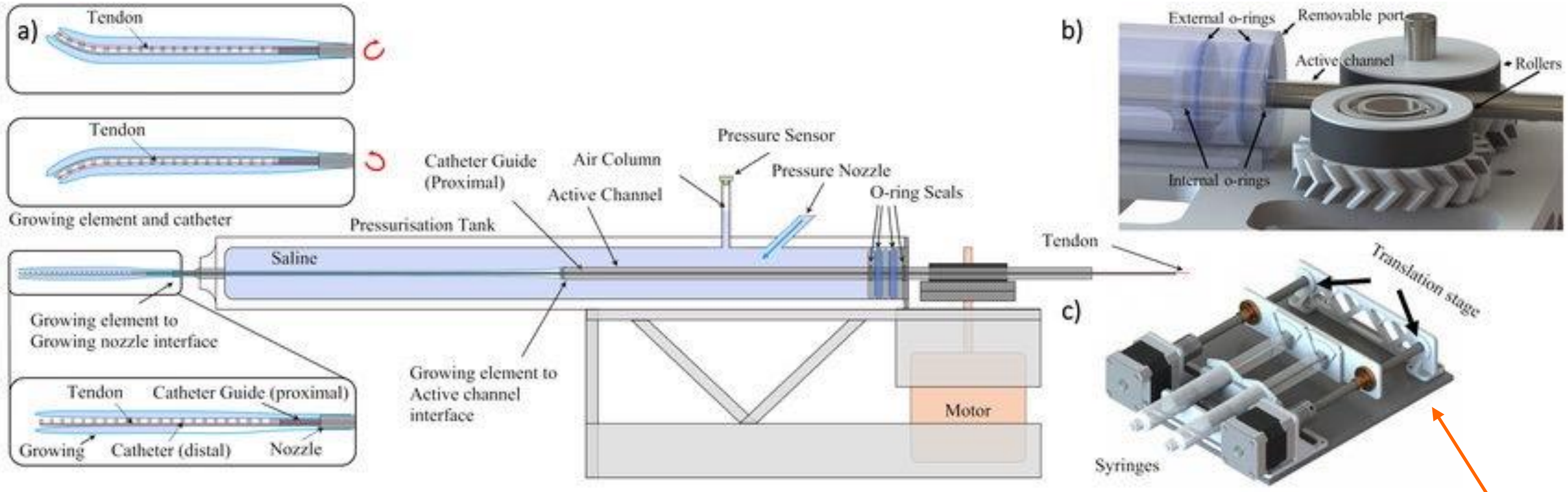
Soft Robotics in Biomedical Innovation

Target Application: **Medical & Surgical Robotics**

MAMMOBOT:



Berthet-Rayne, Pierre & Sadati, S.M.Hadi & Petrou, Georgios & Patel, Neel & Giannarou, Stamatia & Leff, Daniel & Bergeles, Christos. (2021). MAMMOBOT: A Miniature Steerable Soft Growing Robot for Early Breast Cancer Detection.

It's a tiny, soft robot specifically designed for the early detection of ***breast cancer***.

It uses a technique called ***soft eversion***, which means it grows from the tip, powered by internal saline pressurization. This significantly reduces friction and minimizes the risk of damaging delicate tissue.

As it advances, it carries a steerable catheter inside, giving doctors precise control to navigate the complex network of mammary ducts through the nipple.

It can even carry tools like cameras or biopsy needles, making the whole screening process safer, more accurate, and far less invasive.

