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CIS II Paper Review
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Introduction

Throughout the spring semester of 2021, I have been working with fellow JHU Robotics Master's student Harsha Mohan to design a force-sensing attachment for a surgical drill. We collaborate closely with otologic surgeons and engineers and Galen Robotics, who have developed a hand-over-hand robot for assisting in head and neck surgeries.

Otologic surgeons often do drilling tasks shockingly close to delicate anatomy around the inner and middle ear. For example, in a stapedotomy, the surgeon must drill away a thin layer of bone without pushing through into underlying structures. The ability to measure the applied drilling forces in real-time during these procedures enables future work to incorporate force feedback and to develop sophisticated virtual fixturing to further minimize surgical errors.

Additionally, there is a surprising lack of data in the literature documenting the applied drilling forces in these procedures. Nevertheless, there are numerous studies discussing the evaluation of surgical models using chicken eggshells to simulate thin bones encountered in delicate drilling tasks. In this paper, I will review two of these training methods. I am motivated to review these papers so that I can highlight the gap in the literature that I hope to explore with my own work this semester.

Chicken Egg and Skull Model to Improve Trainee Drilling Skills (Okuda et al. 2014)

Endoscopic Endonasal Transsphenoidal Surgery (eETSS) is a highly specialized class of procedures and is very technically challenging. Most training (cadaver dissection and hands-on seminars) focuses on anatomy, with less attention given to the technical motor skills needed for successful results. In fact, these procedures are similar to drilling through an eggshell without piercing the underlying membrane. This paper proposes the integration of a chicken egg into a previously-developed skull model.

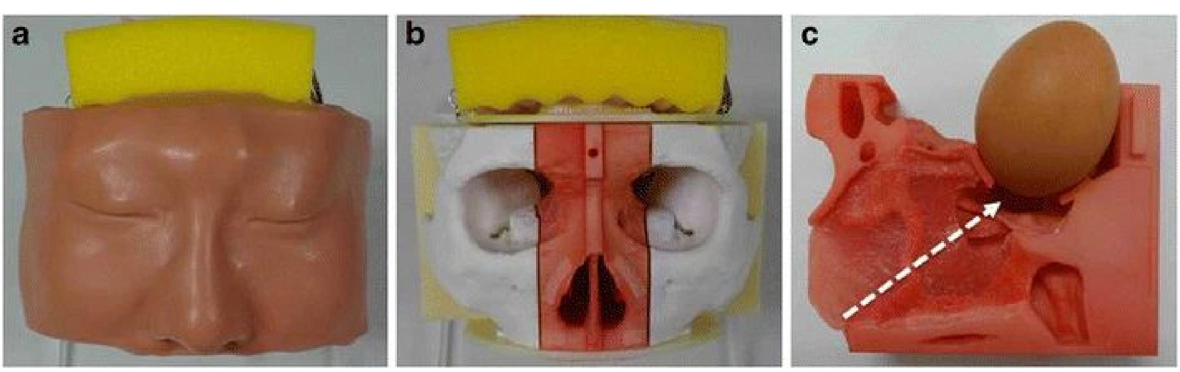

Figure 1: The Okuda training model.

In the experiment, investigators imprinted a 2 mm square grid onto each egg using inkjet printable temporary tattoo paper. Five residents with no experience with neuroendoscopic surgery each drilled ten eggs, and four expert surgeons each drilled 1 egg. After each trial, the area of the shell that could be drilled before rupturing the underlying membrane was measured using the imprinted grid.

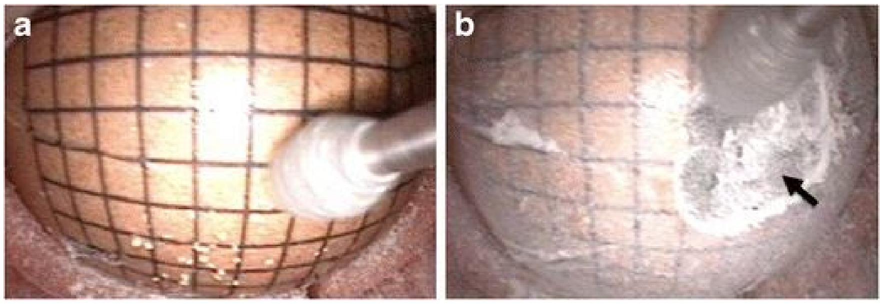

Figure 2: Eggshell drilling test demonstrating use of tattoo paper grid and eggshell removal.

