Engineering Continuum Bodies for Navigation Assistance of a Millimeter-scale Soft Robot for Tissue Biopsy Procedures

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Problem

Traditional Bronchoscopes Issues

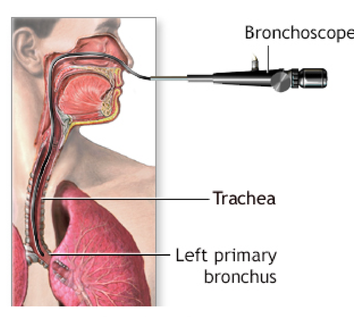


Figure 1: Lung Bronchoscopy
Source: https://courses.lumenlearning.com/wm-biology2/chapter/the-mechanics-of-human-breathing/

Contemporary bronchoscopes struggle to access and navigate the **smaller bronchi** of the lung due to the **large diameter** of the bronchoscopes being 5-6 mm, allowing **cancer tissue to go undetected** in these narrow areas (McCandless et al., 2020)

Furthermore, traditional bronchoscopes have **limited dexterity and mobility** which can hinder their ability to aid in treatment of detected cancer tissue through processes such as drug delivery (McCandless et al., 2020)

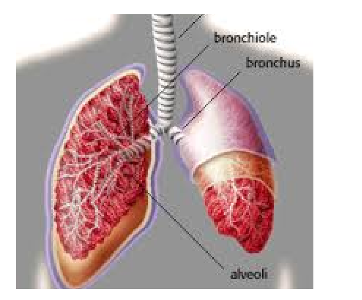


Figure 2: Deeper Look Within The Lung
Source: https://www.polysciences.com/india/polyethylene-glycol-n-4-diacrylate-pegda-200

Research Goal

Engineering Goal

Develop **continuum bodies** that can assist in the **navigation of a millimeter-scale soft robot** for tissue biopsy procedures and evaluate at which wrapping angle pressurization results in the **greatest bending angle and most consistent** bending of the continuum body.

Materials

- Form Labs SLA Printer
- Dragon 10-Medium Silicone Mixture
- Vacuum Chamber
- SolidWorks
- Raspberry Pi
- Arduino

Approach

Silicon Rubber - Dragon Skin 10

Traditional bronchoscopes are made of stiff materials such as fiber glass which can **limit their maneuverability** as well as cause **abrasions within the lung** in the case of contact (McCandless et al., 2020). To combat this, a **softer, silicone rubber** will be used to manufacture the continuum bodies.

Figure 3: Dragon Skin 10 Medium Silicon Rubber

Fluid Actuation

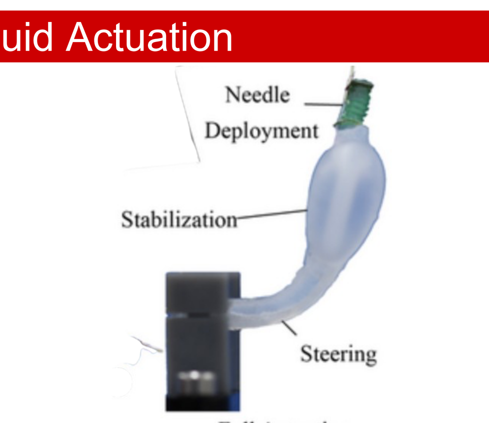


Figure 4: Fully Actuated Continuum Body in Testing Setup
Source: https://onlinelibrary.wiley.com/doi/10.1002/aisy.202200326

Rather than traditional cable-driven actuation, the continuum bodies rely on **fluidic actuation using air**. This method has been chosen due to the **small size** when in a deflated state, **biocompatibility** in case of leak, and **noninterference with imaging** (Van Lewen et al., 2023).

