



JOHNS HOPKINS
UNIVERSITY

Design of a Robotic System for Ultrasound-Guided Central Line Placement

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Mentors: Dr. Axel Krieger, Lidia Al-Zogbi, Dr. Vinciya Pandian, Dr. Mathias Unberath, Wenhao Gu

Project Summary

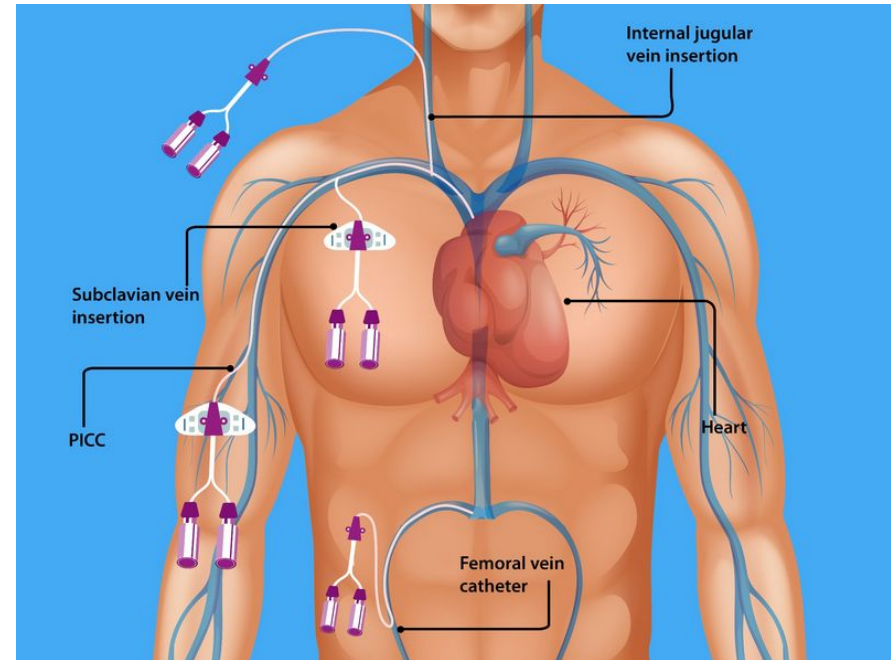
- **Problem:**

The complicated procedure of central line placement is physically and mentally demanding for clinicians, leading to:

- low accuracy
- low consistency
- low efficiency

High complexity leads to increased infection risk:

- Result in increased healthcare costs, and even death.



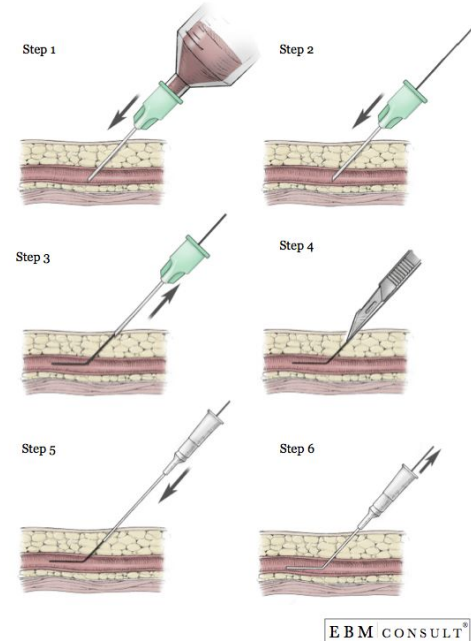
Project Summary

- **Project goal:**

A multi-object insertion system to minimise the risk of infection of non-tunnelled central line placement at the subclavian vein.

- **Deliverables:**

- High-level and low-level specifications
- CAD model
- Prototype
- Documentation
- Experimental evaluation



Design Specifications of the Robot

High-level design specifications:

- Perform needle insertion, guidewire and catheter advancement
- Adapt to variations in patient anatomy
- Reduce the risk of infections (by having sterilisable components)
- Integrate with a wireless ultrasound probe

Assumptions:

1. Clinician scans the region using ultrasound and decides the insertion site and angle
2. Guidewire is straight and not “J-tip”
3. Do not use a dilator
4. Clinicians retracts the needle and guidewire
5. Syringe is detachable from the needle without the need of a twisting motion
6. The clinician feeds the guidewire and the catheter to the robot



