FINITE ELEMENT MODELS OF MECHANICAL BEHAVIOUR OF ENDOTHELIAL CELLS

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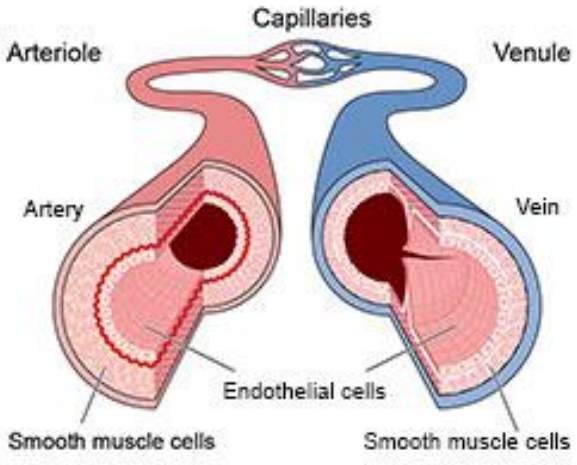
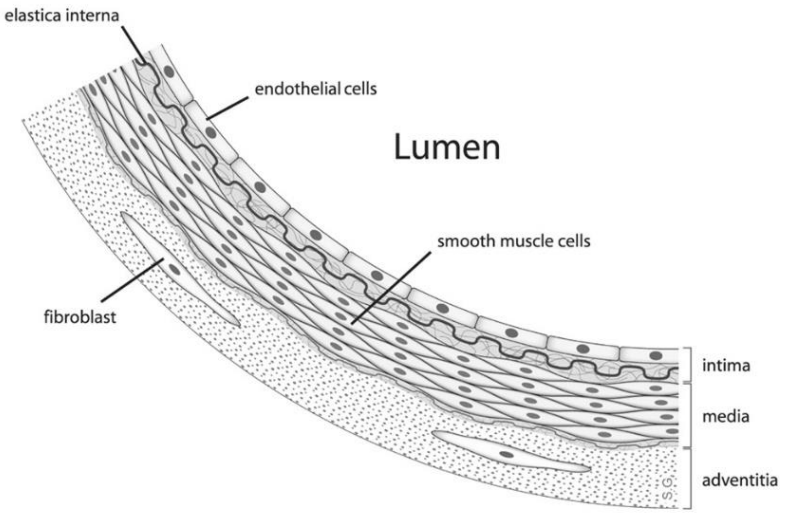
What are Endothelial cells?



