

**ME 563:  
Nonlinear  
Finite Element  
Analysis**

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*A Semester Report on:*

# The Development and Analysis of Needle Insertion and Bending using SPH Analysis

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## **Executive Summary**

The subject of modeling the insertion of needles into human tissue has been studied numerous times for more than a decade. Many of these studies have looked at how to minimize the harm done to patients from needles, and how to minimize cutting forces required to insert needles. The details of cutting and interaction with the needle tip are very complex. However, for this study the very intricate details of cutting have been ignored and another phenomenon has been modeled. It is widely known that asymmetric needle tips, when inserted into tissue, will develop unbalanced distributed loads at the tip and cause the needle to bend as it is inserted. In many cases this bending is undesirable and prevents doctors from accurately performing procedures such as biopsies. But, there is research being done into utilizing this bending phenomenon to help with radiation therapy. The purpose of this study was to determine whether the Spherical Particle Hydrodynamics (SPH) approach would be sufficient for modeling the bending of asymmetric needles during insertion into tissue. It was found that this modeling technique can predict needle bending with only minimal localized mesh refinement. Future work on this subject will be to utilize the SPH method to then do design studies for creating needles that achieve the desired amount of bending.

## **Acknowledgements**

I'd like to acknowledge Dr. Ruben Kraft for his instruction and guidance in modeling non-linear processes, and Brad Hanks for allowing me to help him in his research. I'd also like to acknowledge Penn State for providing access to technology, such as ABAQUS, so these analyses could be done.

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## Section 1: Background and Project Plan

Radiofrequency Ablation (RFA) probes are used for killing cancer cells. These probes are inserted into the cancerous tissue and are heated using radiation. As shown in Figure 1, the heating that occurs from single probes is very localized. It would be desirable to have more uniform heating throughout the tissue region. For this reason, Brad Hanks, a PhD student at Penn State University, has been investigating the design of deployable needle structures that will bend outward to fill the tissue more uniformly. These deployable needles can then accomplish a more uniform heating in RFA procedures.

Figure 2 shows Brad Hanks' design of a deployable needle structure. The outermost structure would be a hollow needle, which would be inserted into the cancer tissue. Once in the tissue, structure will deploy from the outer needle. It is then desired that the tissue will cause the inner needles to bend outward as they deploy into the tissue.

It has been discovered that needles with an asymmetric tip geometry will bend when they are inserted into tissue. This is because the tip develops an unbalanced distributed load, causing the rest of the needle to bend. For this reason, Hanks' needles are designed with asymmetric tips. But, questions still remain. What specific asymmetric geometry will give the appropriate amount of bending for the application? Can the tissue-needle interaction be modeled so that many designs can be tested?

The goal of this project is to determine whether the Smoothed Particle Hydrodynamics (SPH) method is suitable for modeling the interaction between tissue and asymmetric needles, specifically whether the method can predict the bending that has been observed in practice. To accomplish this, the intricate details of the cutting of tissue have been ignored so as to simplify and focus the analysis.

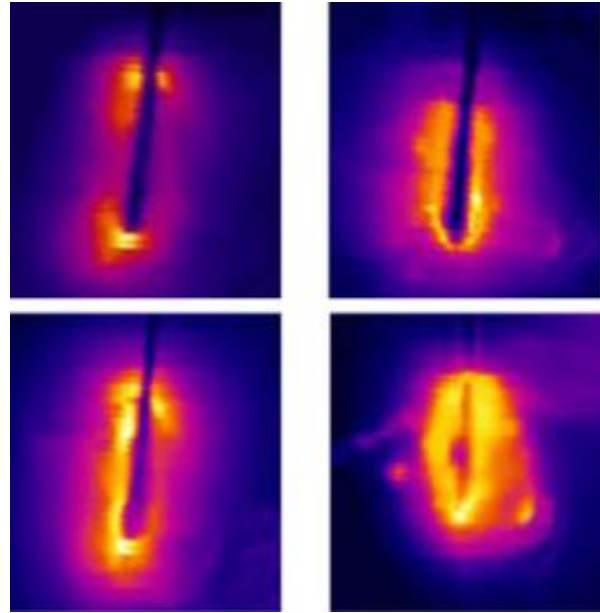


Figure 1: Figure shows very localized heating in an RFA procedure.

