Force Sensing Drill for Skull-Base Surgery

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Force-Sensing Drill for Skull-Base Surgery

Context:

Surgical access for Skull-Base surgery requires precise drilling around sensitive anatomy

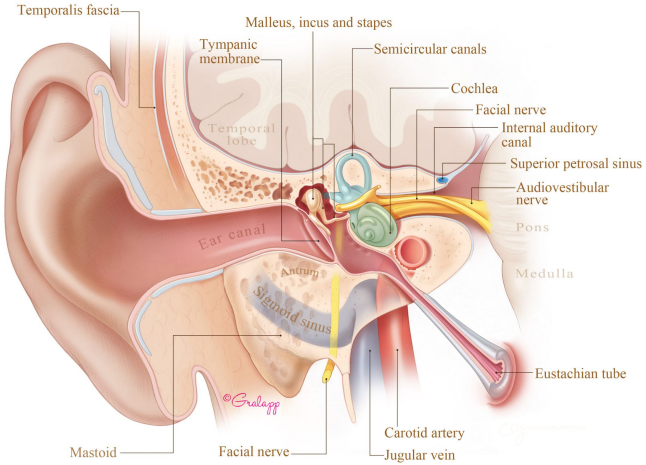
Critical structures are often within millimeters of each other

- Nerves, Veins, Arteries, Spinal Cord Tissue

Accidental movement or slip of surgical drill could lead to

- Changes in taste
- Facial paralysis
- Cerebrospinal Fluid leakage
- Collapse of the sigmoid sinus

These procedures require high precision and accuracy from the surgeon



Credit: Christine Gallup [4]
https://otosurgeryatlas.stanford.edu/

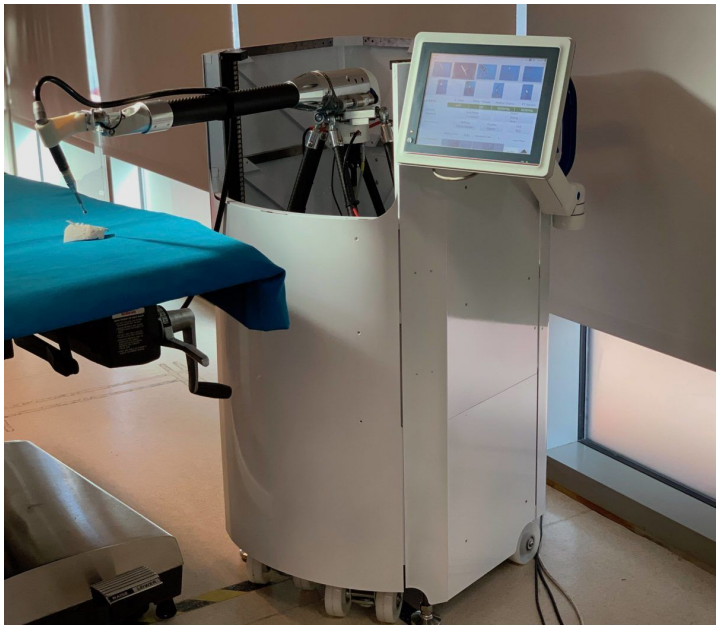
Force-Sensing Drill for Skull-Base Surgery

Motivation:

A force-sensing drill will enable new methods of haptic feedback and virtual barriers. Such a device can also be used to evaluate surgical skill and train resident surgeons.

Goal:

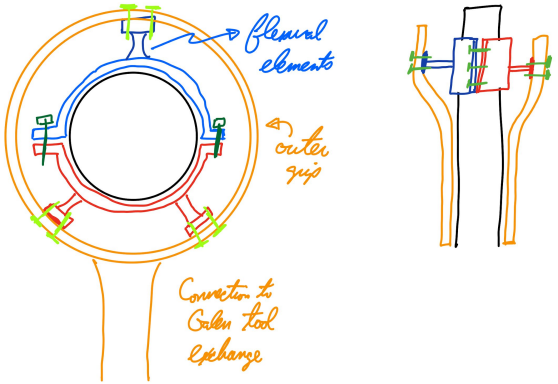
Design and prototype a force-sensing drill for the Galen surgical system