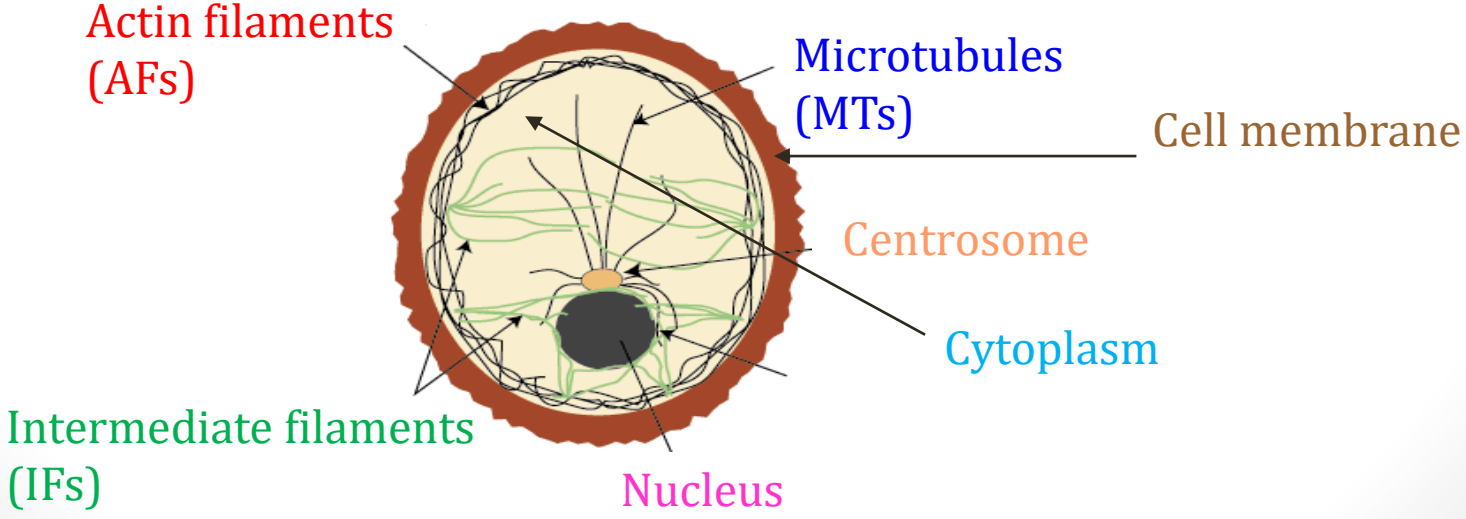


Endothelial cells

- form a one-cell thick wall layer (monolayer) called endothelium,
- line all blood vessels such as arteries, arterioles, venules, veins and capillaries,
- geometry is very flat
  (**0.5 µm thick**, **10-15 µm wide and 25-50 µm long),**
- have a centrally located oval or round nucleus.

Motivation

- Cells convert different forms of energy and signals, maintain and modify their internal structure and respond to extracellular stimuli.
- The coupling between the mechanical forces and biological processes is referred to as mechanobiology.
- The mechanism by which cells transduce mechanical signals into biochemical responses is known as mechanotransduction.
- The mechano-computational studies plays a vital role in evaluating the cell mechanical properties which initiates the understanding of cellular processes involving mechanical changes.
- The cell forces, intracellular structures, and cell function are coupled phenomenon and their quantification using computational models will provide better understanding of their relationship.



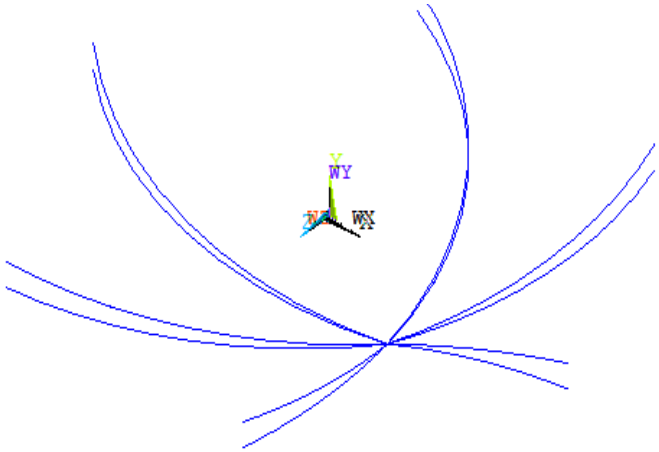
FE model formulation

- the model created in ANSYS (ANSYS Inc. PA, US).
- IFs modelled as wavy with negligible stiffness until being sufficiently extended (by 20% in the presented model)
- AFs and Actin bundles (Abs) are created as a network beneath the CM prestressed by means of their initial prestrain (-24% in their stress-free state)
- both of them were modelled as tension-only truss elements. In contrast, MTs were modelled as bended beam structures.
- Cytoplasm and nucleus were modelled as hyperelastic with eight-node hexahedral isoparametric elements (Solid 185);
- CM on the outer surface of cytoplasm was modelled by shell elements (shell 181), with the thickness of 0.01 μm and no bending stiffness

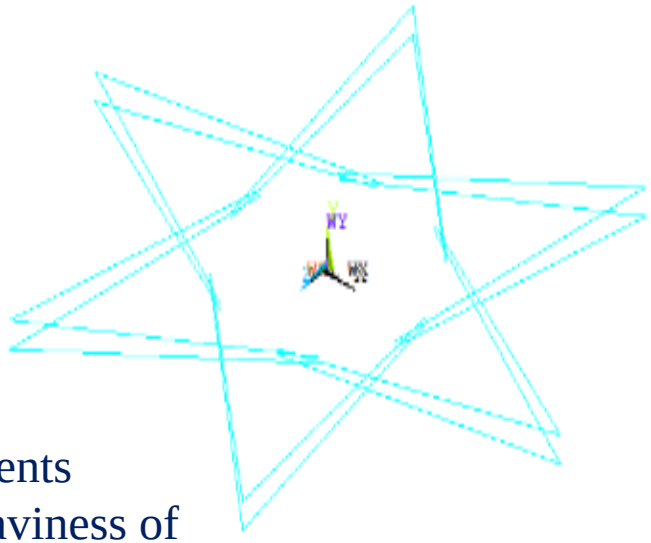
✓FE model of flat endothelial cell- Cytoskeletal components

