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A POROELASTIC MODEL FOR PLANTAR TISSUE DURING GAIT: MAIN FEATURES AND PERSPECTIVES

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Recently a new computational model, based on the thermodynamically constrained averaging theory [1], has been proposed to predict tumor initiation and proliferation [2-4]. A similar mathematical approach is proposed here to study plantar tissue mechanics.

The foot tissue is modeled as an elastic porous medium, in large strain regime and completely filled by a fluid phase. In detail, the tissue cells and their extracellular matrix form the solid skeleton with pores saturated by the interstitial fluid. Transport of nutrients and possible delivery of drugs within the microvasculature are also considered by introducing an effective diffusion coefficient, which is estimated from the real degree of vascularization of the tissue. Furthermore, the tissue may become necrotic depending on the stress level and/or oxygenation degree; thus if an ulcer is formed, the tissue comprises a healthy and a necrotic fraction.

The primary variables of the model are: the interstitial fluid pressure p^f, the displacement vector of the solid phase $\mathbf{u}^s$, and the mass fraction of oxygen dissolved in the interstitial fluid, $\omega^{\overline{Of}}$. With respect to these primary variables, the governing equations are discretized in space by the finite element method [5], in time by using the θ-Wilson method and then solved numerically.

Considering the interstitial fluid allows mimicking the viscoelastic behavior of the plantar tissue observed experimentally by Gefen [6]. This is shown in the simulated cases, where a foot during stance and several gait cycles are modeled. The presented examples integrate experimental data at different scales (patient specific foot geometry, tissue elasticity and permeability, possible tissue vasculopathy, global forces measured during gait, etc.) and allow validating the developed modeling procedure by comparisons between numerical and measured plantar pressures. Being the global response of the bi-phase system viscoelastic, it is shown that the duration of stance as well as of each of gait cycle has an influence on tissue strain and stress fields. In Figure 1 discretization of the foot, load history and total stress field at two instants are shown.

Since the time scale of ulceration is much larger that the typical time increment used to model a gait cycle, a multiscale approach in time is under development. It will allow accomplishing this modeling framework, which final aim is the prediction of risk of foot ulceration in diabetic patients.

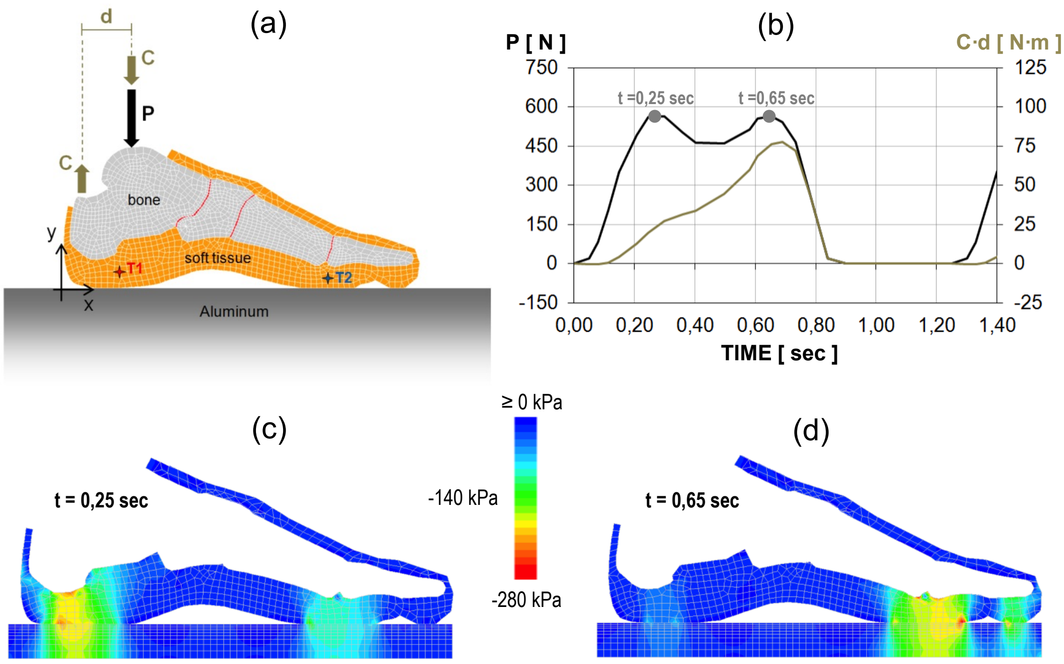

Figure 1: Geometry and load conditions (a); typical load history used in the numerical simulation (b). Total stress field t_{yy} at 0.25 sec. (c) Total stress field t_{yy} at 0.65 sec.(d).

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