Scaling Soft Robotics: Opportunities and Responsibilities

Market Analysis:

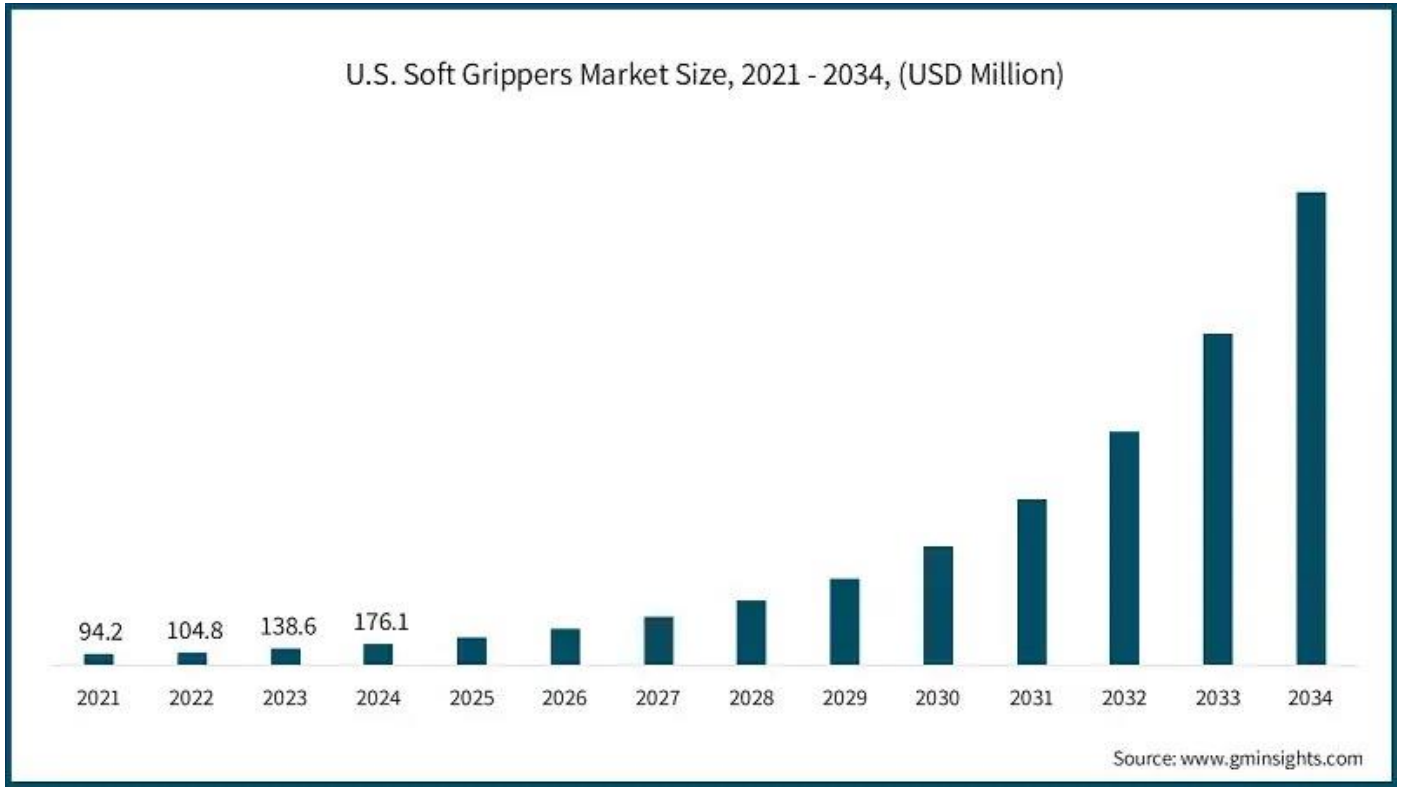
- In the US alone, the soft gripper market is projected to reach 4 billion dollars by 2034. More here on business, with the Soft Robotics Industry estimated to reach approximately USD 15.02 billion by 2030 (Maximize Market Research, 2024)

Challenges:

- Achieving extreme precision, maintaining sterility, ensuring biocompatibility,
- ethical concerns—equal access to these technologies and the impact of disposable medical waste.