(a) Microtubules

Beam 188 elements
(with bending stiffness)



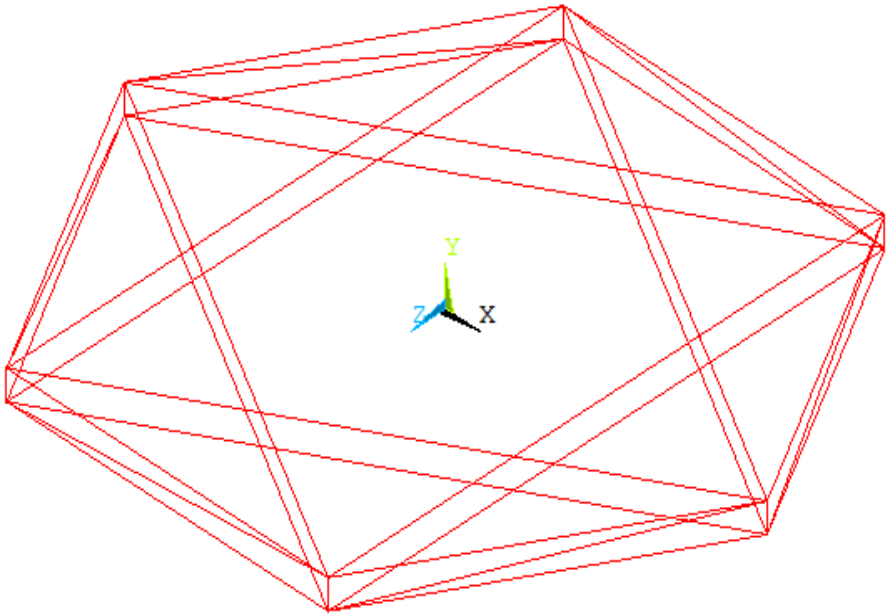
(b) Intermediate filaments



Link 180 elements
(mimicking waviness of fibers)

✓FE model of flat endothelial cell- Cytoskeletal components

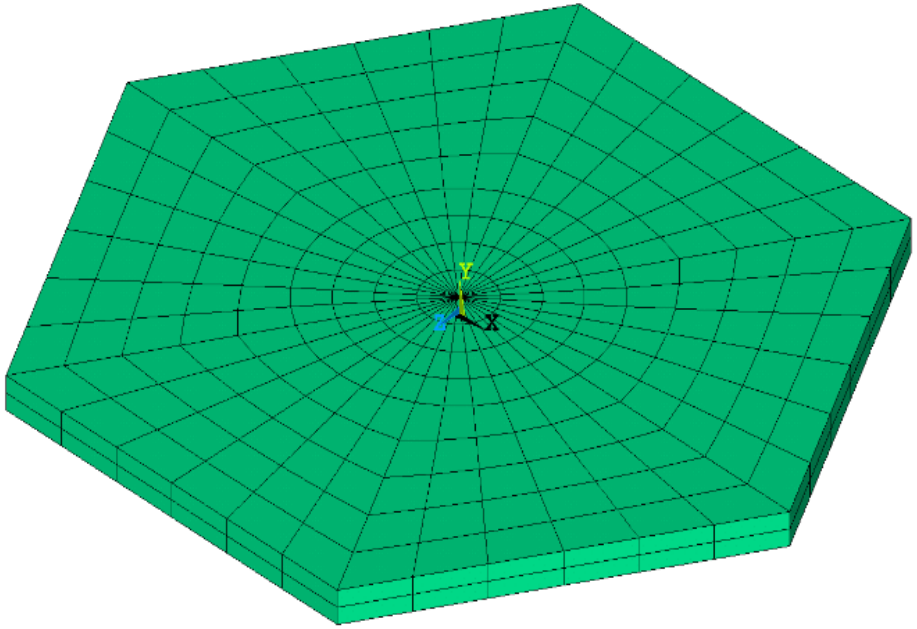
(c) Actin Filaments



Link 180 elements (Pre-stressed)

