THE BIOMECHANICS OF PERCUTANEOUS NEEDLE INSERTION

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Background

Significant patient care complications are due to inappropriate placement of percutaneous (through the skin) catheter needles.[1] Healthcare providers are typically taught these procedures through trial and error on live patients which subjects patients to morbidity and even mortality. Surgical simulation affords learners the ability to make mistakes without consequences and has been shown to reduce patient morbidity.[2,3] A large part of percutaneous needle insertion procedures, however, is recognizing what the needle feels like as it passes through human tissues. Because of this haptic feedback component synthetic mannequin-based simulators may not approximate true perceived tissue forces. We seek to design a simulator with force feedback specific to the tissues and organs being catheterized by determining the forces generated on the passage of needles using the Blue DRAGON system.

Methods & Tools

The Blue DRAGON system was originally designed for acquiring the kinematics and the dynamics of two endoscopic tools along with the visual view of the surgical scene. As at tracking system it was modified to track a suprapubic percutaneous catheter needle (a needle placed through the abdominal wall into the urinary bladder) attached to it. The system includes a four-bar mechanism equipped with position sensors for measuring the positions and the orientations (P/O) of the needle. A three-axis force/torque (F/T) sensor is located at the proximal end of the needle. The physician guides the needle by manipulating the mechanism during insertion of the needle into an in-vitro animal model (Figure 1) and human cadaver. The needle was inserted trough various tissue layers including skin fat and muscle. Data was collected at a sample frequency of 300 Hz. Forces and torques are measured with respect to a coordinate system with an origin at the base of the needle whereas position and orientation are measured with respect to a coordinate system attached to the needle itself with the origin at the insertion point. The Z axis is aligned with the needle long axis.

Results

The needle was inserted though three distinct layers of tissue (skin, fat and muscle). The mechanism of penetrating through each layer of tissue involved stretching followed by penetration. As indicated in figures 2 and 3, the needle tip moves primarily along the Z axis with skin stretching without penetrating it for about 25mm. At one point the force reached a level of 7.5 N in which the tissue failed and led to the penetration of the needle. Once the needle penetrated the layer the magnitude of force was significantly reduced. The value of the force is not reduced to zero since there is significant friction between the needle and the surrounding tissue. This phenomenon is repeated 3 times for each layer given the different inherent mechanical properties of each tissue's force-displacement relationship.

Conclusion

Acquiring force displacement measurements of needle insertion is the first step towards development of a computational model of the phenomena. The computational model may be further incorporated into a medical haptic simulator that provides physically based force feedback to the user.

References

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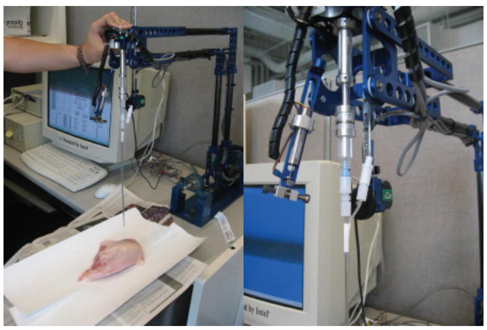
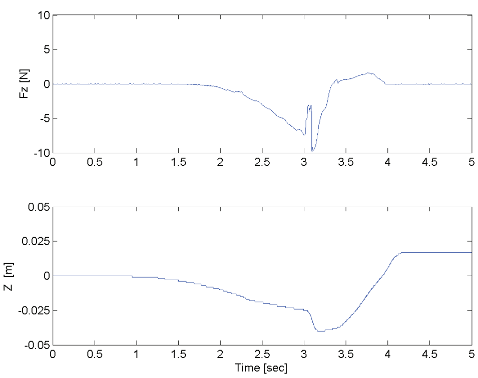


Figure 1. Blue DRAGON system.



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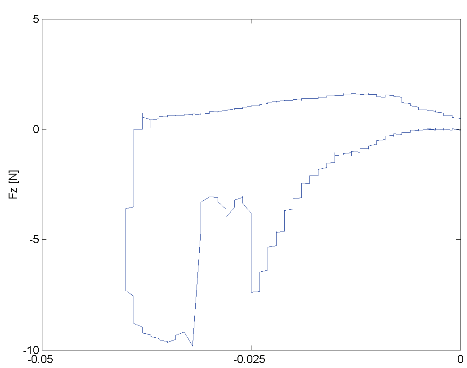
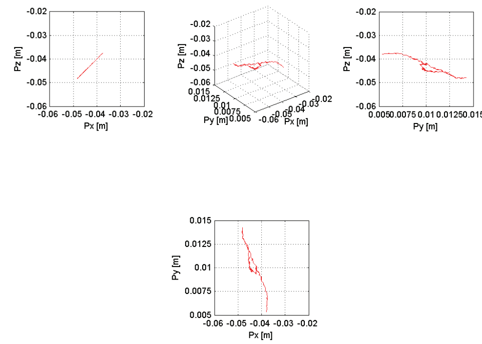


(b)

Figure 2. Dominant parameters during needle insertion (a) Time histories of force along the needle (Fz) and position of the needle tip along the Z axis (Z) (b) The force along the needle (Fz) and as a function of the position of the needle tip along the Z axis (Z)



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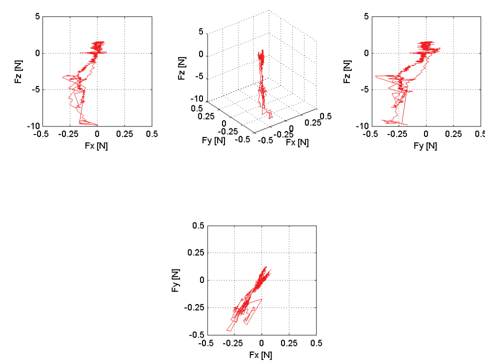

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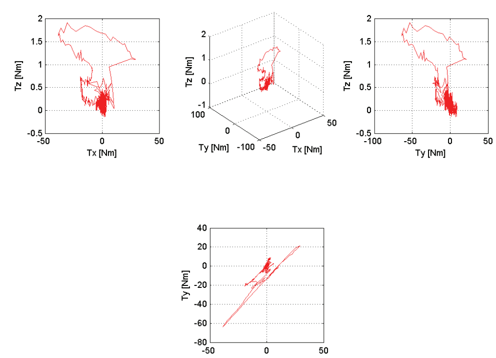

(c)

Figure 3. Three dimensional plots of the needle tip position in space (a) the forces (b) and torques (c) applied on the needle during the insertion