# COUPLED EULERIAN-LAGRANGIAN ANALYSIS OF NEEDLE INSERTION INTO BIOLOGICAL SOFT TISSUE ACCOUNTING FOR MATERIAL RUPTURE

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## BACKGROUND AND OBJECTIVES

- Needles are commonly inserted into biological tissues to inject drugs, place medical devices, and extract tissue samples which can often lead to sudden tissue rupture or uncontrollable crack extension.
- Computational models have been established to investigate the needle reaction force and its relation to tissue deformation or insertion velocity.
- These models are often limited to simulating tissue deformation without material rupture or modeling rupture with material removal.
- In this study, we use the Coupled Eulerian-Lagrangian (CEL) method available in Abaqus to overcome these difficulties.
- Previous needle penetration experiments from literature [1] were used as a source of comparison.

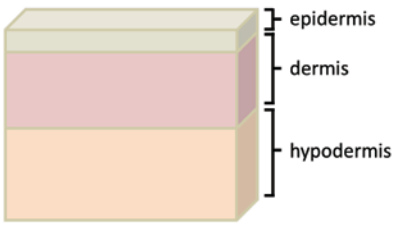


Fig 1. Schematic of skin layers (epidermis, dermis, and hypodermis) modeled in the simulations.

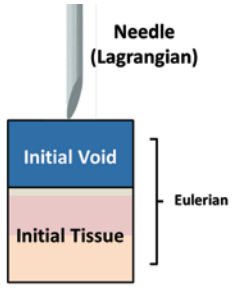


Fig 2. Schematic of Eulerian and Lagrangian domains.

### Methods

- A CEL model was developed in Abaqus/Explicit (v. 6.13) to investigate the needle insertion process into skin tissue.
- A three-dimensional cubically-shaped model consisting of three layers (epidermis, dermis and hypodermis) was used to model the skin (Fig. 1)
- Eulerian and Lagrangian Domains (Fig. 2)
  - Eulerian domain
    - Initial skin tissue
    - Initial void (no material definition)
  - Lagrangian domain
    - Bevel tip needle

### Materials

- Tissue: Ogden hyperelastic model with plasticity. Damage initiation and damage evolution was used to model tissue damage and rupture.
- Needle: Due to its high stiffness, the bevel tip needle was modeled as a rigid body.

### Boundary Conditions

- General contact is defined for the entire model.
- The Eulerian domain is fixed on the four sides and bottom surface of the model.
- Needle insertion is simulated with a velocity boundary condition at a reference point on the needle.

### Experiment conducted by Heverly et al. [1]

- In-vitro porcine heart samples
- A 1.1 mm diameter tri-pointed surgical needle was used to perform needle penetration tests
- Displacement rate was 5 mm/sec
- Force, position, and velocity data were recorded as the needle was inserted into the tissue samples

## RESULTS

- Large deformation of soft tissue with material damage was successfully evaluated using the CEL method (Fig. 3).
- The simulation results reveal a needle reaction force vs. displacement curve comparable to experimentally measured data of biological soft tissue (Fig.4).
- Several peaks were observed in the needle reaction force vs displacement curve (Fig. 5). This could be correlated with the differences in stiffness of tissue layers.

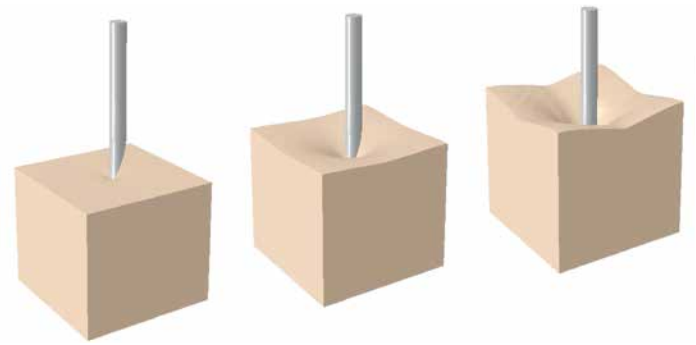

Fig 3. Deformed shapes of the skin model due to needle penetration.

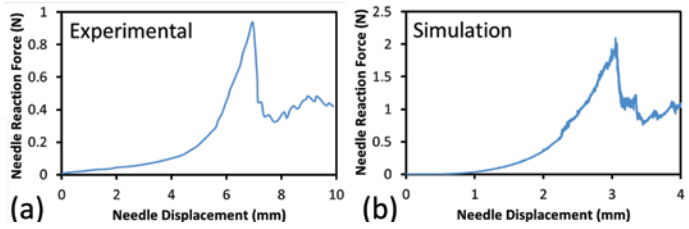


Fig 4. Comparison of needle reaction force vs. displacement plots: (a) experimental results [1] and (b) simulation results.

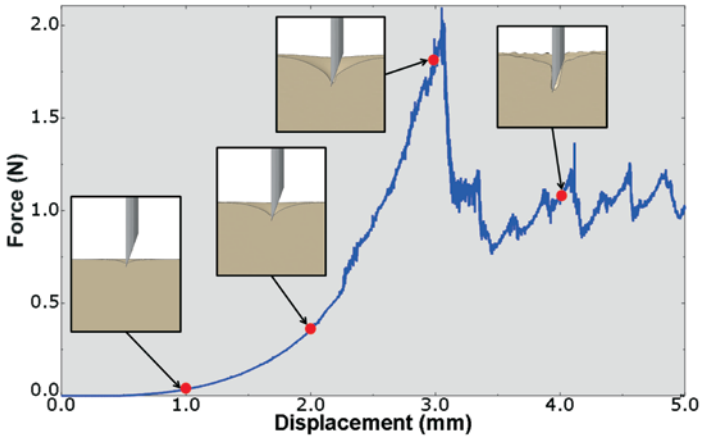


Fig 5. Cross sectional views of the soft tissue model during the needle penetration process along with the reaction force vs. displacement curve.

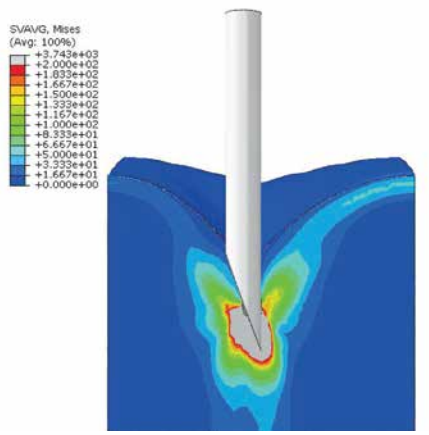


Fig 6. Von Mises stress contour in skin tissue.

## CONCLUSION

- A computational model of needle insertion was successfully developed with the CEL method in Abaqus/Explicit to evaluate reaction force and damage to soft tissue
- Material parameter optimization will need to be performed in order to obtain a reaction force with the same magnitude as the experimental results.
- The current model could be extended to study needle insertion into different biological tissues or with different needle types in the future.

## REFERENCES


1. Heverly, M., P. Dupont and J. Triedman, "Trajectory optimization for dynamic needle insertion", Proceedings of the 2005 IEEE International Conference on Robotics and Automation, Barcelona, Spain, April 2005, pp. 1658-1663.





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