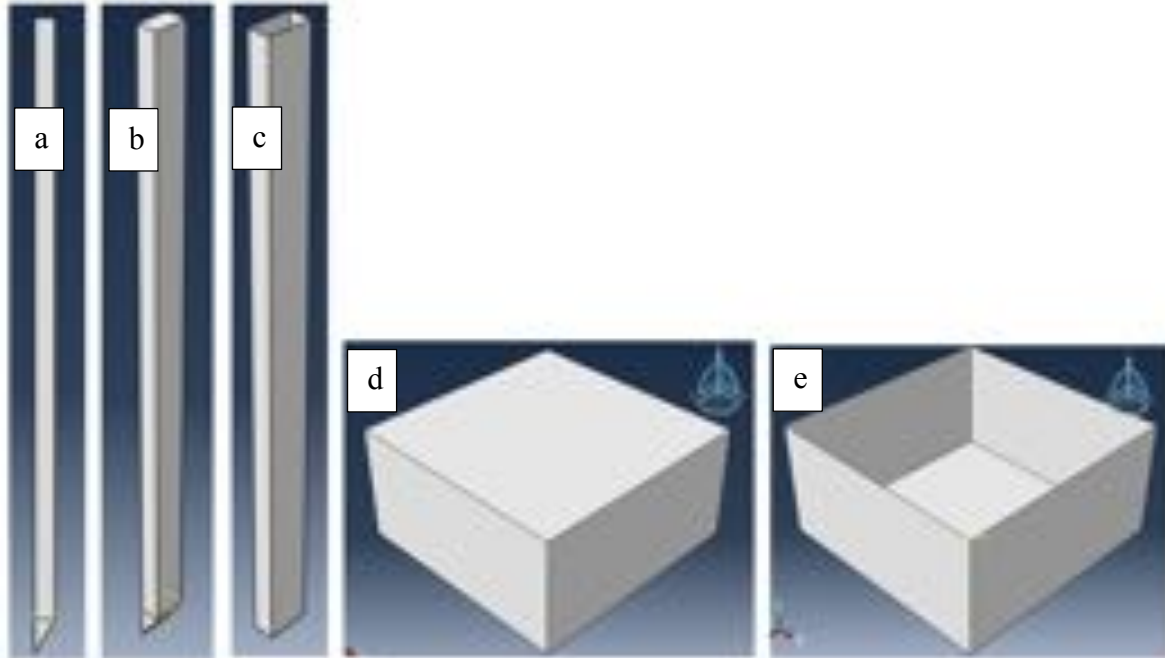


Figure 2: Brad Hanks' design for deployable needle structure.

## **Section 2: Development and Description of the CAD Geometry**

It was decided that instead of modeling the entire deployable needle structure shown in Figure 2, it would suffice to model one asymmetric needle being inserted into a region of tissue. The CAD geometry is shown below. SolidWorks and Abaqus CAE were used to model the geometry.

Figure 3 below shows all of the components used for the analysis. C and e shows the shell parts treated as rigid bodies.



**Figure 3: a and b show the needle. C shows the rigid sheath. D shows the tissue, and e shows the rigid case.**

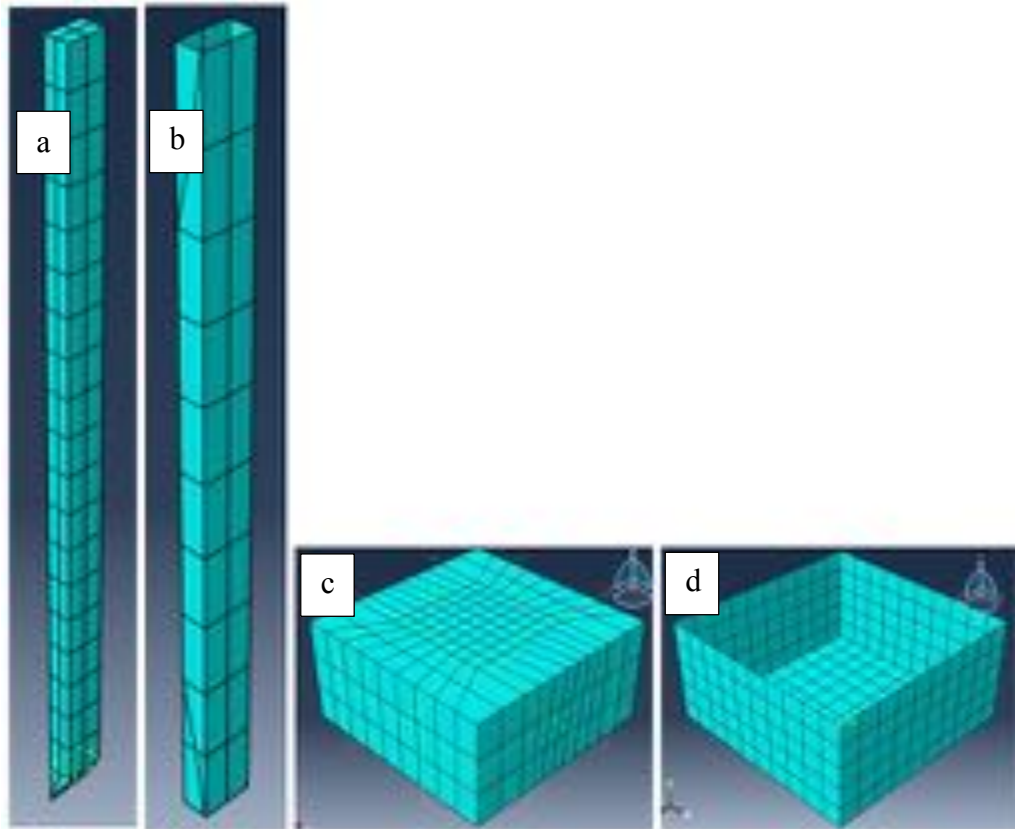
### Section 3: Development of Finite Element Meshes