Methodology

Past Work

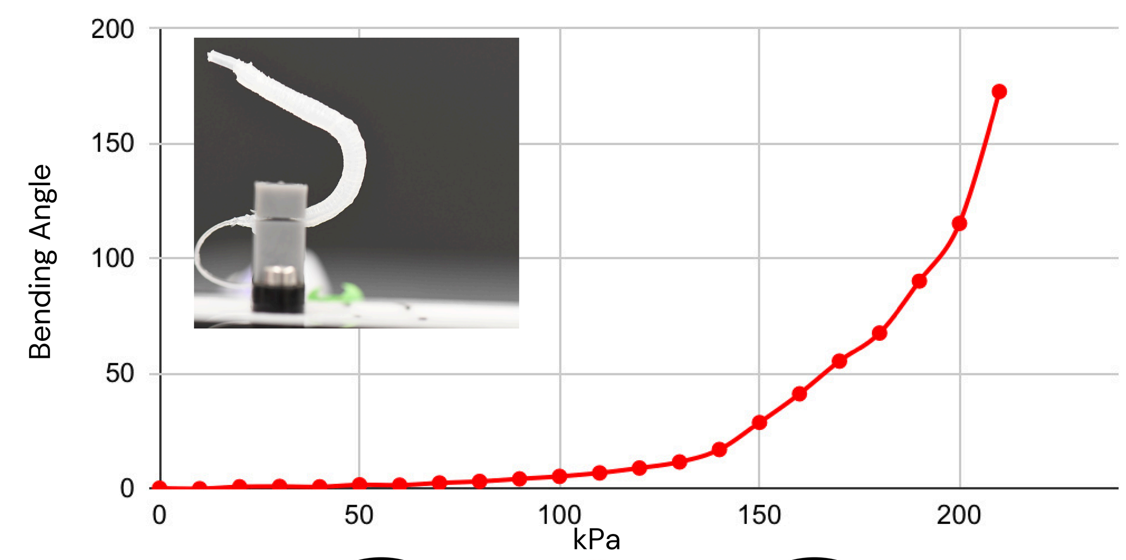
- 3D molds designed
- Process for fabrication developed
- Testing mechanism basis created
- Wrapping mechanism and code finalized

Current Work:

Figure 5: Methodology to create and test the Dragon Skin 10 Continuum Body

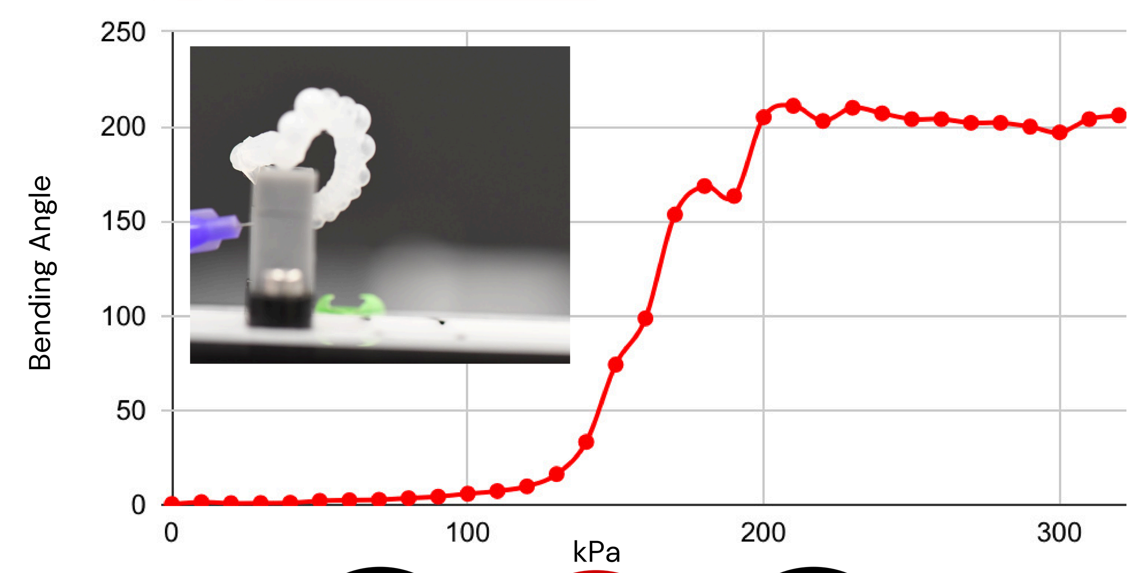
Results

7 Degrees: kPa vs Bending Angle



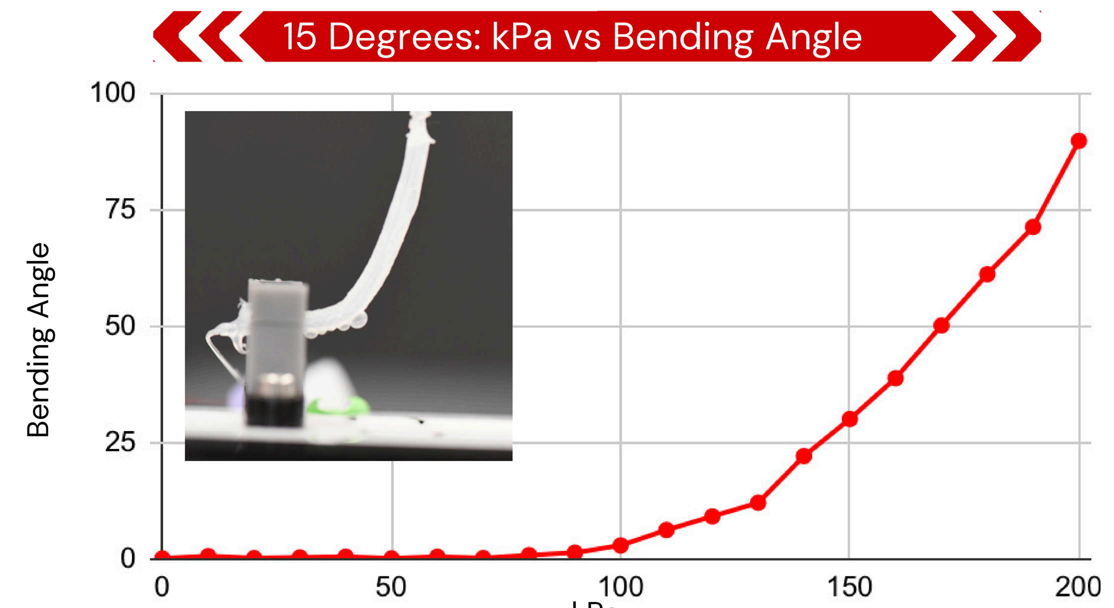
Max kilopascal	Max Bending Angle	Angle to kPa ratio
210	172°	0.82

12 Degrees: kPa vs Bending Angle



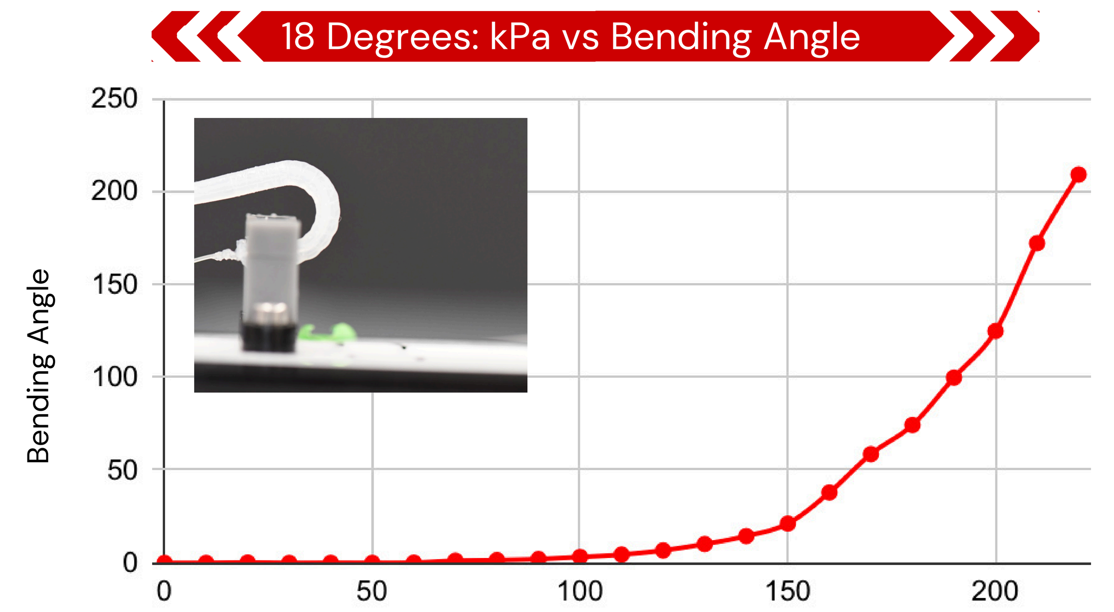
Max kilopascal	Max Bending Angle	Angle to kPa ratio
330	209°	0.63