The 5 residents were able to remove only 31.2 ± 17.5 mm^2 from the first egg. However, all residents demonstrated a learning effect and improved their skill to be able to remove 104.8 ± 3.3 mm^2 on the 10th egg. The increase in mean drilling area and sharp decrease in standard deviation shows that differences in their individual ability were resolved through training.
The experts removed 257 ± 31.73 mm^2 from the egg, clearly performing much better than the residents. The investigators believe that their ability to dexterously manipulate the endoscope played a large role in their better performance. Overall, the results show that this method is effective for training fine drilling techniques necessary in eETSS.

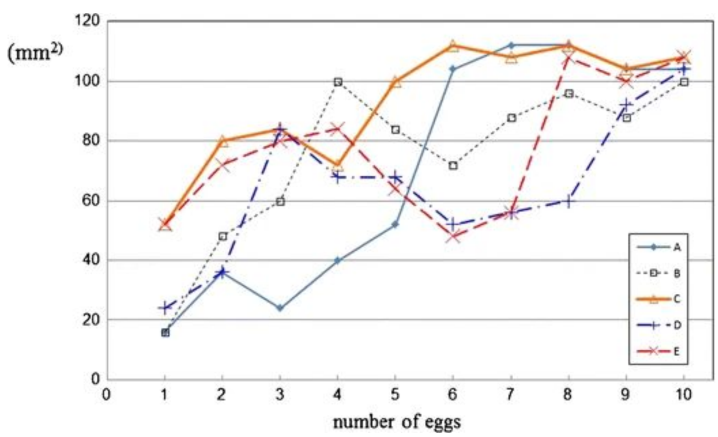

Figure 3: Comparison of areas removed by five residents.

I think the training model used in this paper looked very impressive. I also thought using the tattoo paper was a clever idea, but I am skeptical of their achievable measurement precision with this technique. This was an interesting way to measure surgical skill, but it seems that other measurements may be a more direct measurement of fine control of motor skills. It is more relevant to measure how carefully the surgeon can control their applied forces and their penetrating distance after breaking through the egg shell.

Effect of Haptic Training on Real Surgical Drilling Proficiency (Sewell et al. 2007)

Haptic technology can be used to train individuals to better control their motor skills so that they can perform better in tasks that require force feedback. Although there is a large body of literature to support this fact, little is known specifically about how particular motor skills learned using a haptic simulator can be transferred to surgically-relevant tasks. As noted, procedures such as a stapedotomy require surgeons to perform drilling tasks similar to removing the shell of a chicken egg without rupturing the egg’s inner membrane.

Investigators designed a haptic simulator to train users to minimize penetration distance of a drill when it breaks through a thin resistive layer, clearly mimicking the task of drilling through an egg shell. Users control a virtual drill with a Phantom haptic device. They apply a downward force onto a virtual plane, which resists their downward motion. Once a force greater than 0.3 N is applied onto the plane for a random, predetermined time between 8 and 12 seconds (similar to the time it would take to complete the real-world task. The simulator then measures the distance traveled after breaking through the plane.

The investigators also designed a similar experiment with a chicken egg. The egg was placed in a dish filled with silly putty to hold it stationary, which was mounted on top of an ATI nano17 force/torque sensor to measure the applied drilling forces. These measurements informed their decision for the break-through force of 0.3 N.

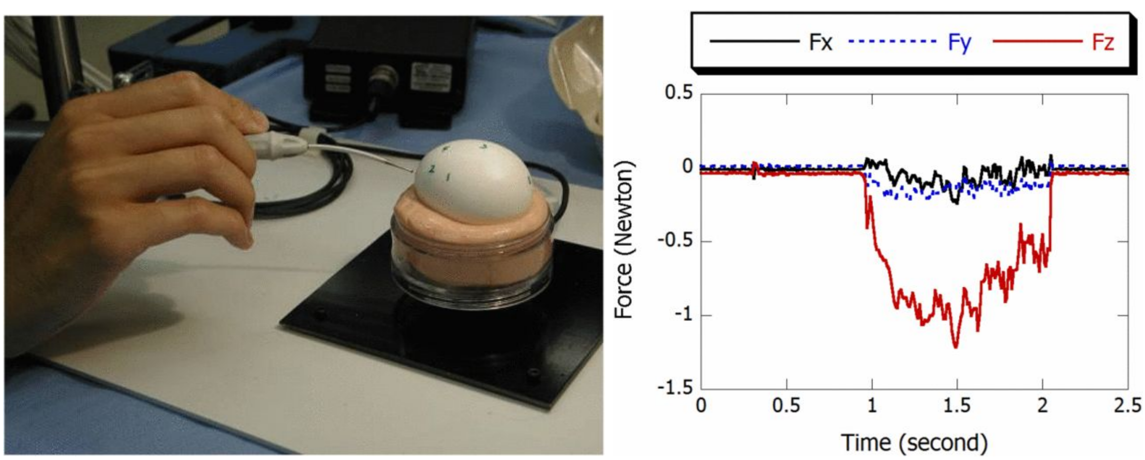

Figure 4: Force measurement set-up and recorded force measurements.