SPH particles were inserted into the tissue automatically by choosing Conversion to Particles->Yes in the Element Type tool under Hex elements. The tissue was partitioned so the middle could have a finer mesh than the outside edges.

Shell elements were used for the rigid sheath and the rigid case.

Hex elements were used for the needle. The needle was partitioned at the tip to help reduce mesh distortion.

Figure 4 below shows pictures of each of the meshes.



**Figure 4:** The meshes for the components in the analysis. A shows the needle, b shows the sheath, c shows the tissue, and d shows the case.

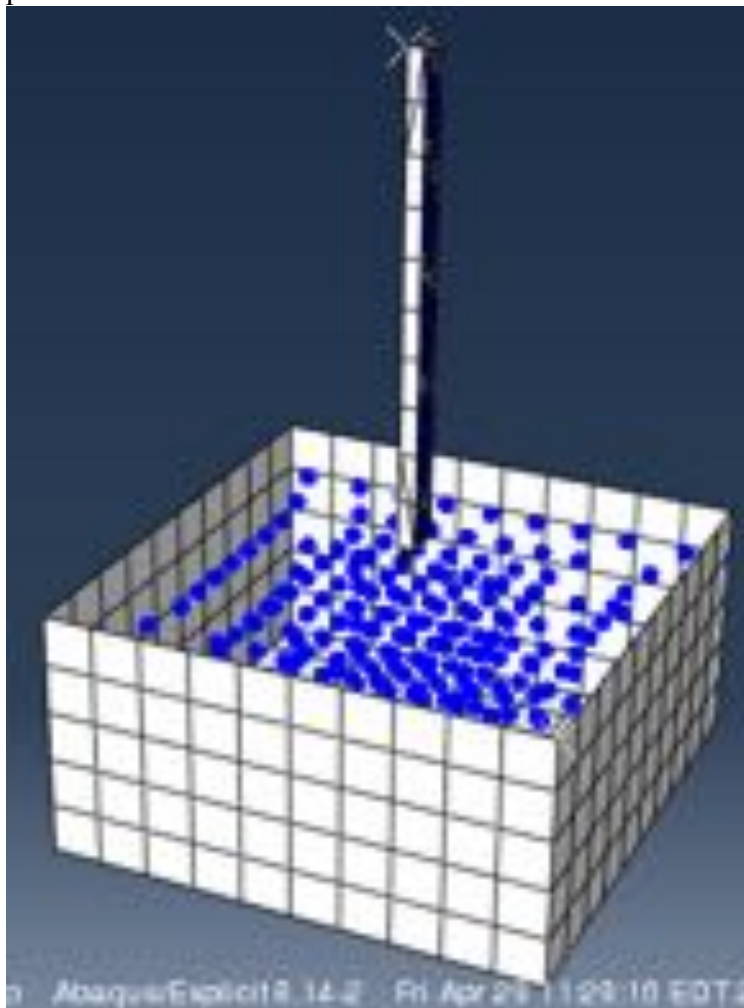


## **Section 4: Development and Description of the Model Assembly and Boundary Conditions and Model Interactions.**

The needle was placed so the very tip was touching the tissue. A rigid sheath was put around the needle to prevent buckling of the needle during insertion. A rigid case was modeled around the tissue to prevent the SPH particles from moving downward or laterally when the needle was inserted. Both the rigid case and the rigid sheath were fixed in space. The needle top was given a displacement boundary condition of 22 mm downward, and the same needle end was prohibited from moving in any other direction.

