Tissue-needle Interaction Mechanics of Steerable Smart Needles

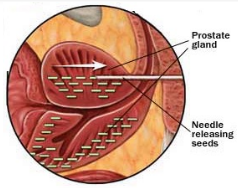
Naresh V. Datla and Parsaoran Hutapea

Mechanical Engineering Department, Temple University, Philadelphia, PA USA

Current Prostate Brachytherapy Procedure

Needle Brachytherapy

- Minimally invasive
- Places radiaoactive seeds



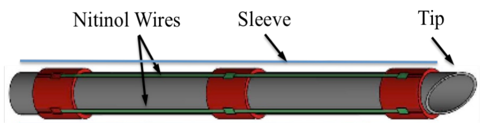
Limitations

- No quantitative feed-back
- Needle rigid; unable to steer

Novel Steerable Smart Needle

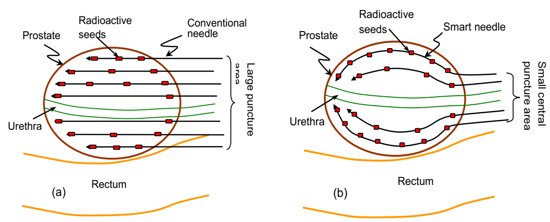
Design of Smart Needle

- Nitinol wires act as actuators to bend needle [1,2]
- The wires shrink by ~5% when resistively heated



Advantages

- Can be steered to avoid critical organs [1]
- Improves placement accuracy with sensory feedback



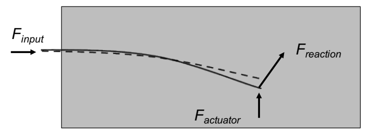
Prediction Model of Smart Needle in Tissue

Energy-based Method: Rayleigh-Ritz approach as in [3]

$$\pi = E_{needle} + E_{tissue} - W_{rupture} - W_{reaction} - W_{actuation}$$

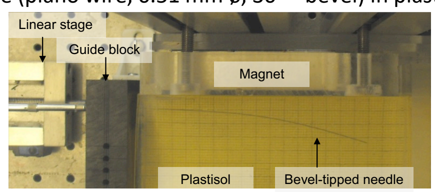
E_{needle}, E_{tissue}: Strain energy stored in needle and tissue

$W_{rupture}$, $W_{reaction}$, $W_{actuator}$: Work done by forces on needle



Validated With Needle Insertion Experiment

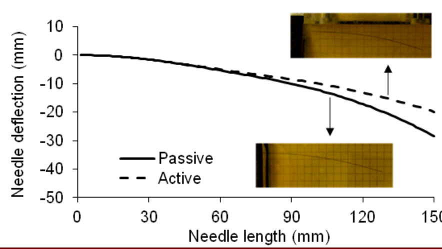
- Actuated with magnetic forces to simplify model and exp.
- Needle (piano wire, 0.51 mm ø, 30° bevel) in plastisol gel



Results: Experiment vs. Simulation

Needle-tip deflections (in mm)

- Passive: 5.5% (27.0 vs. 28.5); Active: 11.6% (22.4 vs. 19.8)



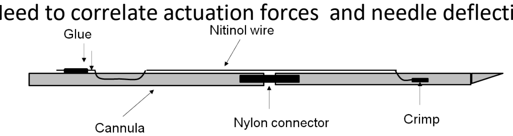
Conclusions

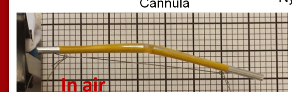
- Actuation forces can control needle deflection in tissue
- Energy-based method was developed for smart needle
- The model predicts needle deflection with 11.6% accuracy
- Developed model can help to improve needle design

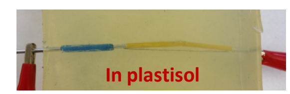
Future Work

Prototype with Nitinol wire

- Preliminary tests in both air and plastisol bent the needle
- Need to correlate actuation forces and needle deflection







References

1. T. K. Podder, A. P. Dicker, P. Hutapea, et al. "A novel curvilinear approach for prostate seed implantation," *Medical Physics*, vol. 39, no. 4, pp. 1887–1892, 2012.
2. N. V. Datla, B. Konh, J. Koo, et al. "Polyacrylamide phantom for self actuating needle-tissue interaction studies," *Medical Engineering & Physics (Accepted)*.
3. S. Misra, K. B. Reed, B. W. Schafer, et al. "Mechanics of flexible needles robotically steered through soft tissue," *Int J of Robotics Research*, vol. 29, pp. 1640–60, 2010.

Acknowledgements

This work is supported by the Department of Defense CDMRP Prostate Cancer Research Program (Grant# W81XWH-11-1-0398).

datla@temple.edu