Opportunity:

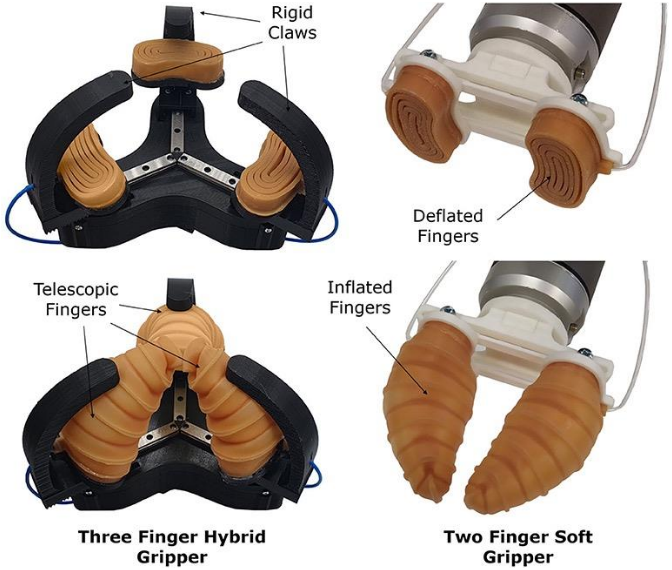
- Soft grippers have the potential to make a profound social impact. By making advanced surgical techniques more accessible, they can improve patient outcomes, enhance the comfort of surgeons during procedures, and ultimately raise the standard of care in hospitals around the world.



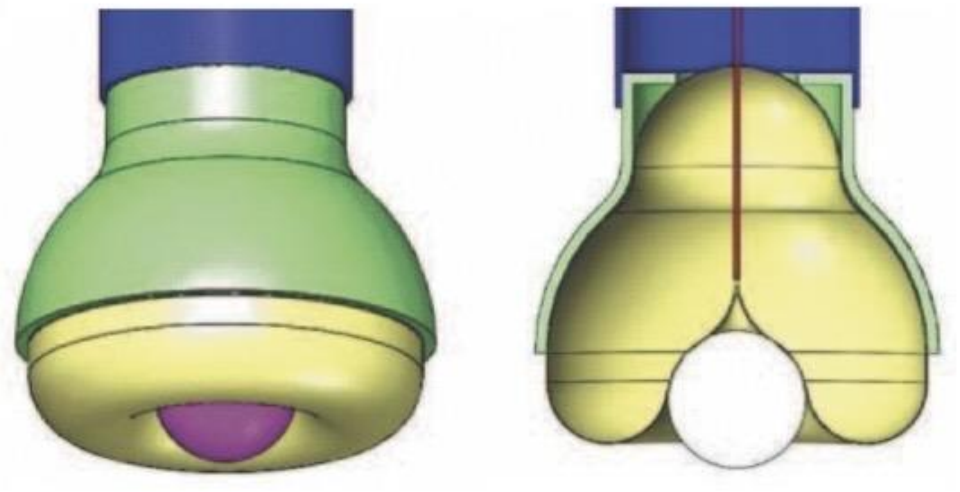
Scientific + Technical background

Soft Gripper Design Variations:

The mGrip soft gripper - Photo: Soft Robotics.



Gerez et al (2020), 'Employing Pneumatic, Telescopic Actuators for the Development of Soft and Hybrid Robotic Grippers'.



Tendon-driven with a compliant elastomeric bag. Copyright 2016, IEEE.

Design Variations Analysis:

- The left and middle image have each "finger" as a **soft, bendable actuator** with internal air chambers that curl when inflated, however the number of fingers vary to suit different purposes
- The image on the right is a **suction-based soft gripper**; it inflates an internal chamber that changes the outer shape to create suction. The flexible membrane deforms inward to "wrap" around the object from below, making it ideal for smooth, small objects where full enclosure or vacuum sealing offers a secure grip.
- All 3 of the design's actuation are Pneumatic (air pressure causes deformation).