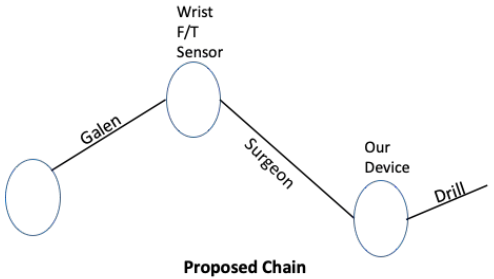


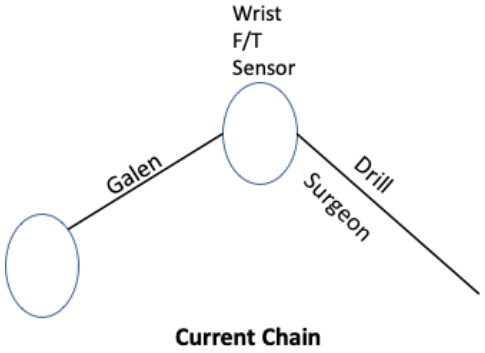
Credit: Galen [4]

Technical Approach - Design

- Design Requirements
  - Sense force at tool tip
  - Ergonomic for surgeon
  - Provide adequate manipulability





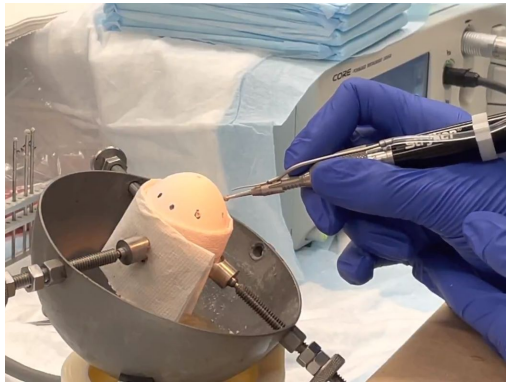


Data Analysis Experimental Setup & Method

- Purpose: Identify requirements for force-sensing element

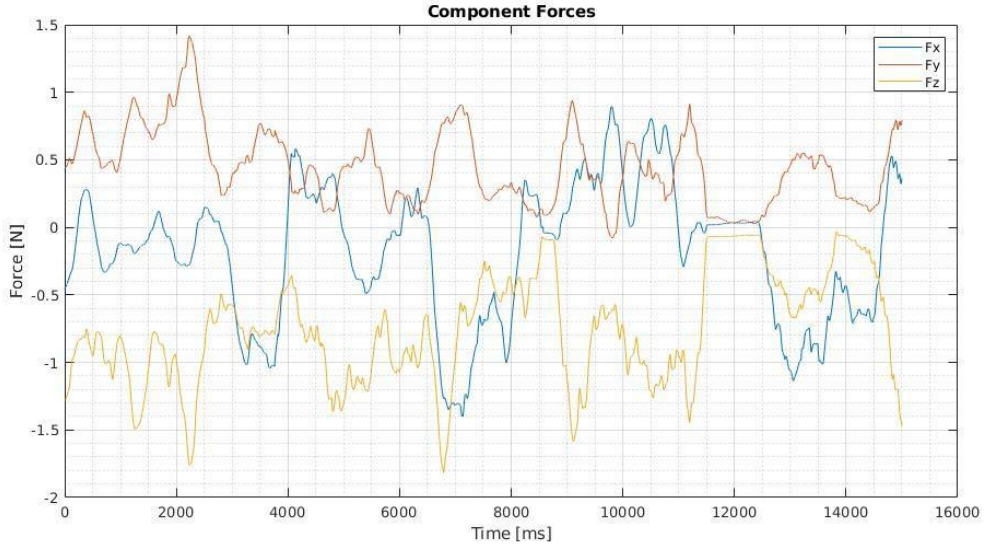
- Sourced phantom temporal bone and egg shells for drilling
- Setup a F/T sensor below specimen fixture
- Surgeon performs multiple drilling maneuvers on various anatomy
- Collected serialized video and F/T sensor data in ROS bag file
    - Use video feed to identify relevant data