Ultrasound probe



J-tip guidewire

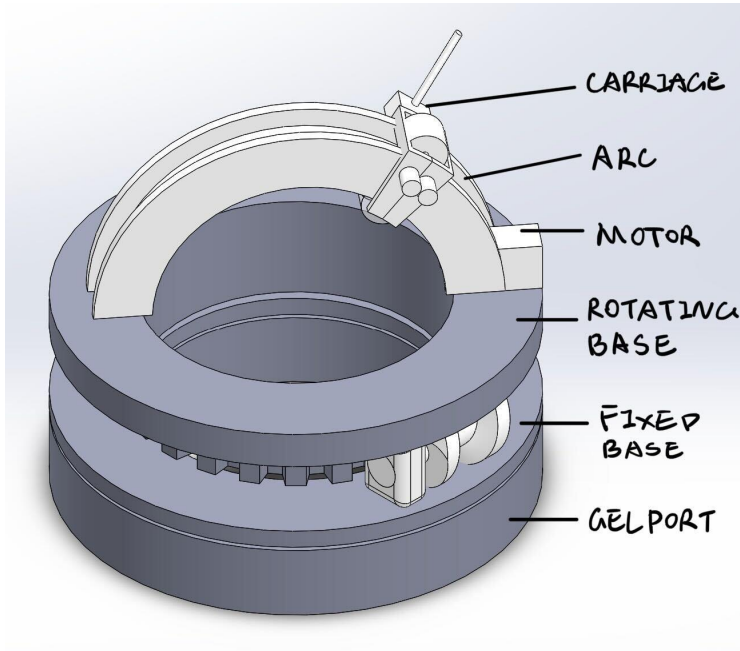
Design Specifications of the Robot

Low-level design specifications:

- Have a minimum workspace of 10cm x 10cm.
- Have all 3 rotational degrees of freedom and 1 translational degree of freedom.
- Have a precision of at least 0.1mm in all movements with an accuracy of 90%.
- Be able to insert a 18-gauge needle with a bevel up of 30 degrees [2] and a depth of 2-3 cm [3].
- Be able to advance about 18 cm of a 50 cm guidewire [4].
- Be able to insert a guidewire with a diameter of 0.035 inches through the needle [2].
- Be able to insert a catheter with a size 8.0 French [2].

1. Suzuki, T., Masahiro Kanazawa, Yoshio Kinefuchi, Haruo Fukuyama, Mamoru Takiguchi, Michio Yamamoto, Kazuhiro Abe, and Yosuke Okuda. "A pilot/introducer needle for central vein cannulation." *The Tokai Journal of Experimental and Clinical Medicine* 20, no. 4-6 (1995): 223-226.
2. Wang, Henry E., and Thomas A. Sweeney. "Subclavian central venous catheterization complicated by guidewire looping and entrapment." *The Journal of emergency medicine* 17, no. 4 (1999): 721-724.
3. Tse, Audrey, and Michael A. Schick. "Central line placement." In *StatPearls [Internet]*. StatPearls Publishing, 2022.
4. Heffner, Alan C., and Amalia Cochran. "Overview of acute and emergency central venous access in adults" in UpToDate, UpToDate Publishing, 2022.

