INTRODUCTION
Tissue is a compound material and adhesion plays a major role in compounding the materials. Brain has adhesive proteins to play this role, i.e. interfacial adhesion between axons as fibers and extracellular matrix, ECM, as matrix. Interfacial adhesion directly influences the load transfer process between fiber and matrix and hence it is responsible for properties including stiffness and fracture behavior of brain tissue. Therefore it affects greatly the response of brain tissue to sudden motions of head, e.g. in civilian accidents or due to blast shock waves, which result in Diffuse Axonal Injuries, DAI, one of the most common types of Traumatic Brain Injuries, TBIs.[2].

In spite of the fact that interfacial adhesion is of great importance in brain injuries, it is almost an undiscovered issue since its constitutive properties are difficult to measure and sensitive experiments need to be devised to identify such material parameters. Therefore it seems essential to have a predictive model in order to understand the influence of adhesive proteins on overall properties of brain tissue.

In this research, a novel micro scale method is proposed to study the effect of adhesion, extent of adhesive proteins and adhesion mechanical properties, on properties of brain tissue through local stress analysis.

METHOD
This method is based on application of windowing technique to an image of brain tissue. In this research an image of rat hippocampal neurons is examined (Figure 1-a). As it can be seen, the heterogeneous portions of brain have complicated geometries which cannot be analyzed using common FEM methods. In order to reduce the expense of computation, it is necessary to homogenize brain tissue. A representative volume element, RVE, which is an appropriate representation of the whole material, is selected (Figure 1-c). Chosen RVE is analyzed using Variational Asymptotic Method for Unit Cell Homogenization, VAMUCH[3], which simplifies the computation by taking advantage of periodic boundary conditions for unit cells. VAMUCH can predict the effective material properties of periodically heterogeneous materials and recover the local fields. The theory uses a variational statement of unit cell through an asymptotic expansion of the energy function.

In order to utilize VAMUCH, it is necessary to digitize the image (Figure 1-b). In order to digitize it, each pixel is determined to belong to axons or ECM. To have a complete model and to perform a more precise evaluation of mechanical properties of brain tissue, the adhesive proteins effects should be inserted into the proposed model. Therefore adhesive part can be added to the model as extra pixels in axon-ECM intersection. However, such a task needs increase in the resolution of image and it would extremely increase the computational costs.

Adhesion influence on brain tissue properties could be studied in two categories: first, effect of adhesion ratio i.e. extent of adhesive proteins divided to the extent of the axons, study I, and second, effect of adhesive proteins mechanical properties on mechanical behavior of brain, study II. Both axons and ECM are assumed to be elastic materials with Young's Modulus of 6000 Pa and 3000 Pa and Poisson’s ratio of 0.3 and 0.35, respectively.[1].

RESULTS
Study I
As mentioned earlier, in order to study adhesion effect on brain tissue properties, it is necessary to insert adhesive proteins in the model. It is known that adhesive proteins make a perfect bonding between axons and ECM throughout brain tissue. In this study, in order to understand the influence of extent of adhesive proteins on overall brain tissue properties, the adhesion ratio is increased (Figure 2) and a sequence of seven different adhesion ratios for the chosen RVE is analyzed.

Figure 3 shows minimum and maximum magnitude of Von Misses equivalent stresses dependency on adhesion ratio due to unit shear loading and Figure 4 shows local stress analysis of different adhesion ratios.

![Image](image_url)

**Figure 1**: Dissociated culture of rat hippocampal neurons (Scale approximately 700 microns)

Prof. Paul De Koninck, Laval University (a)

Digitized image (b) The chosen RVE shown in yellow and white in its place.(c)

![Image](image_url)

**Figure 2**: Different adhesion ratios, ranging from presence of no adhesive proteins to presence of perfect connection between axons and ECM,

0, 0.023, 0.059, 0.107, 0.194, 0.309, 0.499.

![Image](image_url)
Study II
There is no exact data on mechanical properties of adhesive proteins, but it is known that their mechanical properties are between values for axons and ECM. In this part, the Young Modulus of adhesion varies from that of the ECM to the axons'. Figure 5 shows minimum and maximum magnitude of Von Misses equivalent stresses dependency on adhesion Young Modulus due to unit shear loading and Figure 6 shows local stress analysis for different adhesion mechanical properties.

DISCUSSION

Study I
When increasing the adhesion ratio,

- The maximum amount of Von Misses equivalent stress seems to be decreasing slightly. The minimum stress is also almost constant, therefore it can be concluded that Von Misses equivalent stress does not depend on adhesion ratio.
- The stresses imposed on axons decrease which means adhesive proteins are protecting neurons and axons.
- The stresses imposed on the ECM remains nearly constant.
- The stress contour becomes much smoother. In other words, stress is distributed more evenly which is desirable result.

Study II
When increasing the Young Modulus of the adhesive proteins,

- The maximum Von Misses equivalent stress increases up to 20%.
- In general, stresses imposed on each phase are increased which means the situation is more critical for all phases.

REFERENCES