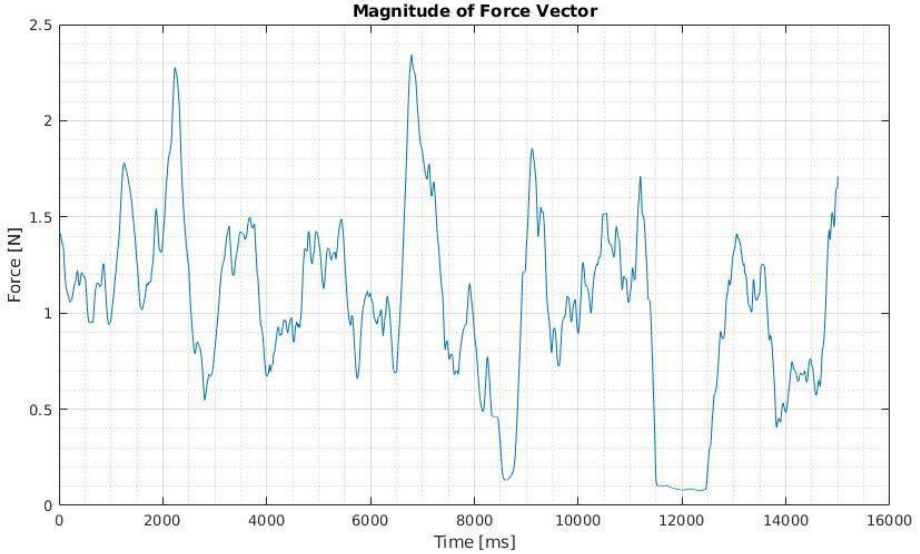
- Possible Sources of Error
    - Irrigation began to pool up and be absorbed by phantom
    - Mass of specimen decreases during drilling
    - Bias and error of the F/T sensor



Data: Phantom Cordial Mastoidectomy

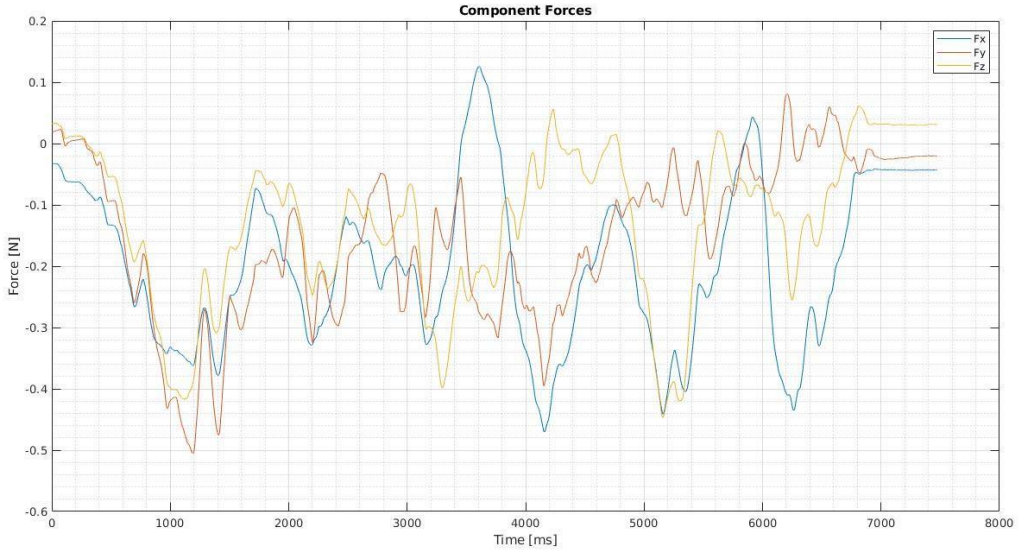
Example of an aggressive drilling maneuver

