3D Printed Ultrasoud Cuff for the Detection of Knee Implant Loosening

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INTRODUCTION

2.3 million patients worldwide undergo joint replacements each year, and in recent years, these procedures are being implemented in increasingly younger patients [1]. Younger patients have begun outliving their implant and requring revision. One of the main causes of revision surgery is implant loosening, which occurs when there is a space along the interface of the implant and the bone.

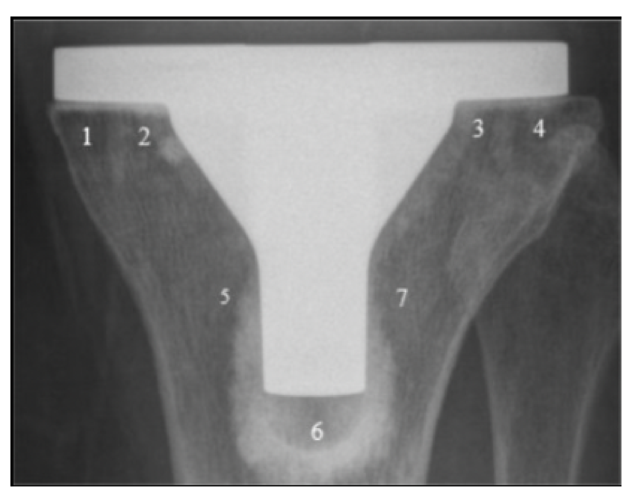

Figure 1: A depiction of a tibial component of implanted knee replacement. Knee implant loosening is focused on sections 5 and 7 in this image. [2]

METHODS

This project had **two goals**: to use COMSOL simulation data to create machine learning algorithms for detecting and categorizing implant loosening and to build a prototype that matches the physical parameters of the COMSOL model and is capable of sending and receiving signals that can be fed into the algorithms.

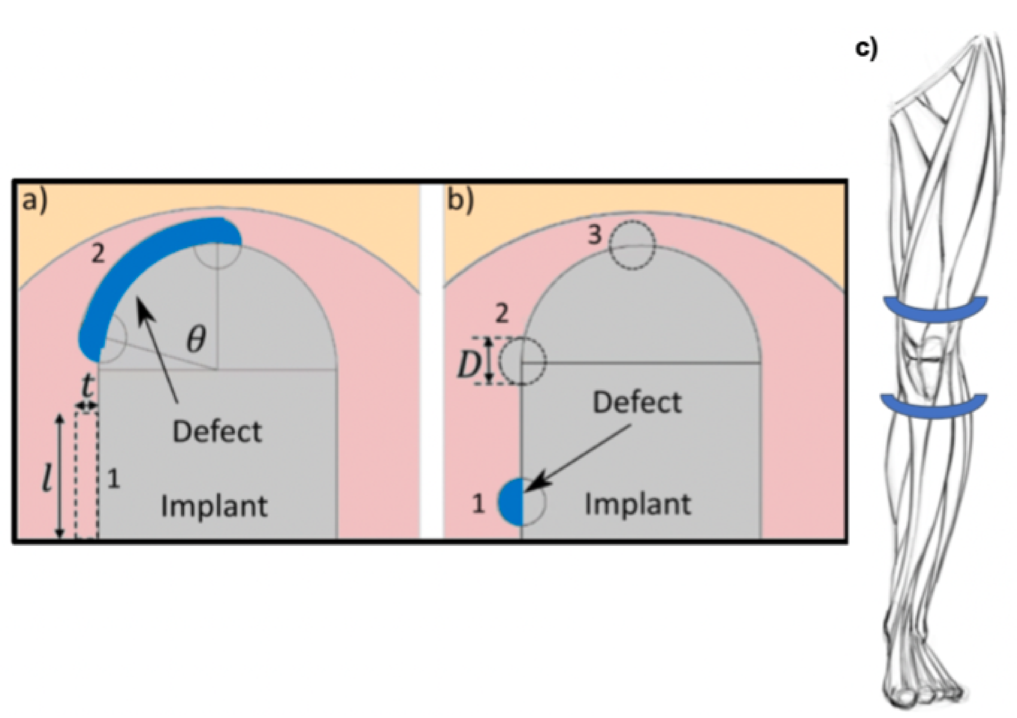

Figure 2: Methodology of simulation and physcial procedures
a) A diagram of gross implant loosening b) A diagram of "bubble" implant loosening c) A diagram of the location of the physcial cuff around the knee

