Effect of Chest Tube on Deflection of Multi-Segmented Steerable Catheter under Pneumothorax Surgical Condition

Introduction

- Enhancing target accessibility of catheter tip during pneumothorax surgery is important
- Effect of chest tube on the deflection of catheter is significant
- Chest tube is critical at determining key parameters locating the catheter tip
- Reliable simulation of catheter deflection that accounts for the constraint of chest tube is required to effectively predict appropriate parameter values

Pneumothorax Surgery Environment

![Diagram of a catheter inside a chest tube showing hard and soft segments, pull wires, and overhang.](image)

Figure 1: Catheter inside a Chest Tube

Analysis of Catheter Deflection with the Constraint by Chest Tube

- Solution of nonlinear deflection of cantilever beam using Euler-Bernoulli Law:

  \[
  y(x) = \frac{f}{y''} \int_{0}^{x} \left[ \frac{f}{y''} \right] dx \\
  y(x) = -\frac{1}{2} \left[ \frac{f}{y''} \right] x^2 + \frac{f}{y''} x + C \\
  z = \int_{0}^{x} \left[ \frac{f}{y''} \right] dx = -\frac{f}{y''} \frac{x^3}{3} + Cx\\n  \]

- Simulation curve is plotted based on equation (2) while being constrained by equation (3)
- Chest tube and portion of catheter inside a chest tube is considered as one segment with higher stiffness

Simulation Reliability

![Comparison between simulation and experimental results for catheter deflection with and without chest tube constraint.](image)

Figure 3: Simulation Reliability Experiment

Table 1: Position Error between Simulation and Experimental Results

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<thead>
<tr>
<th>Force</th>
<th>P1 (N)</th>
<th>P2 (N)</th>
<th>P3 (N)</th>
<th>P4 (N)</th>
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<td>0.4</td>
<td>0.9</td>
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<td>1.3</td>
<td>2.8</td>
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</table>

Effect of Chest Tube on Determining Key Parameters

- Tips of two catheters shown in figure 4 are around 15 mm apart at pull wire tension of 8 N which shows the significance of chest tube constraint
- Key parameters affecting tip positioning are overhang and pull wire tension
- Varying overhang is effective for locating the tip and varying tension is effective for controlling the tip slope as shown in figure 5

![Comparison between simulation and experimental results for catheter deflection with and without chest tube constraint.](image)

Figure 4: Effect of Chest Tube on Deflection of Catheter

Target Accessibility to Defected Location

- Accurate positioning of catheter tip to the defected location is possible by selecting appropriate overhang and wire tension
- The appropriate overhang and wire tension values are found by trial and error of simulation

![Comparison between simulation and experimental results for catheter deflection with and without chest tube constraint.](image)

Figure 5: Curve Shapes of Catheter Deflection Depending on Parameters

Conclusion

- Nonlinear beam deflection theory can effectively predict the large deflection of catheter constrained by chest tube
- Considering the chest tube portion as one segment with higher stiffness can accurately reflect the actual deflection of catheter restricted by chest tube
- Simulation result is reliable showing error less than 5 mm which is reasonable for pneumothorax surgery
- Catheter configuration can be manipulated to adequately position the tip by controlling overhang and pull wire tension

![Comparison between simulation and experimental results for catheter deflection with and without chest tube constraint.](image)

Figure 6: Simulation Results of Catheter Accessibility to Lung Defect