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COMPUTATIONAL SIMULATION OF THE DEFORMATION OF NEURONAL CELLS

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EXTENDED ABSTRACT

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A numerical simulation (finite element method (FEM)) is used to determine the local mechanical response of a neuron based on the real neuron geometry. The real 3D geometry of a neuron can be constructed from the 2D confocal image stack which is taken per micron along the thickness direction from the top surface of neuron to the substrate. By matching the simulated deformation of the neuron with the measured results from the confocal microscopy images, the relative strength of the neuron components can be determined based on the reverse analysis of FEM. Then, the neuron local mechanical response and the relationship between the local response and the global applied deformation can be obtained, which will be the first step of building the mechanical injury model of neuron.

INTRODUCTION

The mechanism of mild traumatic brain injury (mTBI) is directly related to the relationship between the mechanical response of neurons and their biological/chemical functions since the neuron is the main functional component of brain.[1] Therefore, understanding the mechanical response of neurons is an important first step to understand the mechanism of mTBI. Typically, the mechanical response of neurons is investigated based on the deformation of *in vitro* model, in which the substrate deformation is considered to be the deformation of neurons. However, neurons have the irregular shape and mainly include cell main body, neurite and axon which have highly different geometries and mechanical properties. Under the same global deformation (substrate deformation, e.g. substrate stretching), the different parts of a neuron might have the highly different local deformations. Therefore, it is important to understand the local mechanical response of neurons in order to get the accurate mechanical injury model of the neuron which describes the relationship between the neuron mechanical response and its function loss.

COMPUTATIONAL METHODS

A numerical simulation (finite element method (FEM)) can be used to determine the local mechanical response of a neuron based on the real neuron geometry. In FEM simulations, the real neuron geometry can be considered in both 2D and 3D. With the help of the software (Mimics),[2] the real 3D geometry of a neuron can be constructed from the 2D confocal image stack which is taken per micron along z-direction from the substrate to the top surface of neuron, as show in Figure 1. This 3D geometry can be further meshed in the finite element model, as shown in Figure 2. In FEM model, the neuron can be divided into three different regions: main cell body, neurite and axon, which have the different material properties. In the current work, all components of the neuron are modeled as both the elastic and the viscoelastic materials. The standard linear model (SLS) is selected for the viscoelastic materials. Based on the scanning probe indentation, the mechanical properties of the neuron was reported from 480 to 1600Pa in the frequency range of 30~200Hz.[3] These values are considered to be the properties of the cell main body of a neuron since the indentation test is usually applied on the cell main body. The mechanical property ratio of the axon and the neurite to the cell main body can be firstly assumed to be one and then gradually increase or decrease to match their simulated deformation field with the experimental counterpart (confocal images of the deformed neuron).

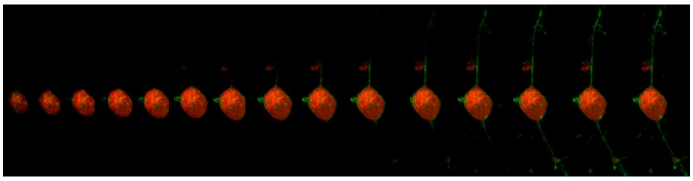

FIGURE 1. 2D confocal image stack of an isolated neuron (0.5µm between each image from the top surface to the substrate) .

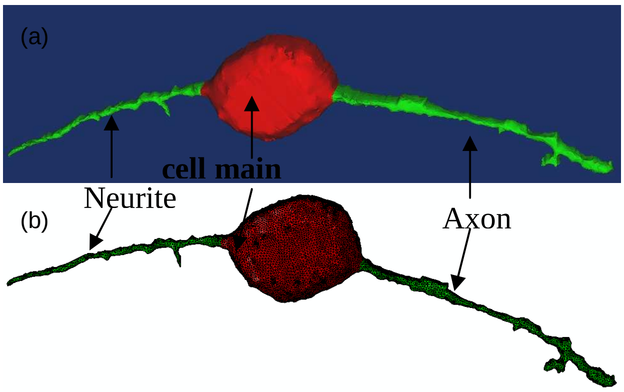

FIGURE 2. (a) 3D geometry of an isolated neuron created from 2D confocal image stack; (b) FEM mesh of 3D neuron structure.

EXPECTED RESULTS

In FEM simulations, the boundary condition of the neuron is selected similar to that used in the experiment. In the experiment, the neuron is assumed to be perfectly boned with the substrate, and, thus, the bottom of the neuron is clamped in the simulation. The uniaxial and equibiaxial stretch is applied on the neuron, respectively. The material properties of the neuron components are the set of properties which give the least difference between the simulated deformation field and the experimental counterpart.

CONCLUSIONS

The numerical simulation based on FEM can be used to determine the relative strength of the components of neurons: cell main body, axon and neurite by matching the simulated deformation field of a neuron and its experimental counterpart. Then, with those determined mechanical properties, the neuron local mechanical response and the relationship between the local response and the global applied deformation can be obtained, which will be the first step of building the mechanical injury model of neuron.

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