Design of the robotic system



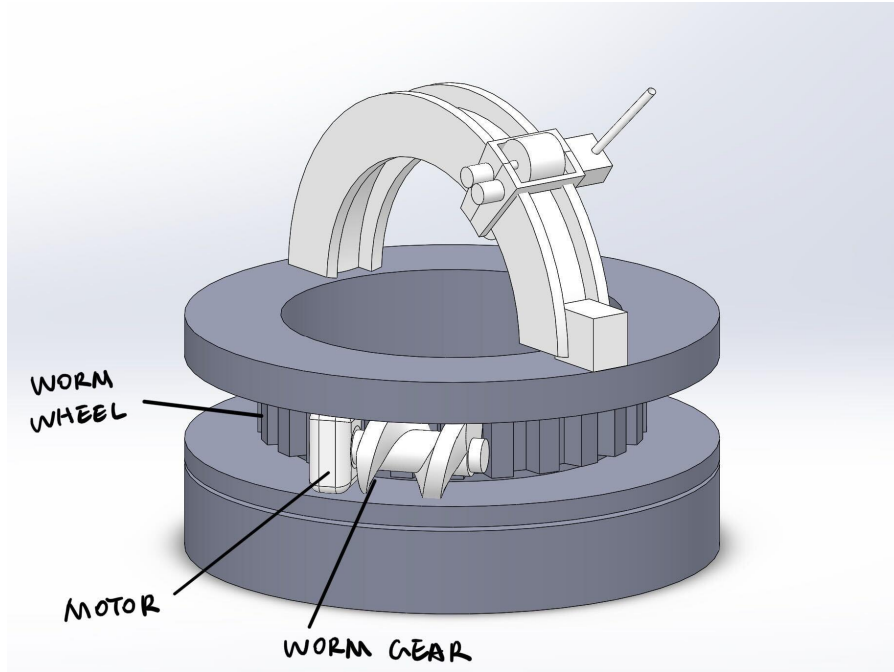
Isometric view of the overall design

- ▶ The robot has a mechanical remote center of motion (RCM).
- ▶ GelPort is a sticky soft material that is generally used in laparoscopic surgery. Here, it is used for holding the robot on the patient
- ▶ The arc has one rotational degree-of-freedom (DoF)
- ▶ The carriage has one rotational DoF and one translational DoF



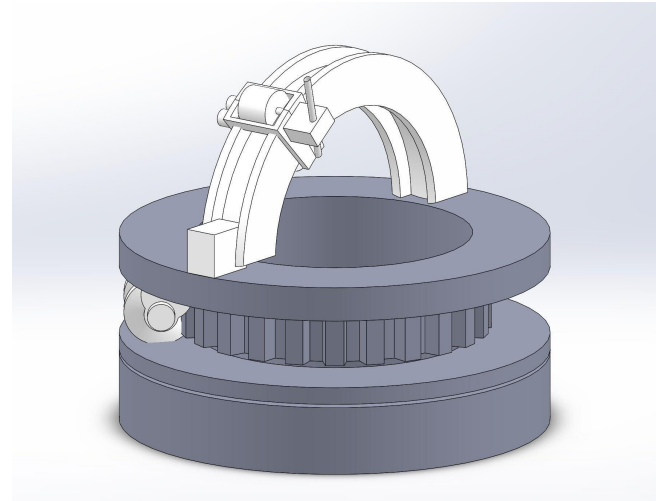
GelPort

Design of the robotic system



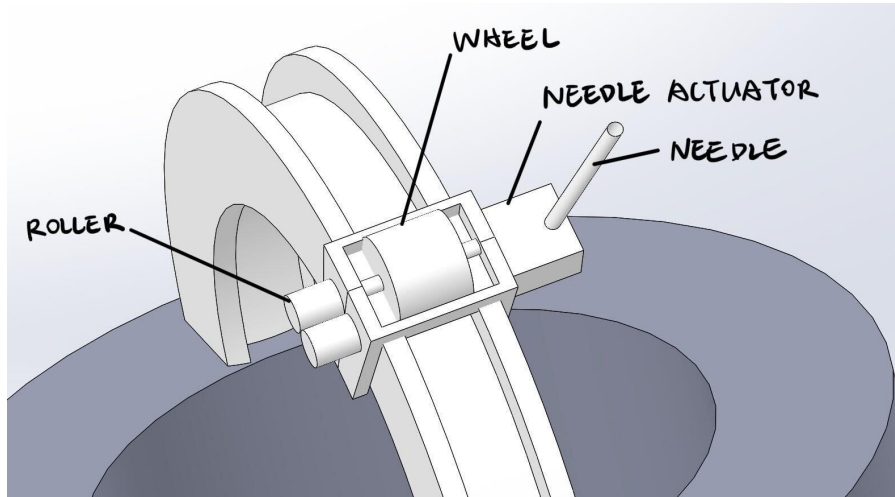
Details of the worm drive

- ▶ Worm drive and wheel provide a rotational DoF at the base



Back view of the design

Design of the robotic system



Details of the carriage and the actuator

- ▶ The carriage uses a cable pulley mechanism to slide over the arc
- ▶ A linear actuator advances the needle
- ▶ One active roller and a passive roller advance the guidewire and catheter

