Simulation of Tissue Insertion Force of Surgical Needles using Neural Network Model

Sai Teja Reddy Gidde[1], Nuo Ivy Chen[1], Tololupe Verissimo[1], Byoung-gook Loh[2], Parsaoran Hutapea[1]

[1]Departmentof Mechanical Engineering , Temple University, Philadelphia, PA

[2]Applied IT Engineering, Hansung University, Seoul , Korea

NEBEC
44TH ANNUAL
NORTHEAST BIOENGINEERING CONFERENCE
DREXEL UNIVERSITY - PHILADELPHIA, PA

Abstract

Needles are commonly used to reach target locations inside of the body for various medical interventions. The effectiveness of these procedures depends on the accuracy with which the needle tips reach the targets. One of the major issues in needle steering is the insertion (penetration) force. The insertion force causes tissue damage as well as tissue deformation. Simulation of surgical procedures provides an effective method for a robot-assisted surgery for pre- and intra-operative planning. This study investigates feasibility of predicting the insertion force of surgical needles based on experimental data using Neural Network modeling. Simulation of the proposed neural network model is performed using Keras Python Deep Learning Library with TensorFlow as a backend. The insertion forces of needles with different bevel-tip angles in gel tissue phantom are measured using an automated needle insertion test setup. The performance of the model is then evaluated using different and unseen input-output dataset. This work shows that the proposed neural network model accurately predicts the insertion force.

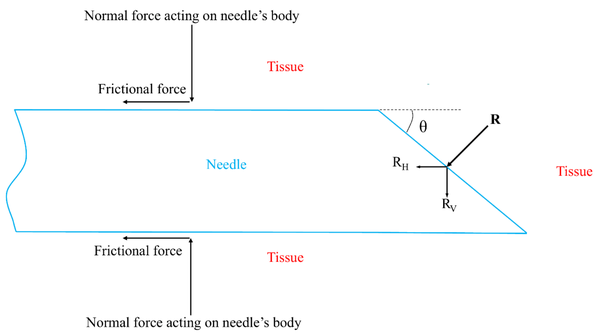

Figure 1. Forces acting on needle's body in insertion

Introduction

The ultimate insertion force is defined as the force acting on the needle hub in the direction of insertion. The ultimate extraction force is equal to the friction force of the needle, since in the extraction there is no cutting forces (Fig. 1).

A properly trained neural network maps input data to output data. Known input and output relationships, i.e. input-output datasets are supplied to train a neural network and the performance of the neural network is evaluated using unseen input-output data sets.

Methods and Materials

CAD software was used to develop the 3D modeling of the needles. Connex350 3D printer (Stratasys, Inc., Eden Prairie, MN) was utilized to manufacture the needle prototypes (Fig. 2). To optimize the design of the needle, some design parameters were defined for the needle as shown in Fig. 2. Design parameters of the needle are $\theta = 15°, 30°, 45°$ & $60°$ angles of the tip and length of the needle is 15cm.

A customized 3D printer which can be used for multiple insertions in x, y and z-axis which is shown in Fig. 4. A force sensor, 6 DOF F-T sensor Nano17® (ATI Industrial Automation, Apex, NC), and a high-resolution camera are used to record the insertion force. A PVC gel phantom (M-F Manufacturing Co., Ft. Worth, TX) with a dimension of 15cmX15cmX7cm was fabricated to mimic tissue viscoelastic properties.

Figure 2. Different Bevel tip angle needles

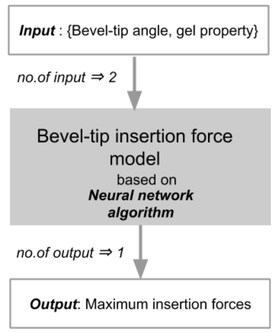

Figure 3. Neural network modelling of maximum insertion force of bevel-tip polymer needle

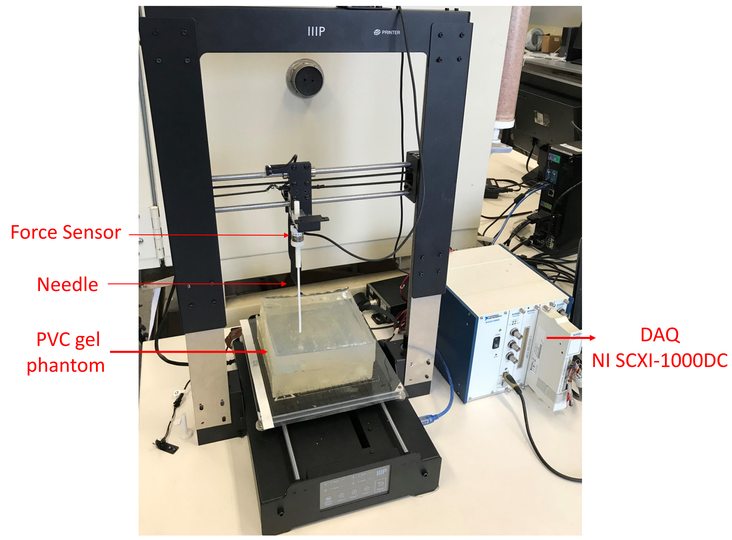

Figure 4. The customized insertion test setup

Results

The insertion tests were performed using needles with different needle tip design. The results showed 25% decrease in the insertion force using different bevel tip angle needles (Fig. 5).

Using different needle tip design has raised some concerns regarding the insertion force and the potential tissue damages it may have caused. In this work, the insertion test of the needles was performed to see how needle tip affect the push-in forces. The insertion forces for the needles with angles of θ = 15°, 30°, 45° and 60° are shown in Fig. 5. The extraction force can be reduced by 25% using needles with different tip angles.

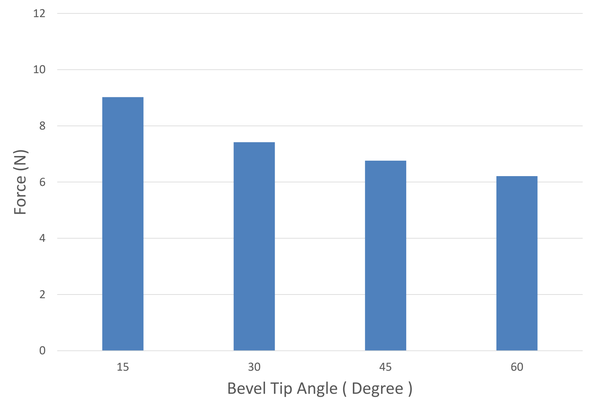

Figure 5. The insertion force results for different bevel tip angle needles.

Conclusions

Our results on the insertion tests using different needle tip design shows that insertion force decreases significantly using bevel tip angle needles. Design parameters of the needles were modified experimentally to minimize the insertion forces and it has been shown that it is feasible to decrease these forces. Future work focuses on decreasing extraction forces and ongoing work is being performed to further assess tissue damage by performing tests on real tissues as well as to explore manufacturing techniques to develop smart (active) bioinspired needles and metal-based needles. Also focusing on modeling accuracy of a neural network maximum force model which is expected to increase with more experimental data.

Acknowledgement

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