BIOROBOTICS

SOFT ROBOT: HEART

Project Report

by

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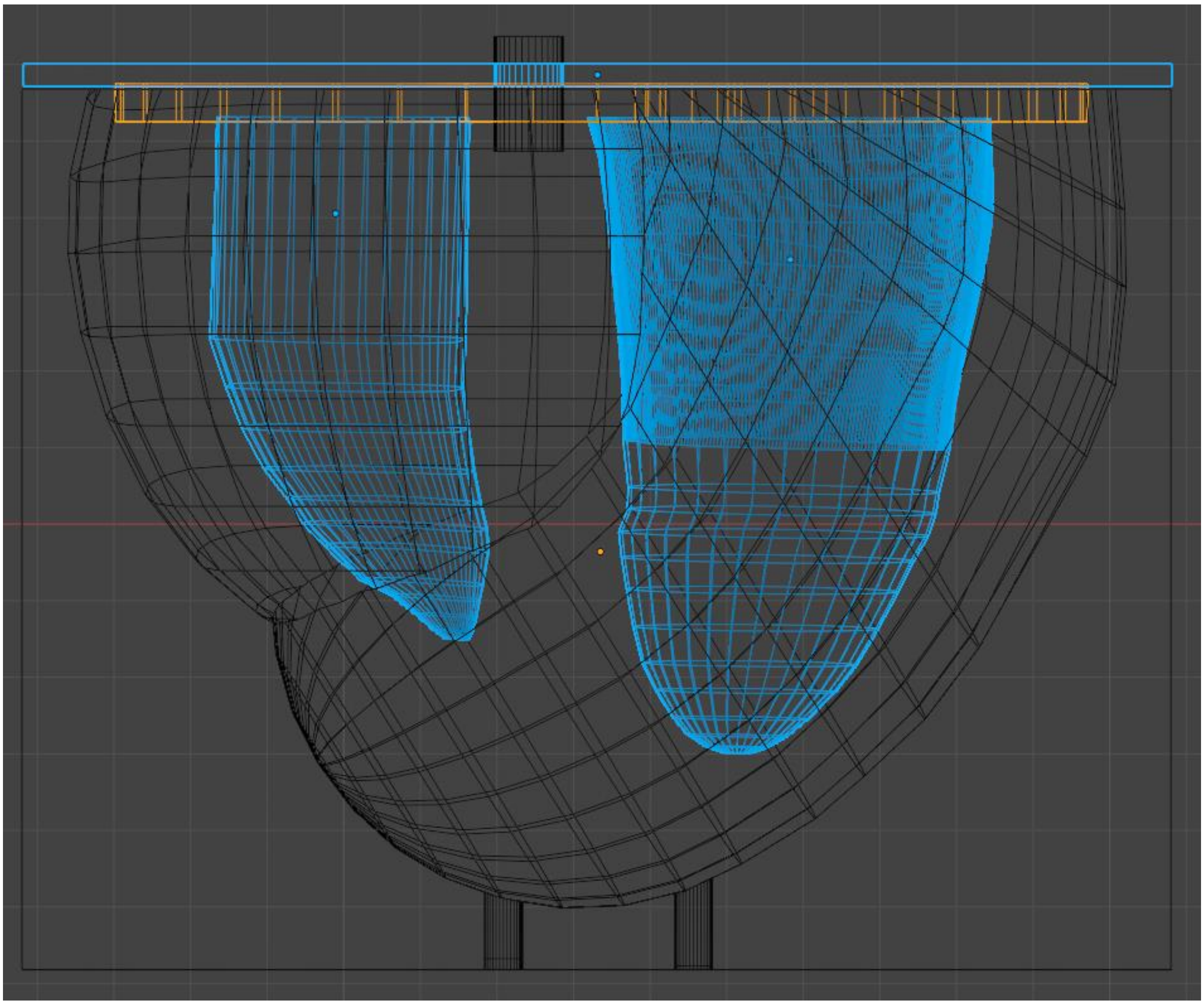

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The project was planned and executed together with Robin Neubauer.