Improvements for the next version

- ▶ The robot has to have a provision for intra-procedural ultrasound scanning
- ▶ The arc has a curved rack and pinion mechanism instead of a cable pulley mechanism
- ▶ The rollers for the guidewire and catheter advancement would be connected together through a spring
- ▶ The robot needs to have a clamping mechanism closer to the skin maybe using hydraulics
- ▶ The robot needs to have a structure to guide the guidewire into the needle
- ▶ The robot can have a provision to hold the guidewire and catheter before their respective advancements

Management Plan

- **Meeting plan**

- (1) Mentor meeting

- Time:* Tuesday 10:00 - 11:00

- Location:* Zoom or Hackerman 116

- Weekly meeting scheduled with Lidia Al-Zogbi and Wenhao Gu, Dr. Axel Krieger will attend the meeting biweekly

- (2) Group meeting

- Time:* Thursday 10:00 - 11:00

- Location:* Zoom or Hackerman 136

- Weekly meeting scheduled for three group members

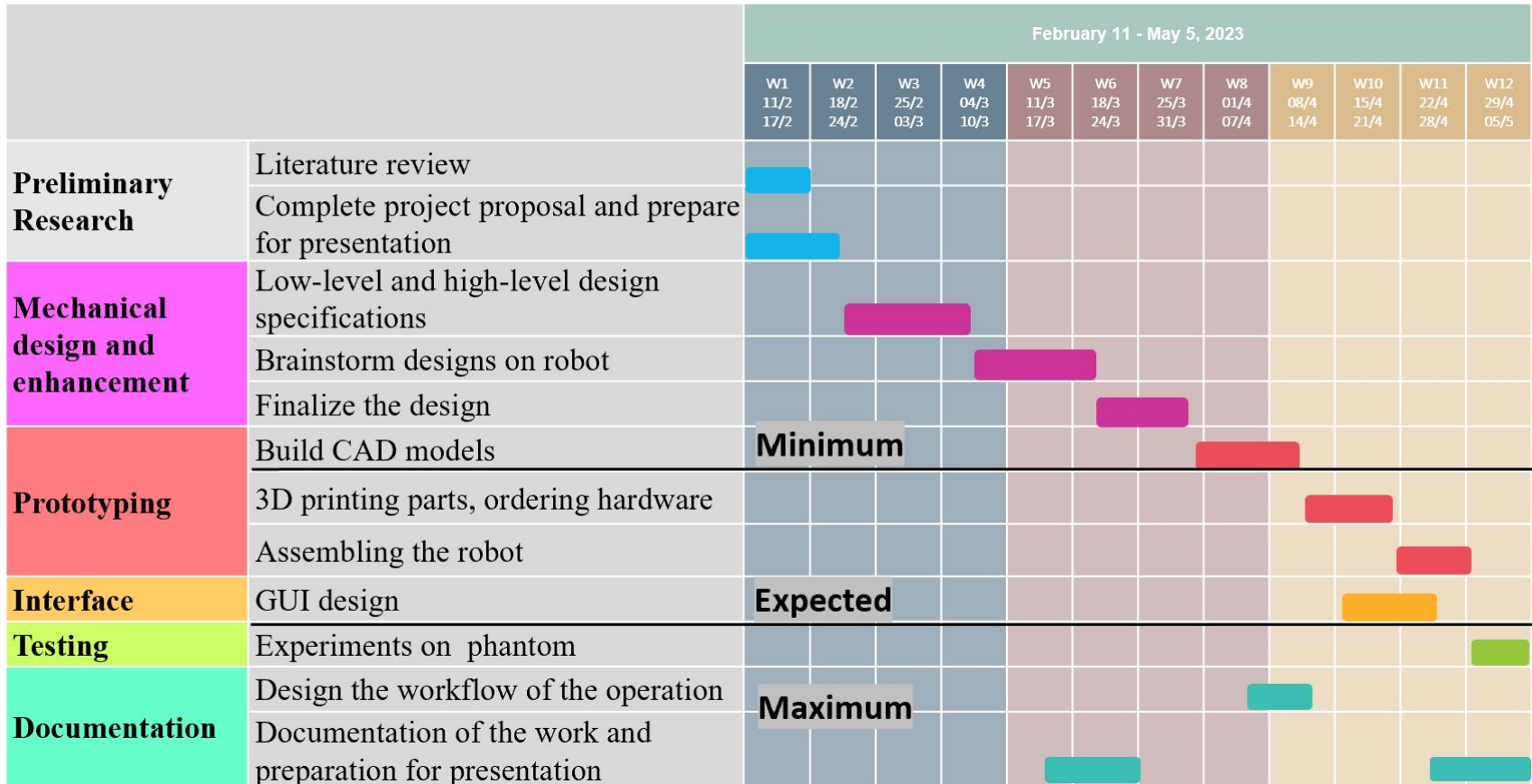
- **Communication platform**

- Slack, Zoom, Overleaf, Dropbox, Email

Dependency

Dependency		Need	Status	Follow-up	Contingency Plan	Deadline
Prototyping/ Fabrication	3D printer and laser cutting	To do model prototype	Resolved	N/A	N/A	3/25/2023
	Ultrasound probe	Used as the sensor of the system	Resolved	Will be provided by Lidia	N/A	3/15/2023
	Hardware (Arduino board, motors, screws, and nuts)	To assemble the system	Partially resolved	Few parts already available; will purchase rest on McMaster-Carr	Purchase new ones if necessary, or borrow from Prof. Axel Krieger's lab	4/11/2023