The experiment involved ten participants randomly assigned to two groups of five. All participants watched a brief video of an expert demonstrating how to drill the holes in the eggshell properly. Each hole needed to be at least as wide as the drill burr and created in under 15 seconds without rupturing the underlying membrane. Participants in Group A drilled 8 holes in each of 4 eggs. Participants in Group B first completed 24 trials on the simulator, and then drilled 8 holes in only 1 egg.

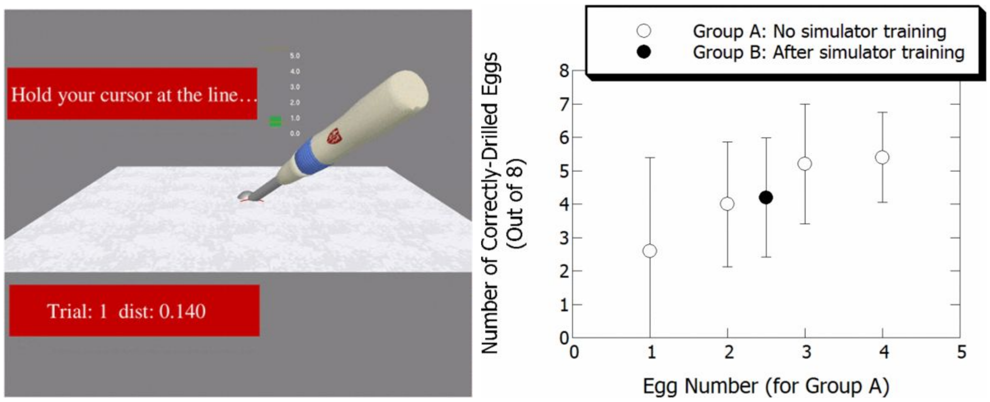

Figure 5: Screenshot of the simulator and experimental results.

The results show that Group A demonstrated a learning effect through their trials. Group B was not as proficient after their 24 trials with the simulator, but the data shows that they clearly started farther along the learning curve. It was thus concluded that the simulator trials are not as effective as the same number of real-world trials, but when considering cost and availability, it may often be beneficial to complete many simulator trials. That being said, the investigators note that the relatively high variance and limited number of participants do not yield statistically conclusive results.

Unfortunately, their results do not directly address their goal of understanding transference of specific motor skills from the haptic simulator to real-world tasks. Furthermore, comparison of drilling through eggshell and the thin bones of the stapes footplate is based entirely on anecdotal notes.

Although I am skeptical about their use of silly putty to fix the egg, the drilling force data presented is directly relevant to my team's investigation. However, more data about these applied forces could have made an interesting and relevant addition to their paper. Overall, I think these results were really interesting, despite the inconclusive statistics.

As noted in their paper, future work is needed to improve their simulator and recruit more participants. The investigators would also like to redesign the experiment to separate the skills of preserving the membrane and making a sufficiently large hole.

Conclusion

The measurements each study uses to determine surgical skill complement each other nicely. As noted, both papers assume that drilling through chicken eggs is sufficiently similar to sensitive surgical drilling tasks around the skull base. By exploring these experiments, I have demonstrated a notable lack of data in the literature about the actual drilling forces applied in procedures such as the stapedotomy. This data, if similar to the drilling forces measured by Sewell et al. (2007) would reinforce the justifications for using chicken eggs in surgical training models. My team hopes to fill this gap with our experiments this semester.

References

1. Okuda, T., Yamashita, J., Fujita, M. et al. The chicken egg and skull model of endoscopic endonasal transsphenoidal surgery improves trainee drilling skills. Acta Neurochir 156, 1403–1407 (2014). https://doi.org/10.1007/s00701-014-2035-7
2. C. Sewell, N. H. Blevins, S. Peddamatham and H. Z. Tan, "The Effect of Virtual Haptic Training on Real Surgical Drilling Proficiency," Second Joint EuroHaptics Conference and Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems (WHC'07), Tsukuba, Japan, 2007, pp. 601-603, doi: 10.1109/WHC.2007.111.