The heart muscle is a biological actuator and one of the most vital organs within the human body. It achieves its task, i.e. pumping blood through the circulatory system, by rhythmic contraction. For this reason and inspired from a video [1], we thought it might be a very interesting, as well as challenging project to build a soft robotic heart. The biggest difference between a biological and our mechanical heart is that the former achieves its task by contraction, while the latter expands to potentially fulfill the same task. A great example of mechanical actuators that mimic biological muscle contraction are vacuum-actuated muscle-inspired pneumatic structures (VAMPs) (Yang et al., 2016). Expansion of our heart results from self-made hollow tubes that are integrated into the heart structure and inflate due to excess pressure created with an attached bicycle pump.

To get started we used Autodesk Fusion 360 to design a 3D printable [2] form to craft flexible and inflatable tubes by filling the form with Ecoflex silicone (Figure 1). Additional information on the exact designs and its working principles will be given in the figure descriptions on the following pages. Due to silicone leakage this form didn't work however, so we designed a second form (Figure 3). To prevent the tubes from collapsing and sticking together along the inner walls later on, prohibiting air to flow through them, we pushed a 3D printed stick into a flexible, not de- or inflatable air tube (Ø inside: 4 mm, outside: 8mm) with evenly distributed small holes cut into it to allow an even distribution of air to the surroundings (Figure 2). We then filled the form with silicone and let it harden, again for at least 4 hours. The silicone forms the outer part of our final tubes, which thus consist of an inner flexible, not inflatable air tube with evenly distributed holes in it, and an outer air tube, which will inflate if air is pumped into the system. We used connectors that perfectly fit the inside diameter of the inner air tube to assemble the whole tube system, finally consisting of 5 self-made tubes and 4 bought connectors [3], and responsible for air flow through and therefore actuation of the heart.

In Blender 2.92 we designed the inner and outer form of our soft robotic heart, both of which we then 3D printed as well (Figure 4). The outer form roughly mimics the anatomy of the outer heart, while the inner form does the same for the heart chambers. We only modelled the lower part of the heart, i.e. the inferior located, bigger heart chambers. We then poured silicone over the inner form and attached the tube system to it with silicone glue (Figure 5). Then we mixed all the remaining silicone we had and poured it into the outer form. Unfortunately, we could fill only $^{2}/_{3}$ of the form, but since we didn't know if we'd be able to get more silicone in time we went with it and put the inner form with attached tube system into the silicone in the outer form (Figure 6), and let it harden. The tubes that remained at the surface were covered with silicone about 24 hours later, when we had more silicone to fill the whole form. After letting the silicone harden for another 4 hours we removed the inner form and then removed our soft robotic heart from the outer form. The transition between the first and later hardened silicone to our surprise wasn't noticeable. We then attached the bicycle pump to the inner tube system of the heart and tested how well our soft robotic heart worked (Figure 7).

While hard to capture on camera, by visual inspection there definitely is movement of the walls of the heart, however not as much as expected. This has to be due to the thickness of the walls. There's much less excess pressure, that we can generate with our ball pump, available than needed to really fill all the tubes and thus the heart with enough air. When holding the heart in our hands it is also well noticeable, that the heart works as intended. In a second attempt we will shortly undertake at building such a soft robotic heart, we are confident that we can make it function as intended by making the heart smaller and with thinner walls.

Review Questions:

1. What is the main difference between the contraction of a biological and our mechanical heart?
2. Explain the two functions of the inner tube with holes.