The General Contact, All with Self option was used for the analysis. The interaction properties were Hard for Normal and Frictionless for Tangential.

Figure 5 below shows the full assembly, with the tissue elements converted to SPH particles.

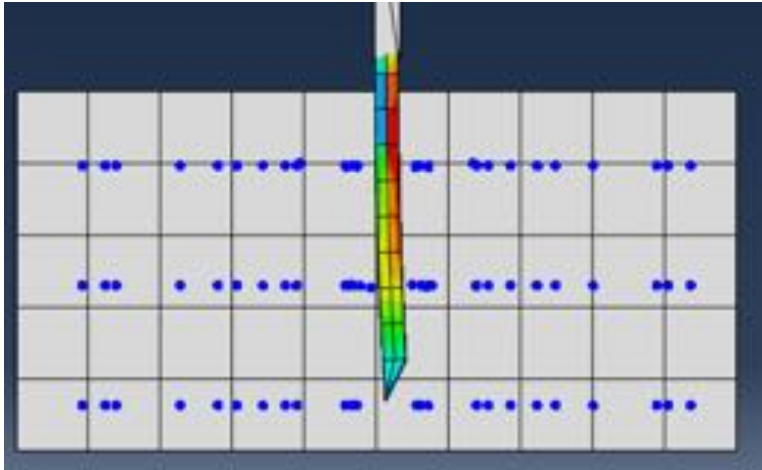


**Figure 5: Full assembly, with tissue elements converted to SPH particles.**

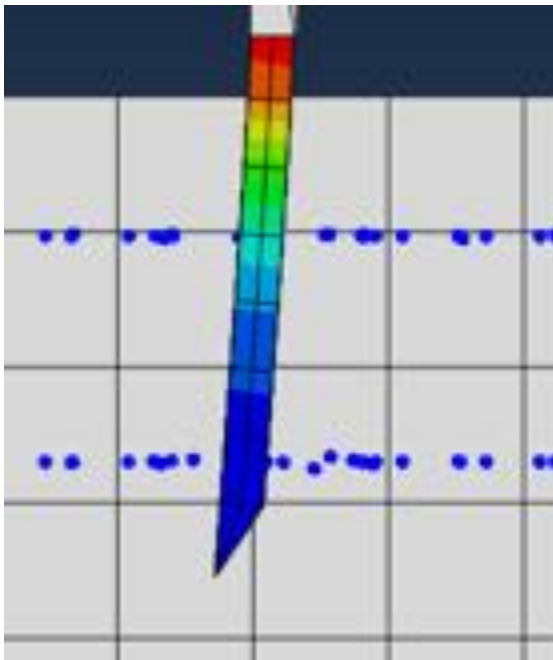
## Section 5: Analysis of Finite Element Model

The analysis was run using a Dynamic Explicit Step. One processor was used, and took about 2 hours to run.

Figure 6 shows results from a more coarse mesh. As can be seen, the needle is bending opposite from how experiments have shown it should. Figure 7 shows results after a very slight mesh refinement to the middle particles only. This resulted in the needle bending in the correct direction. This results shows the SPH method is promising for modeling the bending due to needle insertion.



**Figure 6: Results with coarse mesh. Needle is bending in the wrong direction.**



**Figure 7: Slightly refined mesh. Needle is bending in the correct direction. This shows the SPH method has promise for being able to model needle bending.**

## **Section 6: Summary of Major Findings**

The initial mesh was too coarse and predicted the needle bending in the wrong direction. After a very mild mesh refinement, the model predicted the correct bending of the needle. SPH has shown to be sufficient for modeling the bending interaction of asymmetric needles in tissue.

Because this method has shown promising results, further work will be done using parametric studies of needle geometry and the bending of needles.

## **Section 7: Works Cited**

1) **Picture of Figure 1.** K. Hong and C. Georgiages, "Radiofrequency Ablation: Mechanism of Action and Devices," *J. Vasc Interv Radiol*, vol. 21, no. 8, 2010.