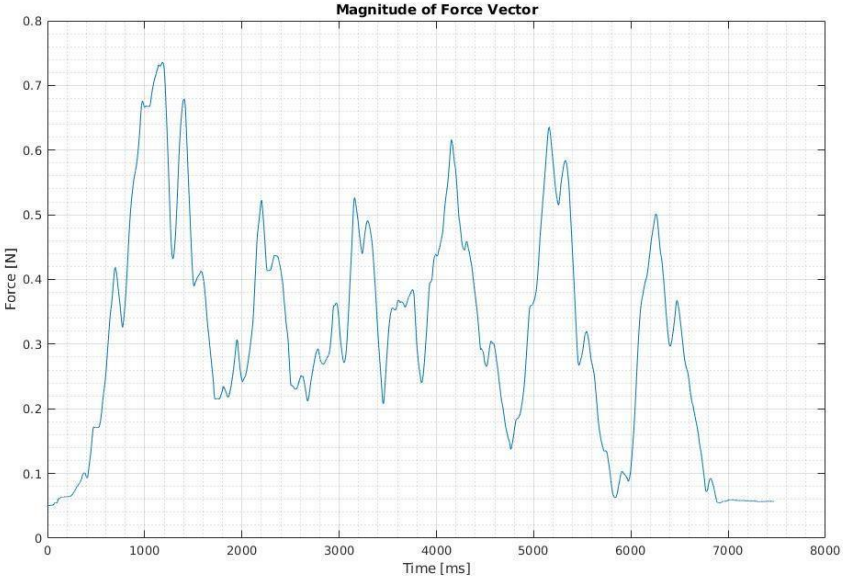




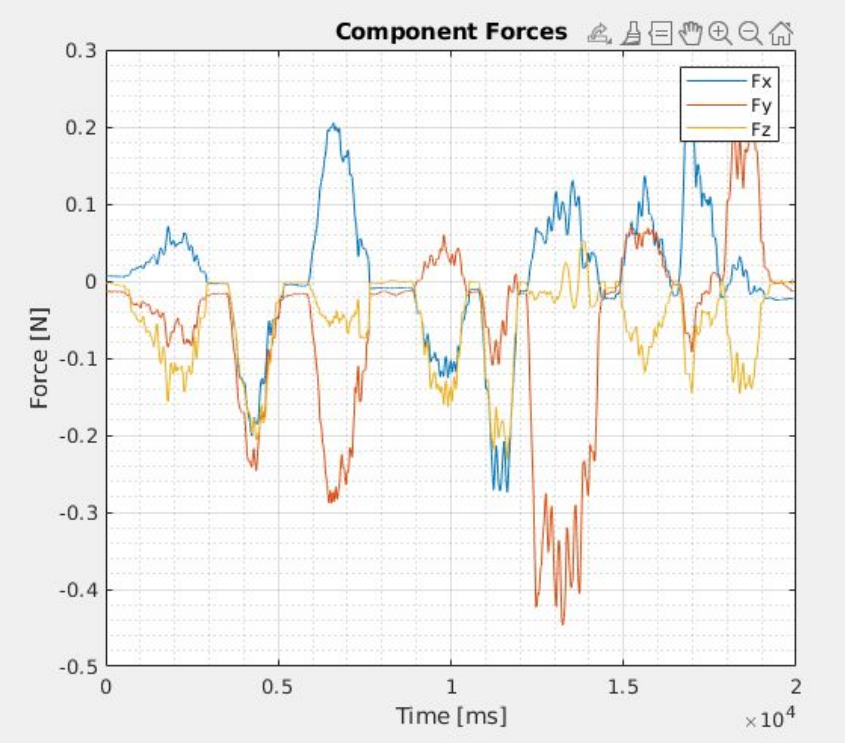
Data: Phantom Cochlea

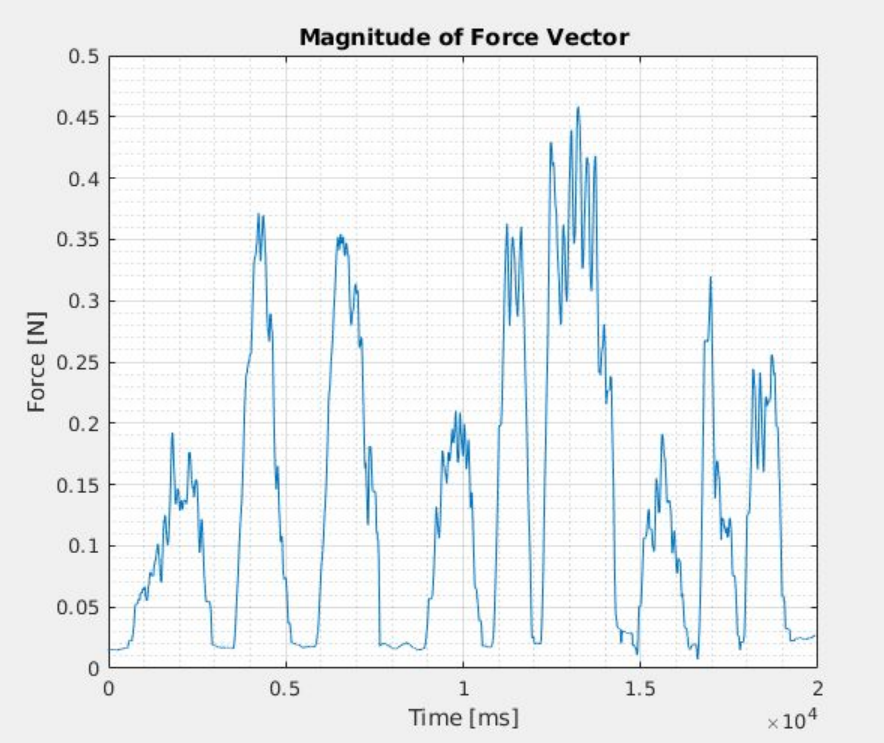
Example of a sensitive drilling maneuver