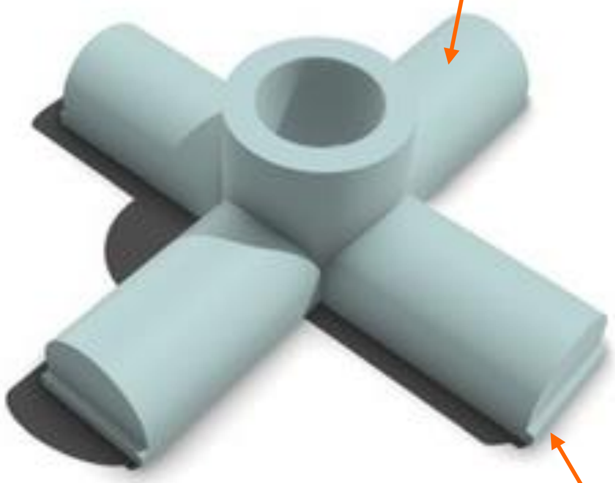
Soft Gripper Material:

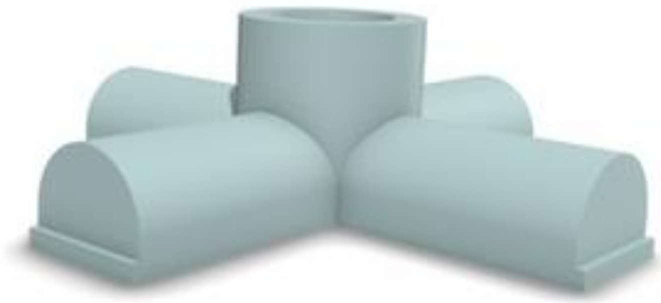
- Flexible materials: silicone, elastomers, or polymers
- Silicone is super flexible, durable, and has **great elastic recovery**, so it returns to its original shape after deformation.
- This flexibility allows them to adapt to different shapes and sizes, making them perfect for handling delicate or irregularly shaped items safely and efficiently.

Design Steps:

Four Arms = Symmetry = Stability:
- It gives you a balanced grip around objects of all shapes.
- The even spacing (90° apart) ensures **uniform pressure distribution**

Modular & Scalable
- A design like this can be **scaled up or down**, depending on the object size you're targeting.





Soft, Rounded Geometry:
- The rounded, **semi-cylindrical arms** are ideal for inflating and curling inwards when pressurized as curved surfaces bend more smoothly than sharp ones, which helps avoid stress concentrations and improves durability.

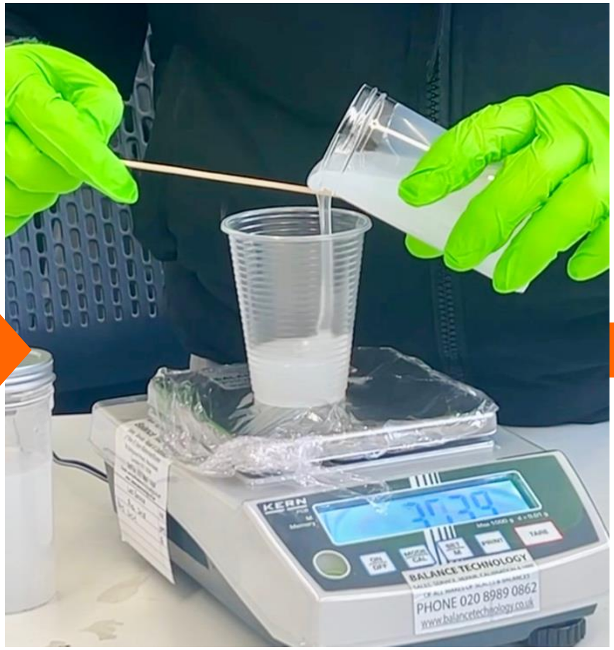
CAD + FEA are Essential in Soft Robotics Design:
- **Linear FEA:** Useful for early-stage testing; Fast and gives a good first impression of how the gripper behaves structurally under light load.
- **Non-linear FEA:** Accounts for **hyper elastic material properties**; Can simulate **how the gripper deforms under air pressure**