✓FE model of flat endothelial cell- Continuum components

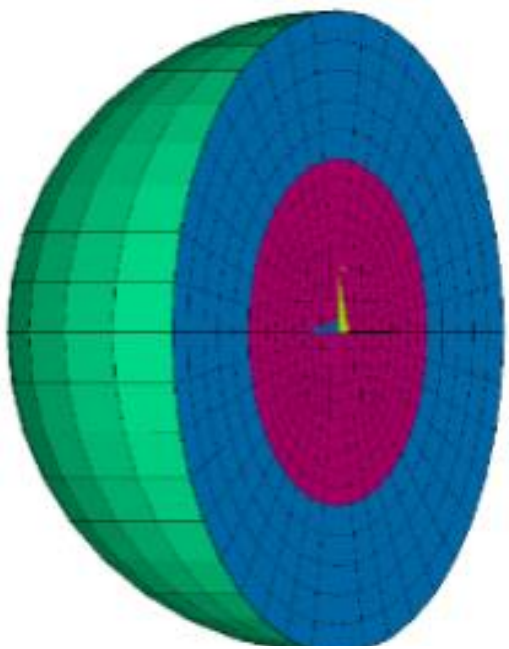
(a) Hybrid flat model



(b) Sectional view of flat model showing the nucleus (in pink color)

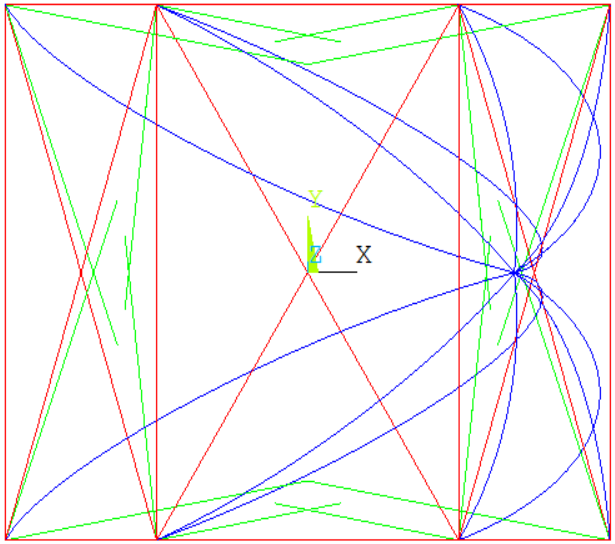
✓FE model of spherical endothelial cell

(a) Spherical model Continuum part



- Nucleus
- Cell membrane
- Cytoplasm

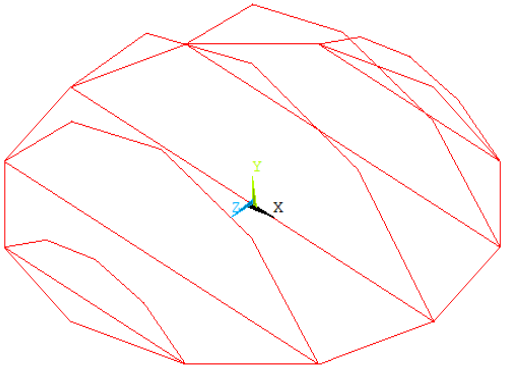
(b) Spherical model Cytoskeleton



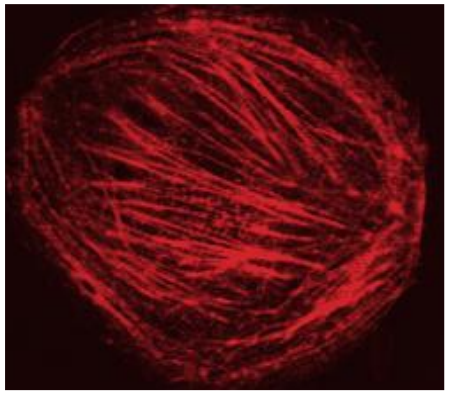
---- Actin Filaments (AFs)
---- Intermediate Filaments (IFs)
---- Microtubules (MTs)

