Finite Element Study of Needle Insertion in Tissue

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Abstract

Significant research efforts have been focused on modeling the interaction between surgical needles and soft tissues. These models are useful for studying tissue damage caused by the needle due to the insertion forces generated from the interaction between the needle and the tissue. The models can be used to observe the effects of needle physical properties and geometry on the insertion forces. In this work, we will model the insertion force of a surgical needle by simulating the needle-tissue interaction using finite element analysis (FEA). We then compare the computed results with the results from insertion experiments into PVC gel using 3D needle steering.

Introduction

- One of the most common procedures employed in modern clinical practice is the subcutaneous insertion of needles and catheters. In many cases, such procedures are difficult to plan and to perform, and can lead to significant complications if performed incorrectly [1].
- Needle insertion procedures involve three basic steps where physicians can make mistakes: determination of the insertion point, needle orientation, and needle movement into soft tissues. The needle's path may traverse some sensitive tissues such as nerves, bones, arteries, or organs. Adverse damage to these tissues may lead to many side effects. Therefore, it is important that the needle does not cause any damage to these crucial tissues [2].
- There have been continuous demands for an appropriate model for evaluating the mechanics of different needle designs inside the tissue. The behavior of the needle while being inserted into the tissue becomes complicated due to the tissue deformation, its viscoelastic properties, and the overall nonlinearity of the system.

Parts	Density (gr.cm^{-3})	Bulk Modulus (MPa)	Short-term shear modulus G_0 (kPa)	Long-term shear modulus G_∞ (kPa)	Decay constant β (s^{-1})
White M.	1.04	2371	41.0	7.8	40
Gray M.	1.04	2371	34.0	6.4	40

Table 1. Viscoelastic material properties of white and gray matter [3]

Methods and Materials

The model will be based on realistic measurements of the needle and the tissue as shown in Figure 1. A 50-mm conical tip cylinder of a 2-mm diameter with the properties of steel was used to represent the needle. The tissue was modeled as a 50x40x30mm3 block with viscoelastic material properties (similar to the properties of soft tissues). FEA method was used to simulate to mechanics of the needle during insertion. The LS-DYNA software was used to simulate the insertion test.

- LS-DYNA software is developed by Livermore Software Technology Corporation (LSTC), is a multi-purpose explicit and implicit finite element and multiphysics program used to analyze the nonlinear response of structures.

Steel Properties:

- RO: 7.85e-6 kg/mm3
- E: 200 GPa
- PR: 0.3

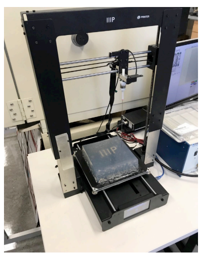

Figure 1. . Experimental setup of the needle insertion

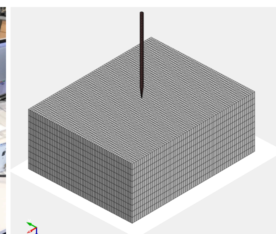

Figure 2. Needle-Tissue model in LS-DYNA

Preliminary Results and Discussion

In our model, the needle was inserted from the top face of the tissue after applying constraints on the bottom side. The needle is modeled to move at a constant speed of 10mm/s. The results of needle insertion (Figure 2) show an increase in the resultant force as a function of time (the longer the simulation the deeper the needle goes into the tissue). This preliminary data matches well with the results from experimental tests where the insertion force is proportional to the insertion depth

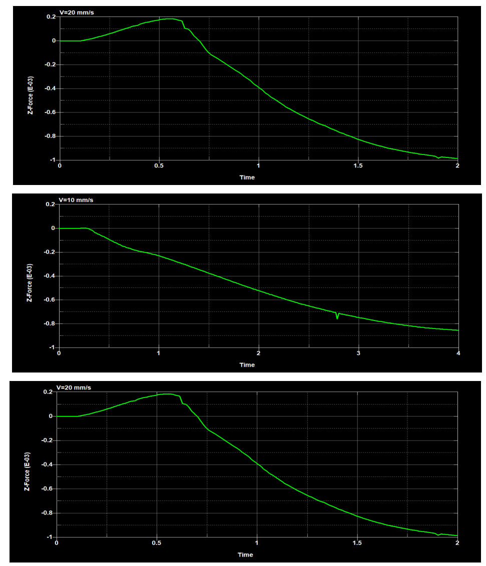

Figure 3. Force plots from the LS-DYNA simulation

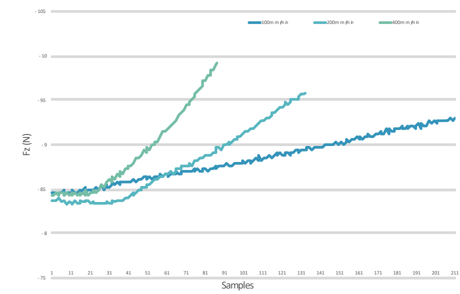

Figure 4. comparison between three different needle insertions velocities from experimental tests

Discussion

Although, the preliminary results show some promises, the main challenge in this study is to model the tissue-needle interaction where the solid elements of the needle penetrate the fluid elements of the tissue. Our ongoing work is to improve the FEA model for studying the mechanics of surgical needles during insertion.

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References

1. S.P. DiMaio and S.E. Salcudean "Needle Insertion Modelling for the Interactive Simulation of Percutaneous Procedures".
2. Gourishetti Ravali, Muniyandi Manivannan "Haptic Feedback in Needle Insertion Modeling and Simulation: Review"
3. Taylor, P. A., Ludwigsen, J. S., & Ford, C. C., (2014). Investigation of blast-induced traumatic brain injury. Brain Injury, 28(7), 879–895