Data: Egg Shell Drilling





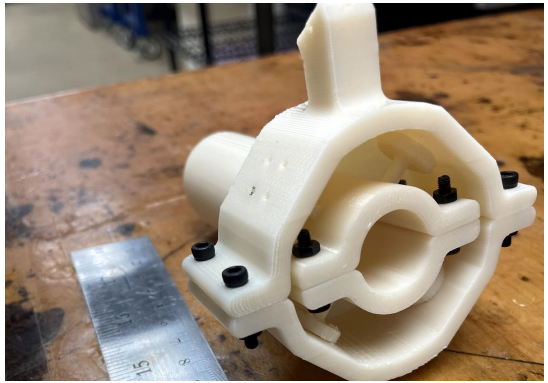
Drilling Data Analysis Conclusions

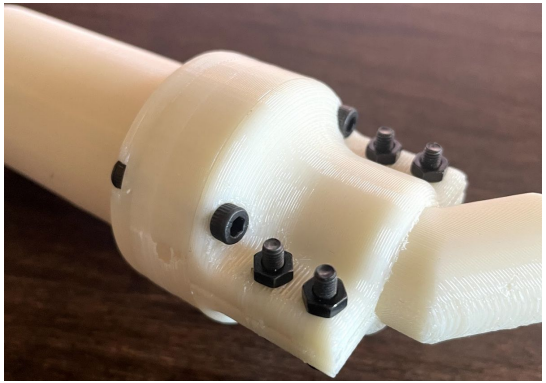
- Aggressive drilling rarely exceeds|F| > 2.5 N
- Sensitive drilling rarely exceeds |F| > 1 N

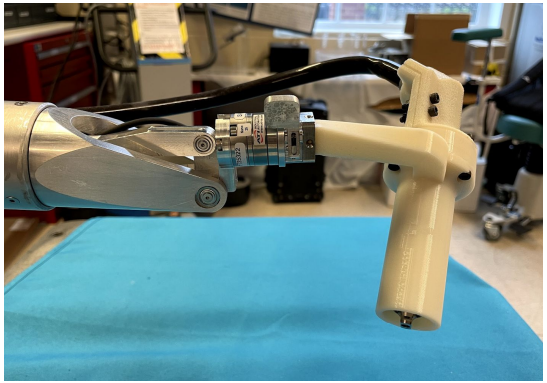
- Selected ATI Nano 43 (SI-18-0.25)
  - Range: [Fx, Fy, Fz = 18N], [Tx, Ty, Tz = 250 Nmm]
  - Resolution: [Fx, Fy, Fz = 1/256N], [Tx, Ty, Tz = 1/20 Nmm]

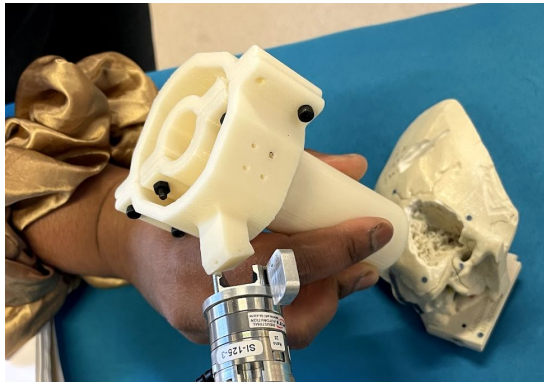
Calibration	Fx,Fy	Fz	Tx,Ty	Tz	Fx,Fy	Fz	Tx,Ty	Tz
SI-9-0.125	9 N	9 N	125 Nmm	125 Nmm	1/512 N	1/512 N	1/40 Nmm	1/40 Nmm
SI-18-0.25	18 N	18 N	250 Nmm	250 Nmm	1/256 N	1/256 N	1/20 Nmm	1/20 Nmm
SI-36-0.5	36 N	36 N	500 Nmm	500 Nmm	1/128 N	1/128 N	1/10 Nmm	1/10 Nmm
	SENSING RANGES				RESOLUTION			