✓FE model of adherent endothelial cell

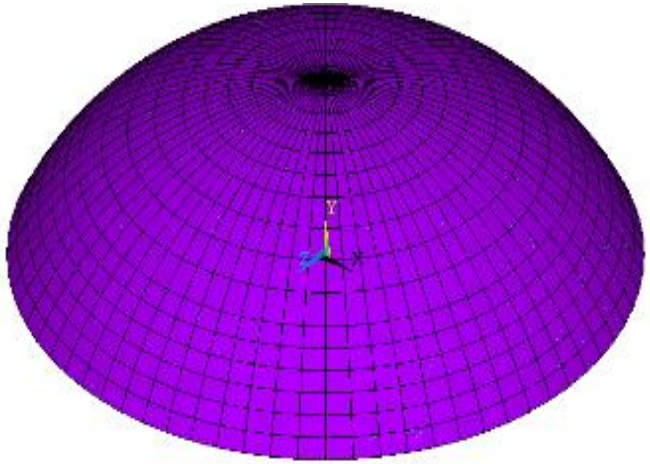
(a)



(b)



Actin bundles (Abs) **Microscopic image of Abs (cytoskeleton, Inc)**



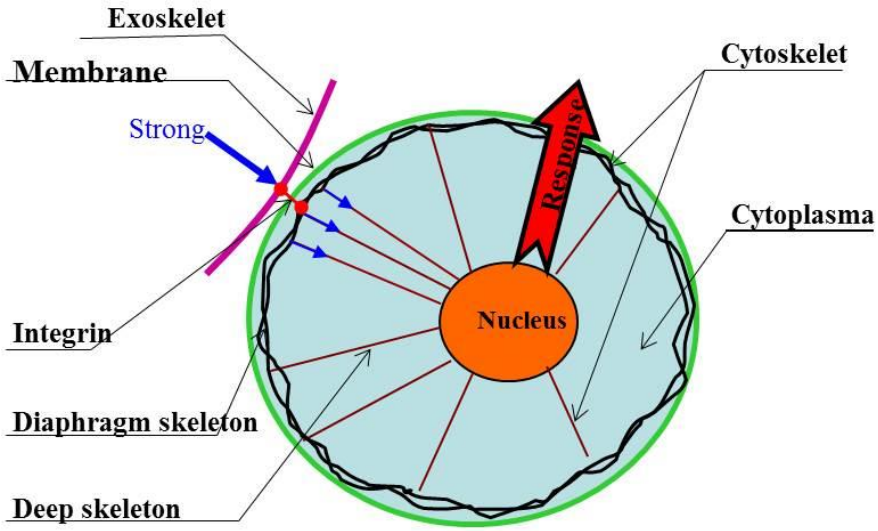
(c) Hybrid adherent model

Conclusion and future work

- The presented work aims at realistic computational modelling of mechanical behaviour of cytoskeleton and the endothelial cell as a whole. The FE hybrid model of smooth muscle cell created in (Bansod et al., 2018) and exploiting bendo-tensegrity principle was modified to mimic specific shapes, properties and cytoskeletal arrangement of endothelium cells.
- It focuses on cytoskeletal mechanics of the endothelial cell in its suspended, flat and adherent shapes to study its passive behaviour.
- The proposed FE models of the endothelial cell are intended to be used for simulations of mechanical tests of endothelial cells under different loading conditions to validate the model and to enable us to transform different mechanical stimuli into a chosen unique quantity representing the cell mechanical response under different loading conditions.

Mechanotransduction Principle

Remodeling affected by mechanical stress concerns both the components of the cytoskeleton (membrane, deep and nuclear skeleton) as well as the exoskeleton



This work was supported by Czech Science Foundation project No. 18-13663S.

Thank You Very Much For Your Attention