie student/scientist exchange Actions—grant number 251649;