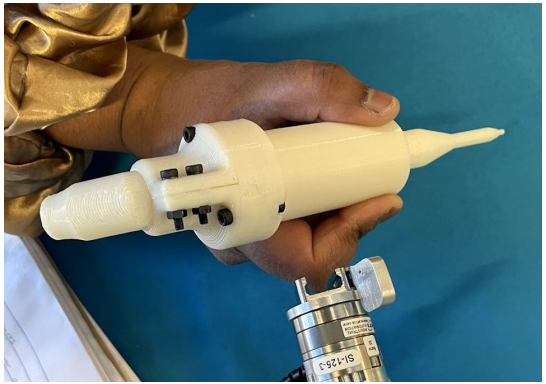
Project Progress

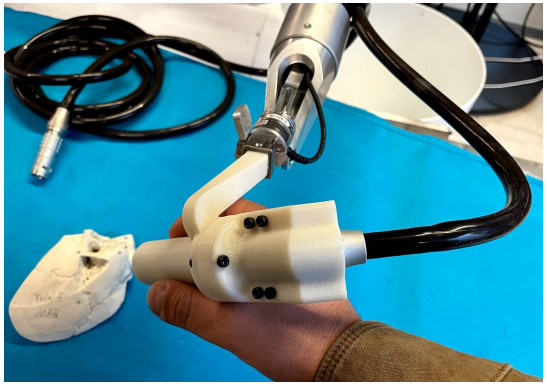




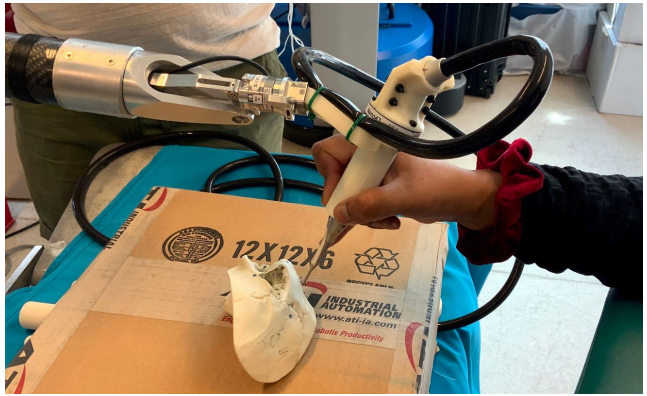








Final Prototype



Testing & Validation Plan

- **Ergonomics**
  - *Task:* Iterate on geometry based on surgeon feedback
  - *Evaluation Criteria:* Unobstructed field of view, Comfort, Manipulability

- **Eggshell Drilling Experiment**
  - *Task:* Drill multiple egg-shells with force-sensing adapter attached to the Galen.
  - *Evaluation Criteria:* Compare magnitude of force readings from fixed sensor and drill sensor

Next Steps

- Get force readings from sensor
- Pivot calibration + drilling experiment to compare values with ground truth sensor
- Mechanical design improvements

Thank You!

References

[3] SLAP Tears. https://charlotteshoulder.com/slap-tear. Accessed April 5, 2021.

[4] Galen Robotics. https://technical.ly/baltimore/2019/11/11/galen-robotics-verte-investment-opportunity-zone-fund-startups/. Accessed April 6, 2021.

[5] Temporal Bone Anatomy. https://otosurgeryatlas.stanford.edu/otologic-surgery-atlas/surgical-anatomy-of-the-ear/overview-of-temporal-bone/. Accessed April 1, 2021

[6] T. B. C Gaudeni, GM Achilli, M Mandala, D Prattichizzo, "Instrumenting Hand-Held Surgical Drills with a Pneumatic Sensing Cover for Haptic Feedback," Cham, 2020: Springer International Publishing, in Haptics: Science, Technology, Applications, pp. 398-406.

[7] R. M. H Sang, E Wilson, H Fooladi, D Preciado, K Cleary, "A New Surgical Drill Instrument With Force Sensing and Force Feedback for Robotically Assisted Otologic Surgery," *Journal of Medical Devices,* vol. 11, September 2017.