FIGURES

Figure 1: First attempt to craft flexible, inflatable tubes. The 3D printed form (black) (w: 2,5 cm, l: 16 cm) consists of an upper and lower part (h: 0,7 cm each), both having a half pipe in the mid and cut outs at the edges of the shorter side (here: left and right side). A 3D printed stick (Ø 4 mm, l: 17 cm), was laid on these cut outs and therefore remained hanging in the air inside the circular cavity of the form. The stick allows to manufacture a hollow tube, through which air can flow later on. The upper and lower part were glued together along the edges to seal the form and prevent silicone leakage. Afterwards we mixed Silicone and filled it into a syringe. The upper form was designed with one hole for a syringe filled with silicone, and one for air to escape. We filled the form with silicone until it started to rise out of the air hole. After hardening, the tubes crafted with this form had holes due to silicon leakage, as can be seen in this figure, and therefore weren't usable.

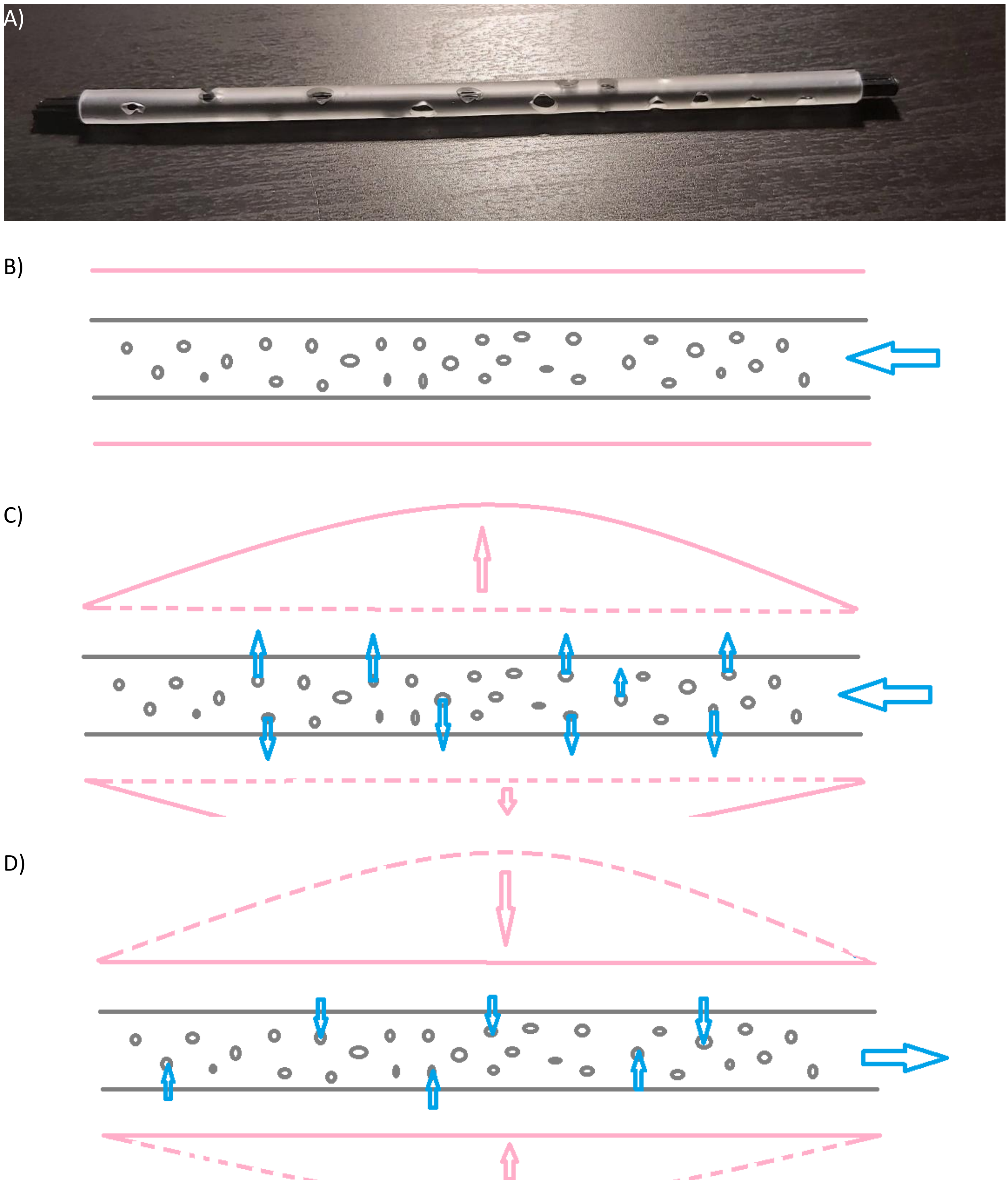

Figure 2: To prevent the tubes from collapsing and sticking together along the inner walls later on, A) we pushed a 3D printed stick into a flexible, not de- or inflatable air tube (Ø inside: 4 mm, outside: 8mm, l: 15 cm) with evenly distributed small holes cut into it (black) to allow an even distribution of air to the surroundings. B-D) Airflow is depicted by blue arrows and movement of the outer inflatable tube by pink arrows.

Figure 3: Second, successfull attempt to craft tubes. The second form we printed is basically a hollow cube (w: 6,3 cm, l: 15 cm, h: 2,8 cm) with four walls inserted. For each of the five compartments (1 cm) we had holes on the short side to insert five 3D printed sticks. We then filled the form with silicone, let it harden, and removed the tubes from the form and sticks, so the inner tube with holes is inside the white tubes (left).