Assembly Steps:

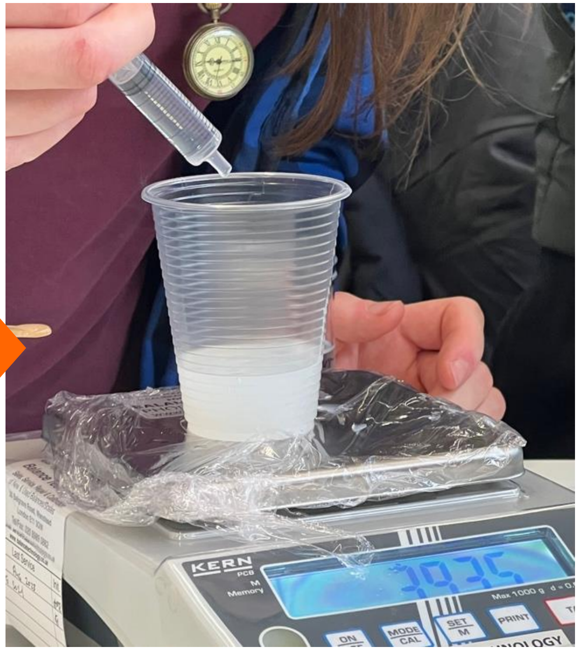
1.

2.

3.



4.



Prepare wax mould:

- Apply a small quantity of blue tack to the square base
- Press the wax insert into the PLA mould

Measure out equal parts (18g) of silicone of DragonSkin 10 part-A:

- Plastic wrap scales + reset the scales

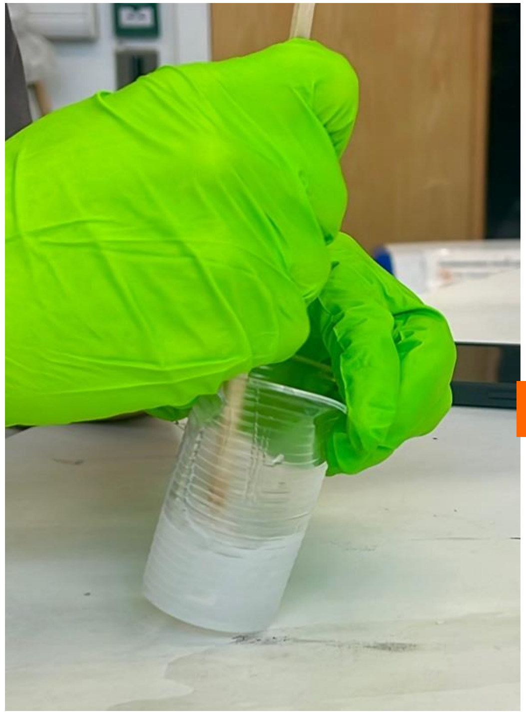
Equal parts of DragonSkin 10 part-B :

- Use a tongue depressor to catch any excess and help control the silicone,

Use a syringe to add 3ml of thinner.

- Helps speed up the vacuuming process

5.



Mix thoroughly - using tongue depressor

6.

Place plastic cup in vacuum chamber and depressurise to about -0.8 Atm

7.

Wait until bubbles have disappeared (Degassing)

- easiest to see by shining a light through the top).