Software	Arduino IDE	For communication with the Arduino board	Resolved	N/A	Other team members' laptop	3/25/2023
	SolidWorks	To build CAD model	Resolved	N/A	Other team members' laptop	3/15/2023
	ROS	Simulate and control the robot system	Resolved	N/A	Other team members' laptop	3/07/2023
Testing	Lab space (B08G)	For testing	Resolved	Two team members have access; other member will request Ashley soon	Other team members' access	3/07/2023
	Testing equipment (catheter kits and phantom)	For testing	Partially resolved	Kit is available, requested phantom from Dr. Vinciya Pandian	N/A	4/11/2023
Financial support		To purchase necessary hardware	Resolved	N/A	If insufficient, need to borrow hardware from other labs	3/25/2023

Timeline



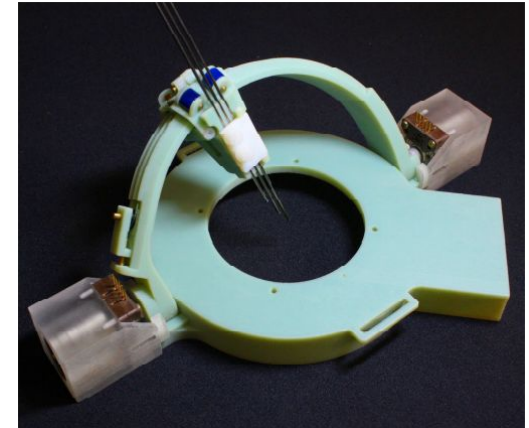
Paper #1 - An MRI Coil-Mounted Multi-Probe Robotic Positioner for Cryoablation

Introduction:

- Main goal: Design of a MRI compatible robotic system to perform multiple probes insertion
- Cryoablation: freeze and destroy abnormal tissue by using a cryoprobe
- MRI is used to visualize the probes and the formation of the ice ball
- Tradition procedure is inefficient and depends on expertise

Specifications:

- Diameter of base: 11 cm
- Remote center of motion: 15 mm above skin
- Maximum force: 2.71 N
- Workspace: average depth of 125 mm and maximum tilt of $\pm 45^\circ$



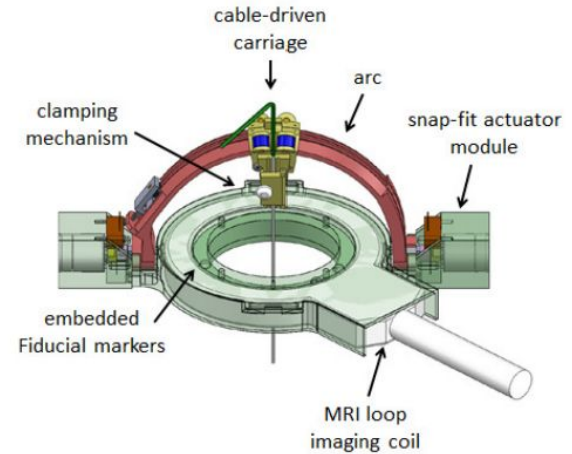
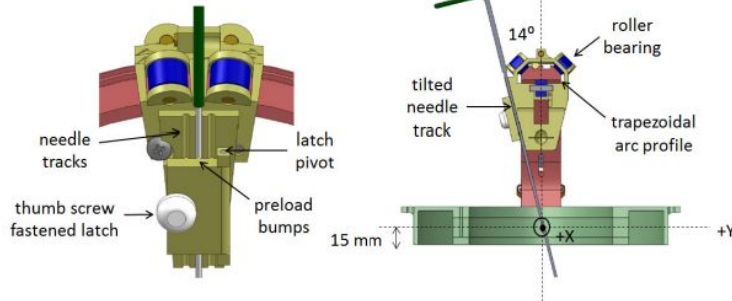
Paper #1 - An MRI Coil-Mounted Multi-Probe Robotic Positioner for Cryoablation

