MECHANICAL ENVIROMENT AROUND OSTEOCYTES DURING PHYSIOLOGICAL LOADING

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Introduction

The shape of osteocytes and lacunae vary with age, bone mechanical stimuli and bone matrix quality. Specifically, osteocytes and lacunae are elongated in lamellar long bones [1, 2], and more spherical in immature long bone [3], aged long bone [4], flat bones [2], woven bone [5], long bones with osteopenia [6], osteoarthritis [6] and osteogenesis imperfecta [1]. Osteocyte-lacunar shape affects cellular and bone strains, and pericellular fluid velocity, when axial loads are applied [7]. To date, it is unknown the mechanical environment around osteoctyes in response to physiological loading conditions. Thus, the aim of this study is to quantity the effect of osteocyte-lacunar morphology on the pericellular fluid velocity and on osteocyte and bone strain during walking and running. Altered osteocytes-lacunar shape may impair bone mechanics and mechanoadaptation.

Methods

We performed monolithic fluid-structure interaction (FSI) simulations (Abaqus) of two idealized osteocyte-lacunar models having same osteocyte volume (built in SolidWorks): a slightly elongated cell (minor and major axes ratio = 0.6) and a spherical cell (minor and major axes ratio = 1) [7]. Bone matrix around the osteocytes was modelled in a beam shape, with an interstitial fluid space of 0.75μm [7]. Ten dendrites (0.6 μm thick) were modeled for each cell. All bodies were meshed with tetrahedral elements. Cell and bone were linear elastic with bone having transversely isotropic properties (E_L = 16.61GPa, E_T = 9.55GPa, G_L = 4.74GPa, G_T = 3.28GPa, ν_L = 0.37) and cell being isotropic (E = 4.47KPa, ν = 0.3) [8]. The interstitial fluid were modeled as salted water ($\rho = 1E^{-9}$kgmm^{-3} and $\eta = 1E^{-9}$MPas-1). The initial pore pressure was assigned to be zero. A multiaxial cyclic displacement was applied on the top, bottom, right and left surfaces of the bone block to simulate bone strain during 10 seconds of walking and running, accordingly to the values of human tibia strains reported in the literature [9]. Cell and bone maximum principal strains and the bone interstitial fluid velocities were calculated for each model. The monolithic FSI approach allowed for the mutual influence between solids and fluid.

Results

The maximum principal strains in the bone matrix were comparable in the more elongated cell vs. spherical one during walking. Controversially, the bone matrix principal strain for the spherical cell were twice as much as those for the more elongated cell during running. Cell strains and pericellular fluid velocities were higher in the spherical cell (Fig. 1) compared to the more elongated one during walking and running. The maximum principal strains were always higher in the spherical cell for both activities. Peak maximum strain and fluid velocity values were reported around the dendrites.

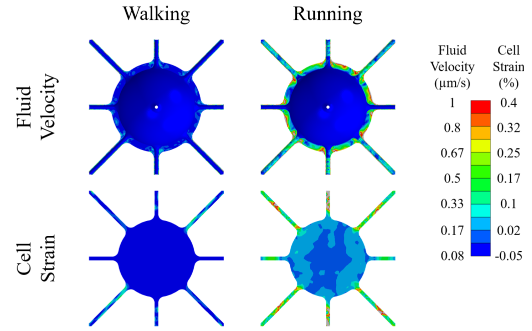

Figure 1 *Pericellular fluid velocities osteocyte strain for the spherical cell during walking and running at peak load*

Discussion

This study shows that spherical osteocytes and surrounding ECM experience higher levels of strain, as well as higher interstitial fluid velocities, during intense physical activity such as running. Moreover, cases of bones that show spherical osteocytes have also been associated with reduced spacing between cells and smaller Young's modulus [1, 10]. This could ultimately lead to an overall increase in bone and cell strains and pericellular fluid velocities, making bone fragile and cells more stimulated. Overall, these data may help us to better understand the implications of osteocyte shape in pathological cases of increased bone turnover and bone fragility such as osteogenesis imperfecta.

References

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