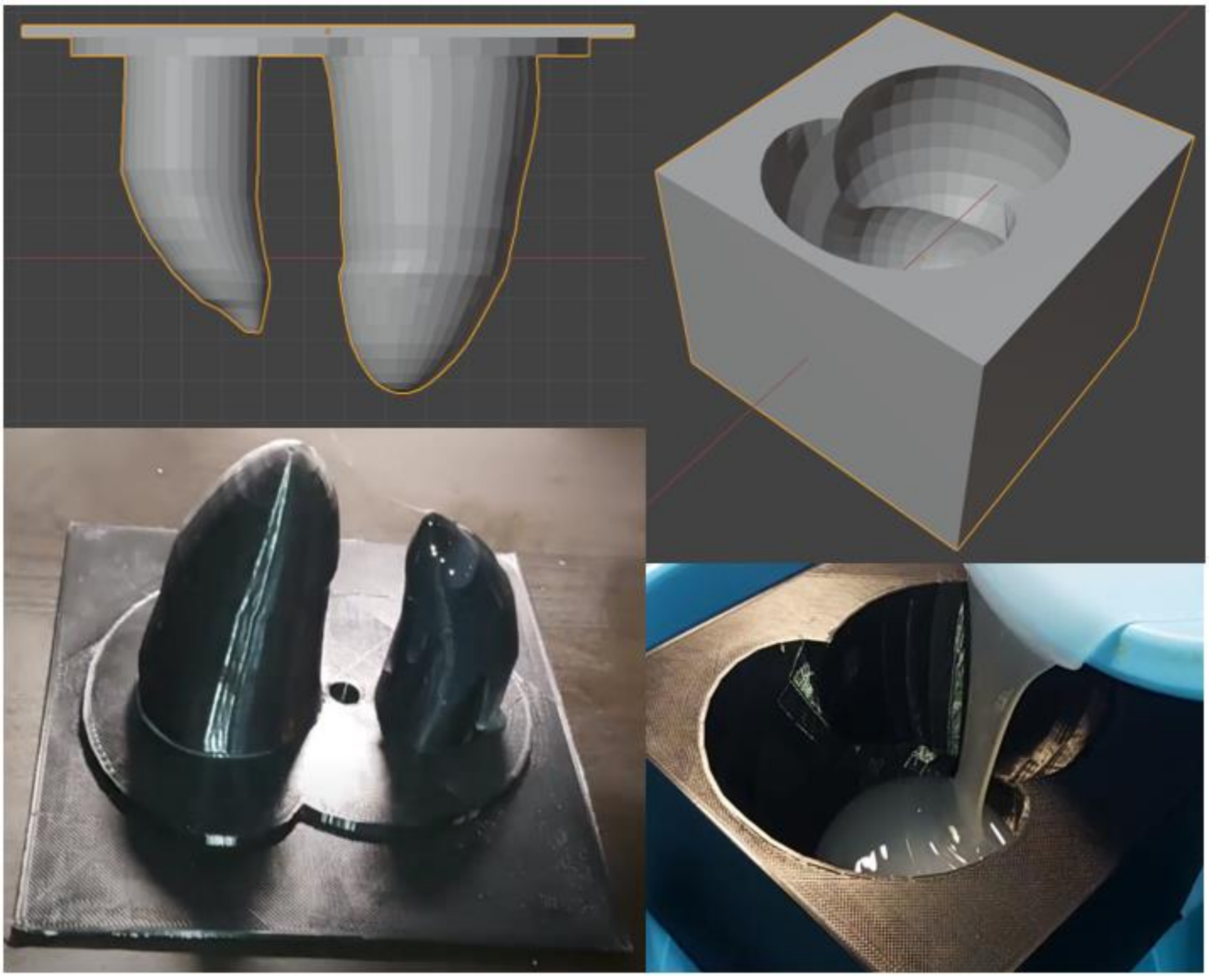

Figure 4: The upper two pictures show our designs of the inner (top left) and outer (top right) form, between which the tube system and silicone will be. These were created with Blender 2.92. The lower two pictures show the 3D printed inner (bottom left) and outer (bottom right) form, being