EFFECTS OF ROTATIONAL MOTION IN NEEDLE INSERTION

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1. Introduction
Needle insertion is one of the most common minimal invasive surgery methods for sampling, radioactive seed implantation, and injections. It might be the most available method in direct reaching to intended target through biological soft tissues. In all robotic needle steering procedures, the needle faces to non-homogenous tissues and therefore, probability of accurate trajectory on insertion remains hapless. Intra-operative image registration on surgical procedures must not interrupted by the work of flow. Many applications of Percutaneous needle insertion might be seen in different works as biopsies, brachytherapy, and neurosurgeries. Some phenomenological models based on general needle steering experiments have been developed to obtain most efficient collection of terms to describe the force-displacement graph of insertion. Nowadays, acquiring data from biological tissues and developing models appropriate for application in soft tissue simulations are so general. Applications in robot-assisted surgery or impedance control of MRI compatible robots have some complexities and difficulties due to tissue deformation, non-homogeneity, and opacity in soft tissue insertion.

Modeling of forces during needle insertion into biological soft tissue is important for accurate surgical simulation, and the pre-work of numerical simulation of needle insertion might be in the modelling of forces for such analysis. The force models developed in related articles can be used in surgical simulation and robot-assisted surgeries. In this work some experiments enacted to compare the effect rotation of the needle than to non-rotation case in different angular and direct velocities. In order to see the effects of rotational motion and angular velocity in needle insertion force graph many number of tests in different directional velocities and angular velocities were held by testing on soft biological tissues.

2. Materials and Methods
Everything that affects to the process of insertion of a needle into soft tissue must be considered in this part but as the most related articles discussed; these phases might be decomposed into totally two complete different phases for constant velocity of needle soft tissue interaction with soft tissue. It might be seen in the whole process of experiments of needle insertion:

Phase 1: Non-Linear Elastic Deformation: The needle tip comes into contact with the tissue and deforms it without any penetration. It continues with puncture in the end of the first phase.

Phase 2: Steady-State Visco-Plastic Penetration: Once an energy threshold is reached, the liver capsule ruptures and a crack initiates. Then, steady state penetration initiates and the force increases with depth with an almost linear relation. This phase finishes when the needle tip stops at target point. The authors discuss about two more phases for continuing the process of sampling with tissue relaxation and also with needle extraction phase. There are 4 different types of needle insertion:

− General quasi-static needle insertion
− Fast needle insertion
− Rotational needle insertion
− Needle insertion with tapping

In order to make a mathematical model from this process, some terms might be considered. Friction force happens in needle-tissue interaction which is related to needle diameter and depth of insertion linearly. Therefore, force-displacement equation might be stated as follow:

\[
F_z = Kz + b\dot{z} + m\ddot{z} + f_f.\text{sgn}(\dot{z}) + k < z - z_0 >^1
\]

In this formulation the last term presents the first order Macouli parenthesis, which is related to plastic deformation of the tissue. Quasi-static needle insertion disappears term of inertia in the formulation of force. Other terms might be involved in the process of insertion in rotational and general motion.

The experimental results from insertion of 8.5 centimetre length, 1.54mm diameter, 22° bevel tip needle into a non-human tissue (camel liver tissue) with the directional velocities of 50, 100, 150, and 200 mm/min acquired. Soft tissue with the dimensions of 5*5*3cm³ faced with needle insertion tests in compression with a Zwick/Roell desktop by the mark number of HCT/405/25 which enjoyed 0.01 N and 0.001 mm axial force resolution. In some works researchers do not use any types of fixture for the desired tests. They use big amounts of tissue for needle insertion while it better simulate body conditions in experiments.
In order to create a rotational motion, we need to fabricate a manipulator with the capability of rotation.

Figure 1: The mechanism of rotation for needle trajectory planning and capability of giving angular velocity

Four different angular velocities of 50, 100, 150, 300 RPM were used in needle insertion tests with rotational manipulator.

3. Results & Discussion
Results of the experiments in needle insertion tests in general and rotational have many differences. As it obvious from the force-displacement graphs:

We might consider to many points in needle insertion force graph, however, information of the insertion in two first phase of insertion presented in table 1:

<table>
<thead>
<tr>
<th>Needle insertion speed (mm/min)</th>
<th>1st phase length (mm)</th>
<th>1st phase force (N)</th>
<th>Mean force value 2nd phase (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>1.18±0.45</td>
<td>1.21±0.21</td>
<td>0.87±0.21</td>
</tr>
<tr>
<td>100</td>
<td>0.83±0.22</td>
<td>1.03±0.16</td>
<td>0.68±0.10</td>
</tr>
<tr>
<td>150</td>
<td>0.72±0.31</td>
<td>0.98±0.12</td>
<td>0.73±0.14</td>
</tr>
<tr>
<td>200</td>
<td>0.70±0.24</td>
<td>0.87±0.24</td>
<td>0.61±0.28</td>
</tr>
</tbody>
</table>

There are some advantageous in robotic needle insertion with the capability of rotation:

- One more degree of freedom with rotation
- Capability of circling from orthogonal Obstacles
- Better in control in flexible needles
- Decrement in force magnitude in process
- Disappearance of maximum points in force function
- Completely disappearance of the first phase

In other works the authors use to describe the phenomena of fast needle insertion, in which their gauge for pain is the variation of force-displacement diagram. The results show the difference of almost 50% for one hundred times change in needle tip velocity. Force function in rotational insertion is less than what is in fast needle insertion.

The effect of different angular velocities might be seen in the following figure.

Figure 2: Compare between two different needle insertions into soft tissue, with or without rotation with repeatability.

Figure 3: Compare of rotational needle insertion force graph during two different angular velocities.

These diagram compares between two different angular velocities, which shows the increment of force function in lower angular velocity. Two different angular velocities of 50 and 150 RPM with the directional velocity of the 50 mm/min were used for this experiment. It might be added that correlation effect of different parameters occurs in force modelling of needle insertion into soft biological tissue.

Rotational needle insertion has some disadvantageous as presented:

- More bleeding during surgery time
- Denying effects on tissue microstructure

4. Conclusion and Future Work
This work will continue with comparing the effect of needle tapping by other methods, and might be explained as the effects of impulse instead of steady state penetration. Eventually, it will be used in impedance control of MRI compatible robots.

References