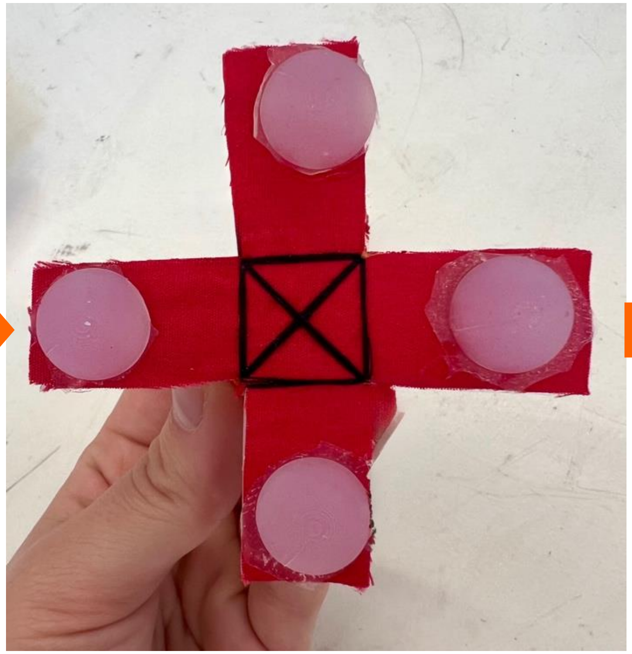
8.

Pour the silicon into all 5 moulds.

9.

Carefully remove the silicone part from the mould

10.

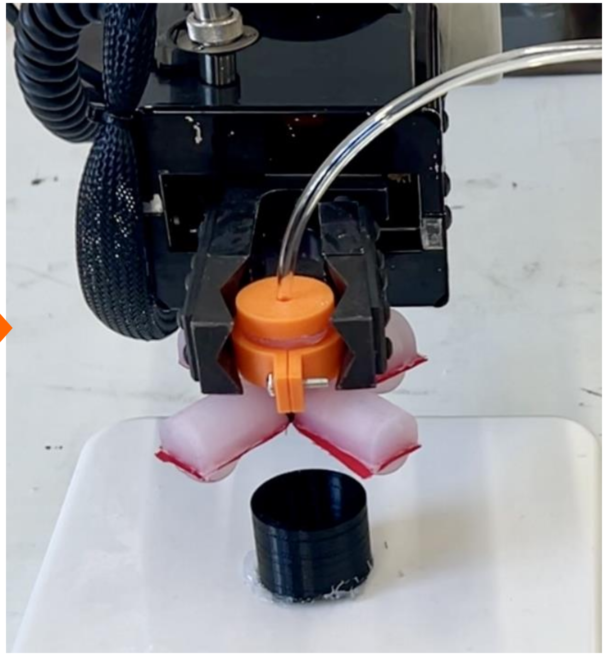


Cut out cross shape fabric and adhere with Syl-poxy + Wrap thread around the centre of the gripper

11.

Attach the solid connector – insert the air inlet and adding the clamps.

12.



Place Benchmark-Gripper in the Mitsubishi. Attach PLA cylinder to the centre of scales. Reset pressure and scales.

Final Step + Experimental Procedure Explained

Mitsubishi Electric robotic arm:

- Used to **position and actuate the soft robotic gripper** with high precision.
- Repeatable vertical and horizontal motion to ensure consistent placement
- The robot was programmed to lower the gripper onto the cylinder and lift it to assess gripping capability and payload handling.

13.

SF-400A Electronic Compact Scale:

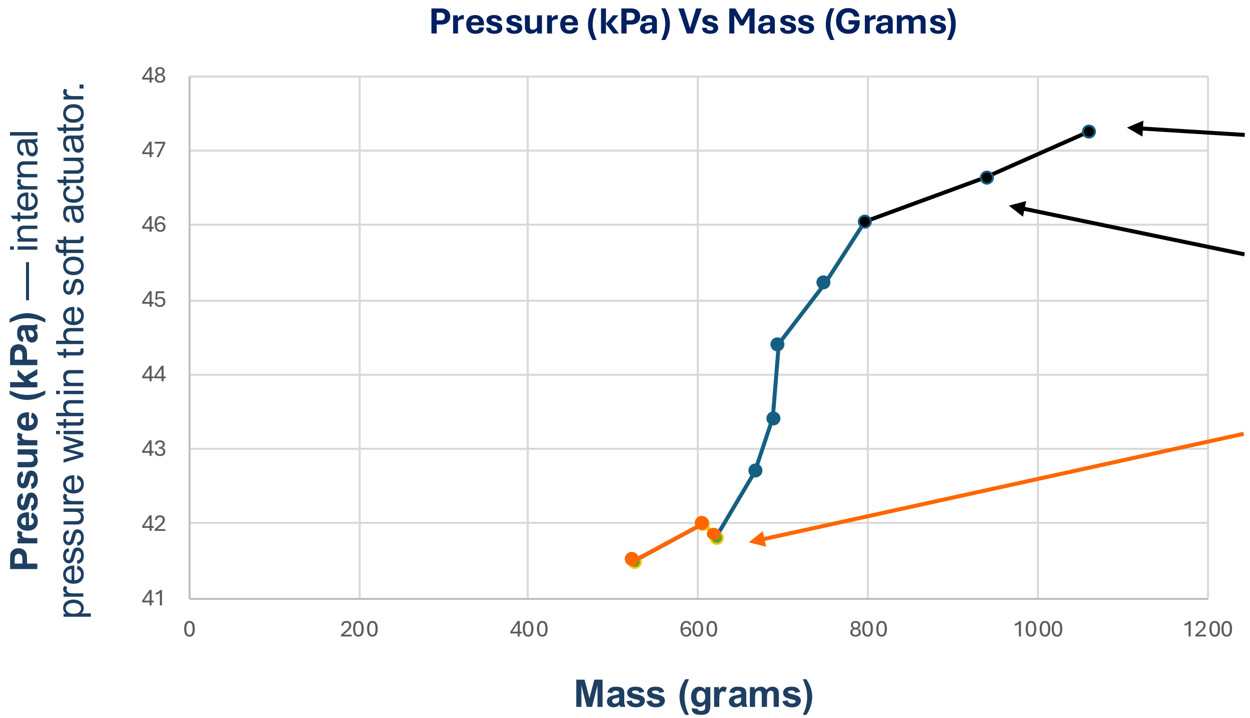
- Mass in grams (g), which can be converted to force (Newtons) by multiplying by gravity (9.81 m/s²).
- Used to measure **how much weight the soft gripper can hold or how much downward force it exerts.**
- Range: Up to 10 kg
- Resolution: 1 g

Sped up video (x4 speed) of our gripper experiment

Digital Pressure Indicator:

- Used to monitor and **control the air pressure supplied to the soft robotic gripper's actuators.**
- The internal pneumatic pressure of the soft gripper was incrementally
- This process continued until structural failure occurred.

Results + Discussion



The gripper **failed / ruptured** at 1060 and 47.26 kPa - clear **failure threshold** for safe operation.

The rate of pressure increase slows down - Suggests material stiffening or nearing maximum expansion.

Pressure stays relatively low - Suggests the gripper can easily handle light loads without internal pressure

(Data extraction via frame-by-frame video analysis)

Issues with Data Gathering:

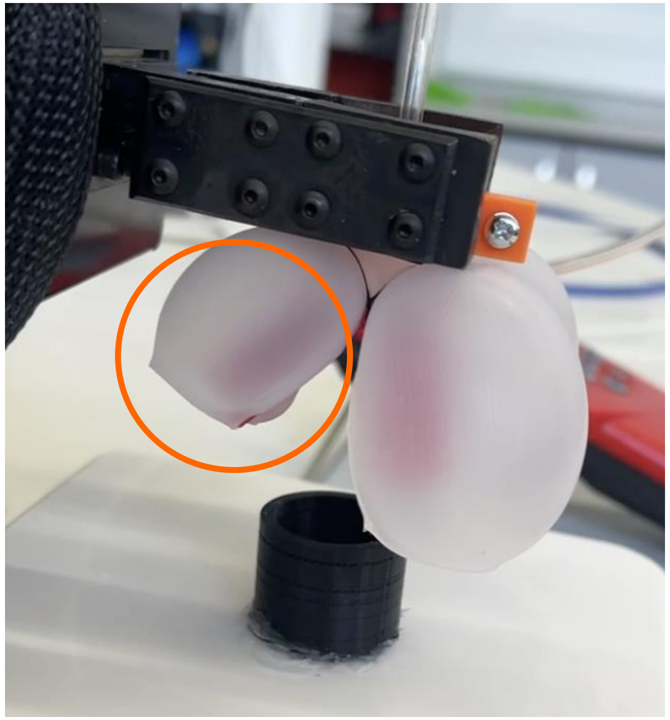
- **Low Temporal Resolution;** video frame rate is low (30fps), limited to a data point every ~33 milliseconds which caused sharp changes in values
- **Visual Estimation Errors;** reading data from video screenshots can introduce parallax errors / estimation inaccuracies, reduces the precision and repeatability

Solutions:

- **Use sensors with data logging:** Connect a pressure sensor and load cell to an Arduino or Raspberry Pi and record values in real time to a CSV file.
- **Repeat experiments:** Multiple runs would help average out any inconsistencies and improve reliability.

Design + Process Improvements

Improving Pneumatic Uniformity Across Actuator Arms:

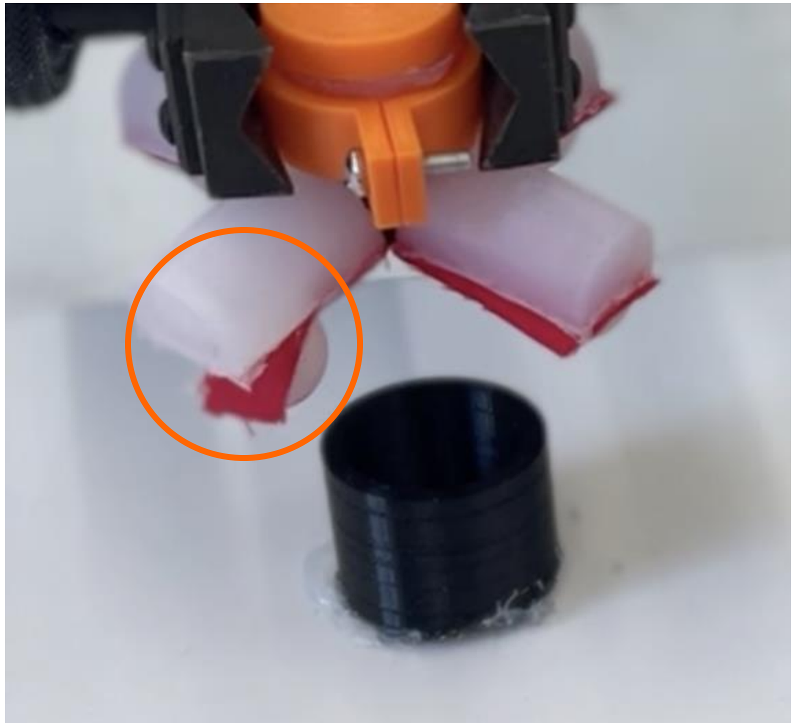


Problem = Significant asymmetry in arm inflation was observed, with some channels experiencing full extension while others remained partially collapsed or unresponsive.

Solution:

- Running more **CFD simulations** (Computational Fluid Dynamics) to predict airflow behavior before fabrication.
- Introduce a **pre-test leak check** step by submerging the gripper in water under low pressure to identify and seal any leaks before the main experiment.

Improve Bonding Between Silicone and Fabric Layer:



Problem = A critical failure occurred when one of the gripper arms detached mid-experiment due to weak adhesion.

Solution:

- **Silicone-based adhesion promoters** to increase surface energy prior to bonding.
- Alternatively, **co-molding** the fabric during casting would form a more integrated, durable bond.