RESULTS

Based on our simulation data, we created and tested a series of machine learning algorithms. The algorithms worked in two phases: the first being classification algorithms for the detection of loosening as either "healthy" (no loosening), "bubble" (a semicircular shape of loosening), or "loose" (a more gross loosening over a length of the interface). We tested 15 differnet algortihms on the data sets and were able to produce an accuracy of 94.9% using nueral networks. The second stage consisted of regression models indicating the location and size of the defect. Once the classification predicted the type of loosening, the data was fed into size and a location regression models. Figure 4 shows the results of these regression models graphically, whereas figure 3 shows the RMSE and R^2 values of the models. We then prototyped our physical design, shown in figure 5. We used Formlabs Flexible 80A resin and piezoelectric sensors 8mm in diameter and 2 mm in thickness.

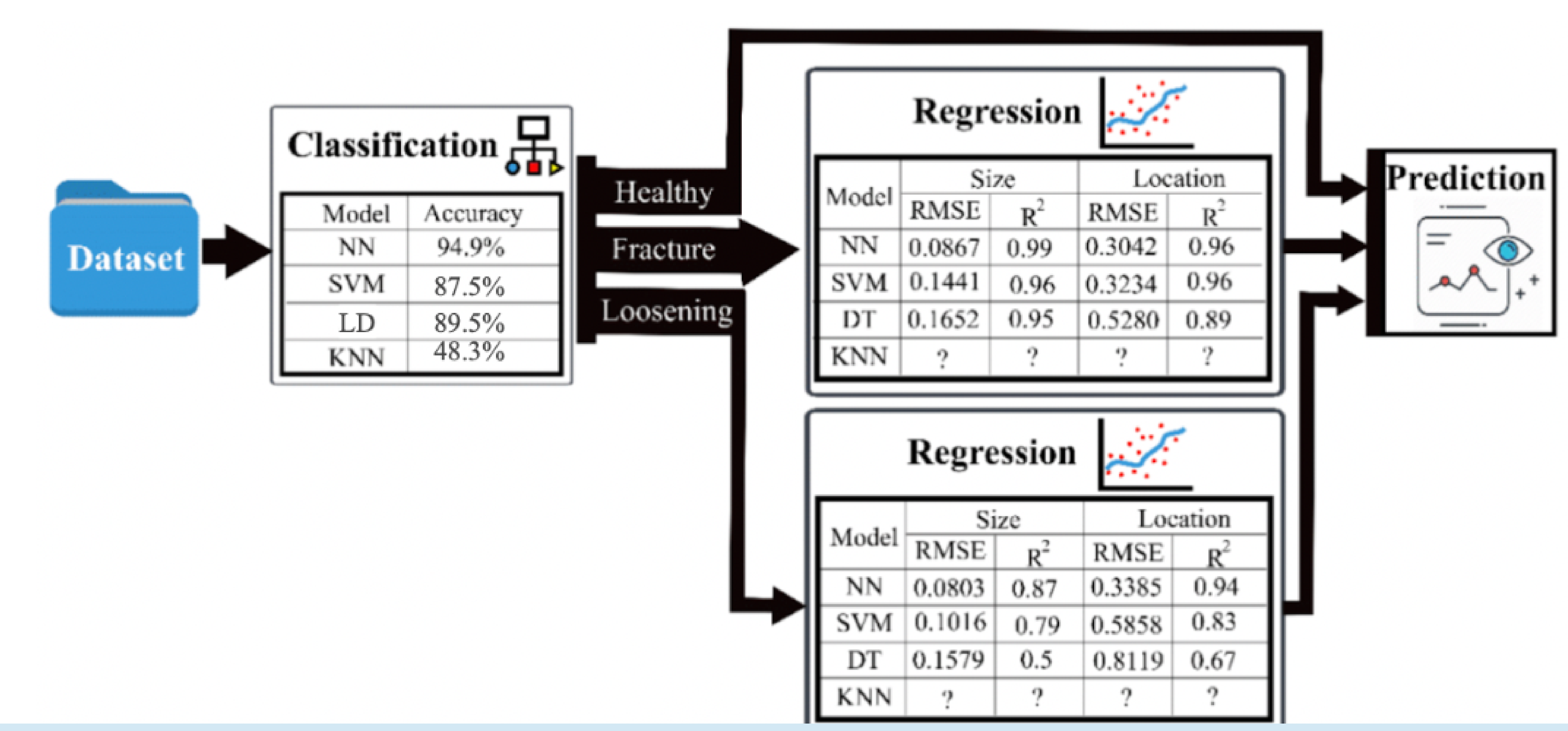

Figure 3: Accuracies and Results of Classification and Refression algorithms

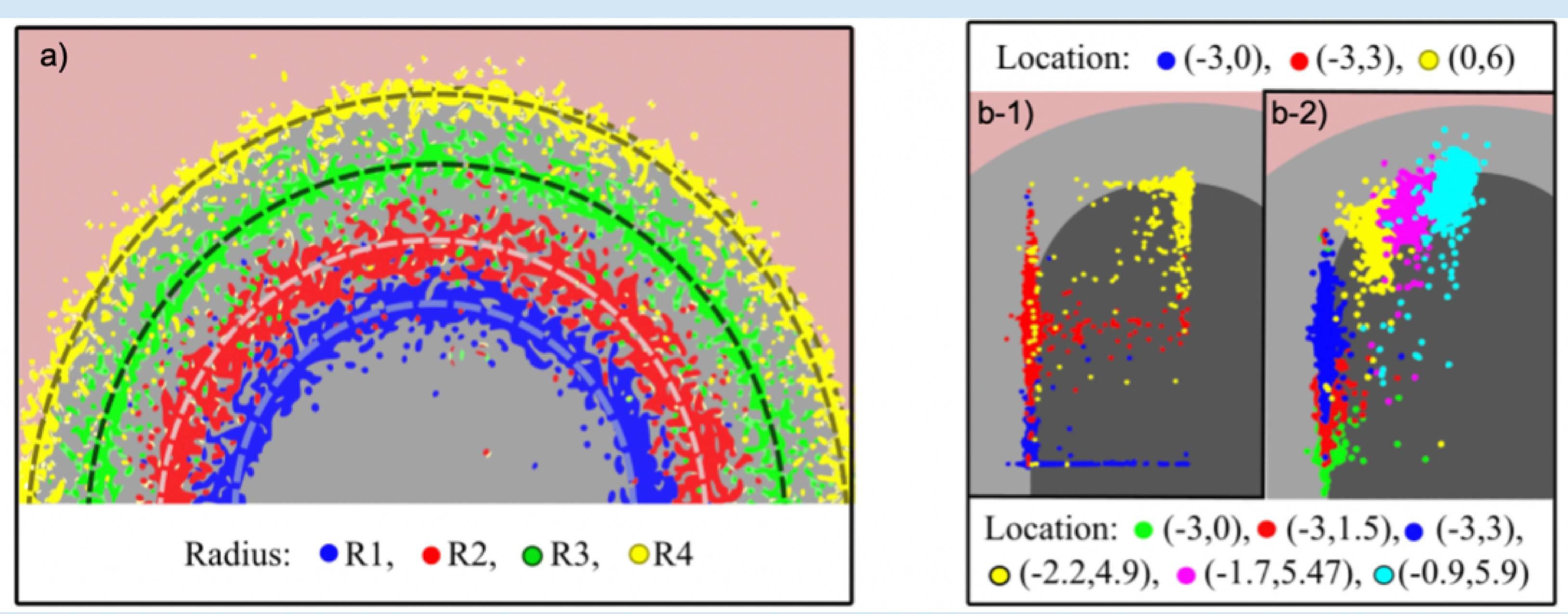

Figure 4: Graphical representation of size and location regression algotithms
a) Graphical representation of bubble size regression data. b-1) Graphical representation of bubble location regression data. b-2) Graphical representation of loose location regression data.