Base:

- Mounted to patient by adhesive pads
- Motors on both sides, driving arc and carriage

Sliding:

- Cable driven: driving pulley -> carriage -> tensioning pulley
- Tensioning mechanism to fine tune the pulley and eliminate backlash



Arc and carriage:

- Add two degree of freedom for rotation
- Use wide roller bearings to decrease friction and stress
- Small actuator modules containing piezoelectric encoder-based motors

F. Y. Wu, M. Torabi, A. Yamada, A. Golden, G. S. Fischer, K. Tuncali, D. Frey, and C. Walsh, "An MRI Coil-Mounted Multi-Probe Robotic Positioner for Cryoablation," Proceedings of the ASME 2013 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference IDETC/CIE 2013, 08 2013.

Paper #1 - An MRI Coil-Mounted Multi-Probe Robotic Positioner for Cryoablation

Relevance to our project:

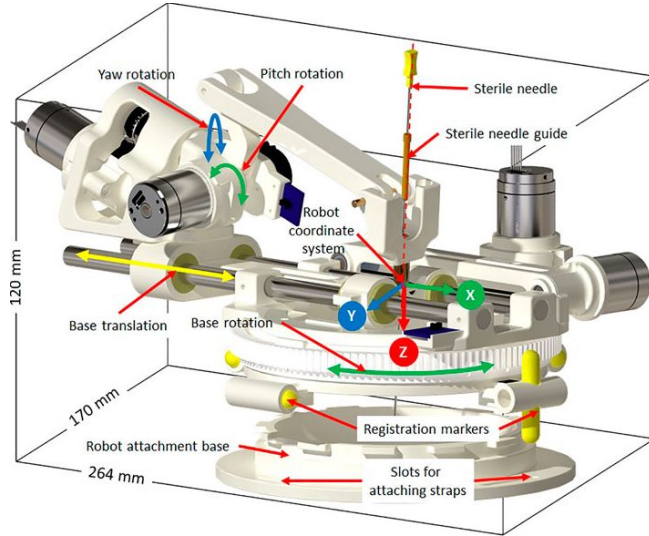
- ❖ Compact patient-mountable device for insertion task
- ❖ Design architecture helps divide problem into subtasks
- ❖ Inspires mechanism design for multiple objects insertion and actuation

Limitations:

- Only adjusts probe orientation, not insertion
- Only two degree of freedom for angle adjustments
- Only works for flat body parts

- We will cover both angle adjustments and insertions
- Add more degrees of freedom for both rotation and translation
- A design for subclavian insertion in our project

Paper #2: Body-Mounted Robotic System for MRI-Guided Shoulder Arthrography: Cadaver and Clinical Workflow Studies



- MRI-guided
- Shoulder arthrography
- Needle insertion only
- **Body-mounted**
- **4 DoF**

Objectives and Assumptions

Objectives:

1. Prototype a robotic system for non-tunnelled central line placement at the subclavian vein with the following specifications:
 - light-weight, body-mountable
 - performs needle insertion, guidewire and catheter advancement
 - adaptable to various patient anatomies

Assumptions:

1. The clinician scans the region of interest using ultrasound and decides the needle insertion site and angle
2. The guidewire is straight and not “J” shaped
3. The adapted Seldinger technique for the robot does not use a dilator
4. The clinicians retracts the needle and guidewire (the probability of infections introduced by insertions is greater than retractions; not backed up by literature)
5. The syringe is detachable from the needle without the need of a twisting motion
6. The clinician feeds the guidewire and the catheter to the robot