15 Degrees: kPa vs Bending Angle



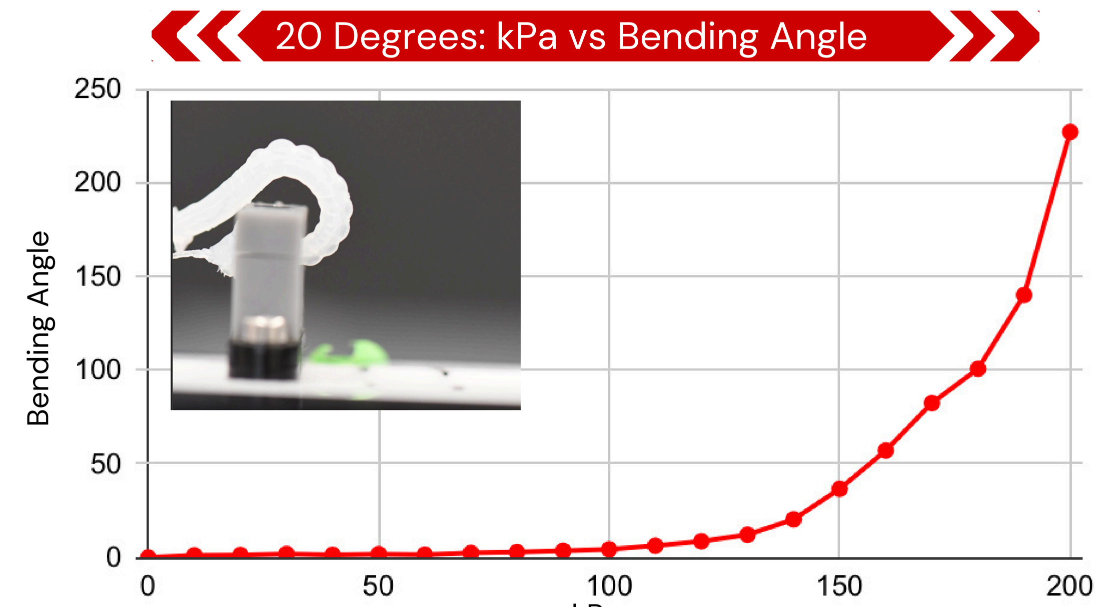
Max kilopascal	Max Bending Angle	Angle to kPa ratio
200	90°	0.45

18 Degrees: kPa vs Bending Angle



Max kilopascal	Max Bending Angle	Angle to kPa ratio
220	209°	0.95

20 Degrees: kPa vs Bending Angle



Max kilopascal	Max Bending Angle	Angle to kPa ratio
200	227°	1.14

Discussion

Continuum Body Implications

The results indicate that the **project goal has been reached,** and that the continuum bodies are ready to undergo further development. All of the continuum bodies were able to successfully bend through fluidic actuation, implicating that they could be a feasible replacement for the traditional cable-driven actuation used in contemporary bronchoscopes. The continuum body that was able to provide the greatest bending angle was wrapped at 20° and achieved an angle of 227° at 200 kPa. The continuum body wrapped at 7° also had the most greatest ratio between bending angle and kPa at 1.14, making it the most efficient as well.

Future Plans

Future continuum body designs will incorporate changes:

- A **third channel** will be consistently incorporated in the continuum body to act as **stabilization** rather than solely relying on soft robot for stabilization.
- Replacing the fiber reinforcement with reinforcement via a **stiffer** silicone rubber lining of the air channel
- Utilizing a continuum body to actively steer the millimeter-scale soft robot in **ex-vivo** and **in-vivo** settings

Figure 6: Future Testing Setup

Conclusion

Application of Continuum Bodies

- **Millimeter-Scale Soft robot**
  - Will be incorporated onto a millimeter-scale soft robot to provide navigational assistance during tissue biopsy procedures of the lung
- **Other Biomedical Devices**
  - Could be utilized to steer other medical devices into small passageways of the body
  - Fluidic Actuation with air provides a safer alternative to other methods of actuation in cases of critical failure

Summary

- Contemporary bronchoscopes are **unable to account for the small size of bronchi passageways** within the human lung and may leave **cancerous tissue undetected** in these areas.
- Testing indicates that the continuum bodies would be able to **functionally steer** a millimeter-scale soft robot down the smaller passage ways of the lung safely

Other Works - ROS2

- Worked in incorporating **ROS2 Iron Irwini** onto a Raspberry Pi 4, 64 bit, 2 GB utilizing Ubuntu 22.04 OS
- Utilized **Raspberry Pi as a separate node** for ROS2 so that it could communicate with priorly developed ROS2 program
- Currently incorporating **ROSbag** in the Raspberry Pi to be able to collect future data for testing of soft robot

Acknowledgement

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References

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