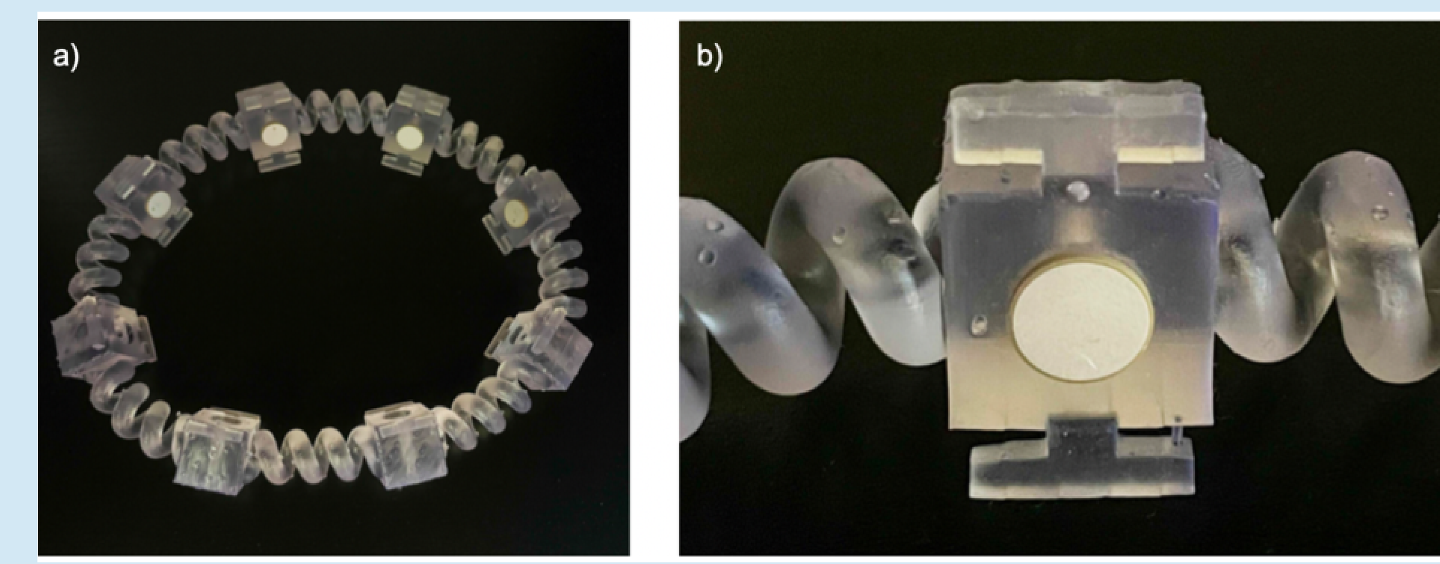

Figure 5: Images of the physical cuff design printed with Formlabs Flexible 80A resin
a) Image of the full cuff design with 8 sensor modules and coil designed for stretch
b) Photo of one individual cuff module with piezoelectric sensor inputted into slot. Piezoelectric sensors used have a diameter of 8mm and thickness of 2mm

CONCLUSION

Through this proof of concept study, we were able to successfully use low frequency ultrasound sensors and machine learnign algorithms to detect the presence and details of aseptic loosening in knee implants with a high level of precision. This research opens doors for the use of this technology for other purposes such as lumbar disk replacement surgeries, torn ligaments, and tumor detections.

The next steps of this project include:

- Fully constructing the cuff prototype and attaching it to a circuit board
- Testing the cuff sensors on cadaver knees with induced aseptic loosening in order to realize the accuracy of the simulation algorithms on experimental data.

ACKNOWLEDGEMENTS

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References: [1] "2013 extremity update," *Orthop Newt News*, vol. 24, no. 1pp. 1–16, 2013. [2] https://www.sciencedirect.com/science/article/pii/S0883540317301201