coated (left) and filled (right) with silicone.

Figure 5: Tube system attached to the inner 3D printed form of the heart.

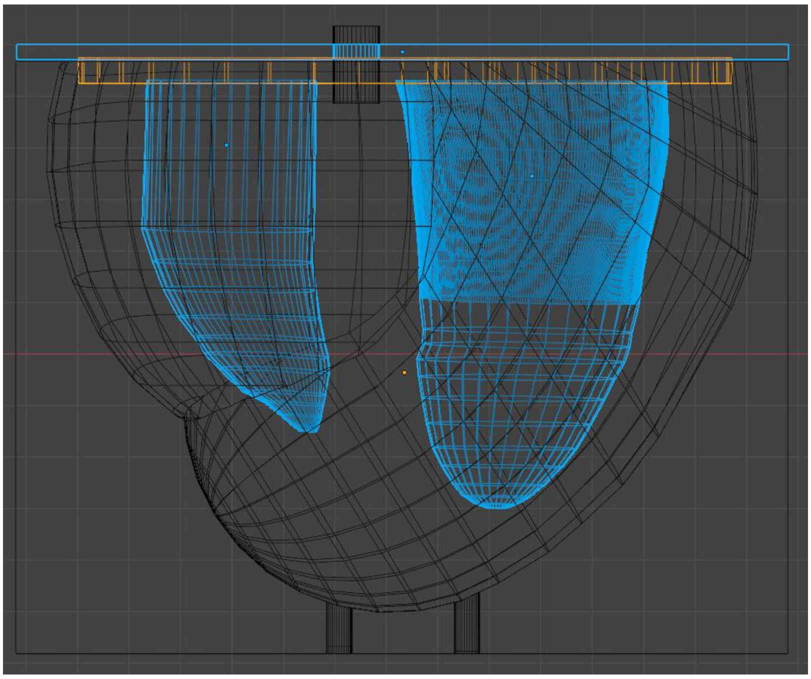

Figure 6: Combined design of the inner (w: 15 cm, l: 15 cm, h: 9 cm) (blue + orange) and outer (w: 15 cm, l: 15 cm, h: 11,5 cm) (black) form in Blender 2.92.

