POSTER DISCUSSION III: PROSTATE
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PD37

Simulation of Needle Insertion and Tissue Deformation for Modeling Prostate Brachytherapy

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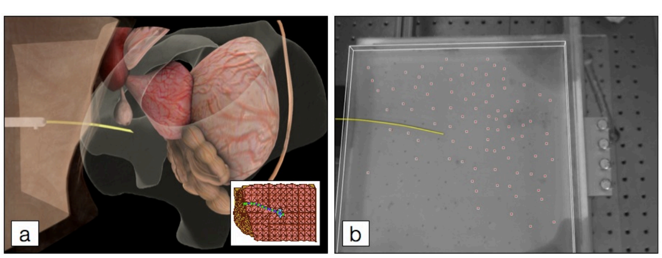
Purpose: Realistic modeling of needle insertion during Brachytherapy can be used for training and in automated planning to reduce errors between intended and actual placement of the needle tip. We have developed a 3D tetrahedral finite element simulation that models tissue deformation, needle flexation, and their coupled interaction. This system addresses the following applications:

- Training physicians to compensate for tissue deformation during needle insertion.
- Incorporating a model of tissue deformation into manual and automated planning for seed placement and dose distribution.
- Developing automated steering procedures for robotic devices.

Materials and Methods: We model tissue elasticity with constitutive equations discretized over a 3D tetrahedral mesh by a finite element method. The needle is modeled as a stiff elastic rod. The two systems are coupled together by shared nodes, and the tissue and needle are dynamically remeshed to allow needle insertion and withdrawal. Nodes are dynamically positioned along a curvilinear needle path in a volumetric mesh, enabling the simulation to apply accurate cutting and frictional forces along the needle shaft and at the needle tip.

Results: We can realistically and interactively simulate needle insertion on a high-resolution prostate mesh at 25 frames per second on an 8-core 3.0 GHz PC. External mesh boundaries conform to the skin, and internal faces conform to organ boundaries, separating regions with dissimilar material properties. The code can model both rigid and flexible needles. Figure 1.a shows a screenshot from the simulator running the prostate brachytherapy scenario. The inset image shows a cutaway view of the finite element mesh used by the simulation. To evaluate the accuracy of the simulation we compare against experiments in which flexible, nitinol needles of diameter 0.83 mm were robotically inserted into a gel tissue phantom. Video showing the needle and motion of fiducial markers was recorded. We then simulated the same configuration and compared the recorded and simulated markers. Figure 1.b shows the simulated needle in yellow and simulated fiducials in white superimposed over the recorded video. The needle trajectories match to within video resolution, and the root-mean-squared error of the marker positions over time is 0.75 mm, with 88.3% of errors under 1 mm and 97.8% of errors under 2 mm.



Conclusions: Our key technical contributions include a fast local remeshing method, an efficient algorithm for computing the coupling forces between tissue and needle, and optimizations to allow realtime performance for high-resolution models. A detail description of the simulation code along with several example videos is posted at *http://graphics.berkeley.edu/papers/Chentanez-ISN-2009-08/*. This simulation can be used as a training tool to help physicians anticipate and compensate for placement errors due to tissue deformation. We are also exploring applications in automated planning and robotic insertion.

Nuttapong Chentanez, Ron Alterovitz, Daniel Ritchie, Lita Cho, Kris K. Hauser, Ken Goldberg, Jonathan R. Shewchuk, James F. O'Brien, Simulation of Needle Insertion and Tissue Deformation for Modeling Prostate Brachytherapy, Brachytherapy, Volume 9, Supplement 1, Abstracts of the 31st Annual Meeting of the American Brachytherapy Society April 29-May 1, 2010, April-June 2010, Pages S72-S73, ISSN 1538-4721, DOI: doi:10.1016/j.brachy.2010.02.118 .