Effects of Bevel Angle on 3D Needle Deflection: Macroscopic and Microscopic Observations

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Abstract

Minimally invasive medical interventions are commonly used for diagnosis and treatment. They involve percutaneous needle insertion where precise tip placement is important. An accurate needle-tissue interactions model can be used to predict the needle tip location during insertion, reducing targeting errors. For this, the dynamics of needle-tissue interactions need to be understood. In this study, we investigate the influence of needle bevel angle on needle deflection in three-dimensional space (in-plane and out-of-plane). Experiment is done using gelatin mixture as soft-tissue simulant. Needle tip is tracked using stereoscopic cameras, while needle-gelatin interactions are observed using laser scanning confocal microscope. Varying needle bevel angle from 30° to 60° is shown to decrease the in-plane deflection and to increase the out-of-plane deflection. The monotonic increase noted in out-of-plane deflection is due to the geometry of gelatin rupture that is noted during the microscopic study.

Keyword(s): biomechanics

1 Introduction

Needle bends and tissue deforms during needle insertion into soft tissue, and these are influenced by the geometry of needle tip [1]. The aim of this study is to evaluate the effects of bevel angle on the in-plane and out-of-plane deflection. Further, we will link the phenomenon observed to the microscopic observations of the needle-gelatin interactions occurring at the needle tip.

2 Methods

To investigate needle deflection in three-dimensional space (3D), a two degree-of-freedom (DOF) insertion device is used. The DOFs are translation along and rotation about the insertion direction. Needle insertion is recorded via two cameras that are positioned at 90° to each other. Microscopic observations of needle-gelatin interactions at the needle tip are done using a similar insertion device with a single DOF, and a Zeiss 510 Laser scanning confocal microscope. The interactions are visualized in 3D using differential interference contrast, epiflouresence and 10x objective lens.

3 Results

The variation in the bevel angle (ß) from 30° to 60° is noted to decrease the in-plane deflection (δ_{in}) by 10%, and to increase the out-of-plane deflection (δ_{out}) by 178%. The monotonic decrease in δ_{in} is due to the decrease in the transverse tip force, as bevel angle increases [2]. Transverse tip force is the component of needle-gelatin interaction force that acts on the needle bevel face. Microscopic observations show that gelatin rupture at the needle tip was narrow and long for small ß, and becomes wider and shorter for large *ß*. The wide and short gelatin rupture provides a larger clearance for the needle tip to move out-of-plane, resulting in the monotonic increase in δ_{out}.

4 Future Work

During biopsy, the use of a needle guide results in a larger tissue deformation than by needle insertion alone, and correspondingly affects 3D needle tip locations. In order to develop a model of needle-tissue interactions that is able to predict 3D needle tip locations during surgical procedures, both needle deflection and tissue deformation have to be studied. Currently, we are investigating the influences of system parameters on prostate deformation, occurring due to the use of a needle guide. These parameters include boundary conditions, the geometry of surrounding anatomical structures, and compression by the needle guide. The results of these studies can be used to build an accurate biomechanical model for pre-operative surgical planning.

References

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