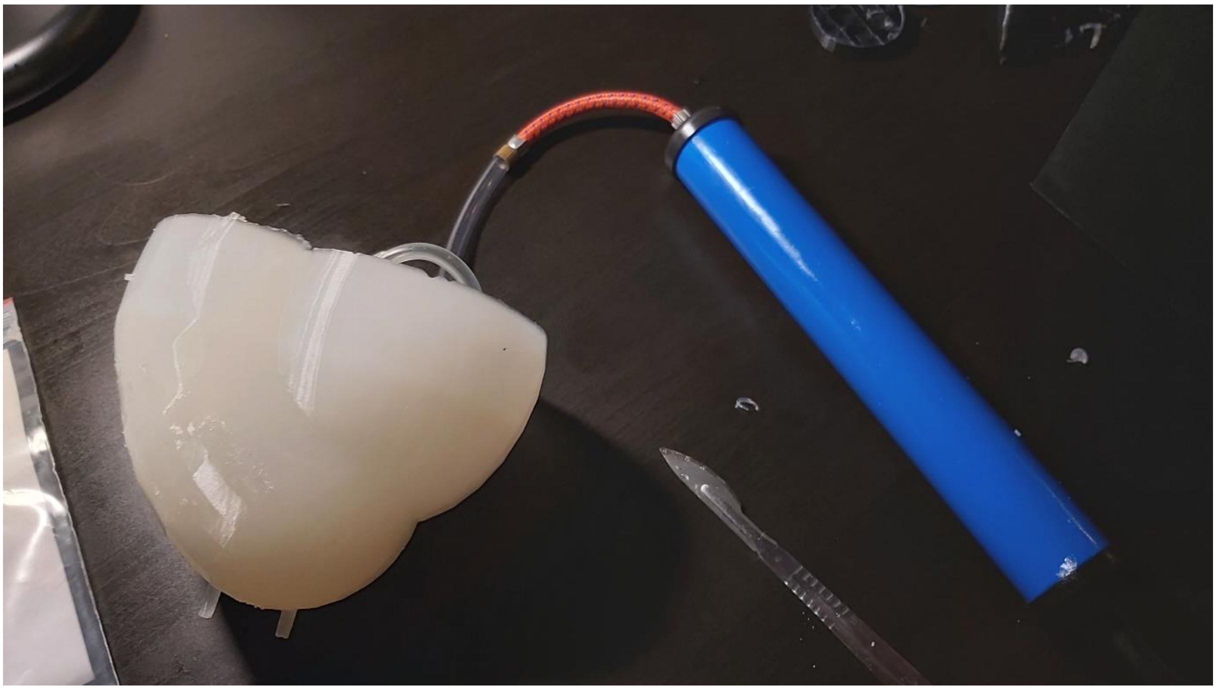

Figure 7: After filling the outer heart form with silicone and placing the inner form with attached tube system inside it, the silicone hardened and was taken out of the form. The inner tube system is connected to the tube coming out on top of the heart and was connected to a ball pump. By pressing the pump, the tube system expands and achieves movement of the soft robotic heart.

BIBLIOGRAPHY

Yang, D., Verma, M. S., So, J. H., Mosadegh, B., Keplinger, C., Lee, B., Khashai, F., Lossner, E., Suo, Z., & Whitesides, G. M. (2016). Buckling Pneumatic Linear Actuators Inspired by Muscle. *Advanced Materials Technologies*, *1*(3). https://doi.org/10.1002/admt.201600055

Inspiration:

[1] https://www.youtube.com/watch?v=k46MASm2of0, last accessed: 17.6.2021, 4 p.m.

3D printer:

[3] Creality Ender-3 V2 3D Drucker

Tube connectors:

[2] https://www.amazon.de/gp/product/B08S6XCPN4/ref=ppx_yo_dt_b_asin_title_o01_s00?ie=UTF8&psc=1