

Fluid Flow Video Analysis of Implantable Valves

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Clinical Need

- ❑ **65–75 thousand** people in the U.S. Are diagnosed with **hydrocephalus** each year.
- ❑ **32–36 thousand cerebrospinal fluid (CSF) shunts** are inserted annually to help severe cases.
- ❑ **100 million USD** is spent on these procedures, with **nearly half** spent on CSF shunt revision.
- ❑ CSF shunts are characterized with a **32% failure rate** within two years, with some causes of these being:
 - Obstruction: 7.42%
 - Infection: 7.20%
 - Migration: 1.60%
 - Malposition: 1.82%
 - Overdrainage: 2.72%

Device Concept

The body utilizes arachnoid granulations (AGs) to drain CSF in healthy individuals. An artificial arachnoid granulation (aAG) comprised of a one-way duckbill valve and short silicone channel could divert CSF into nearby subarachnoid space, rather than the more distant peritoneal cavity as modern CSF shunts do.

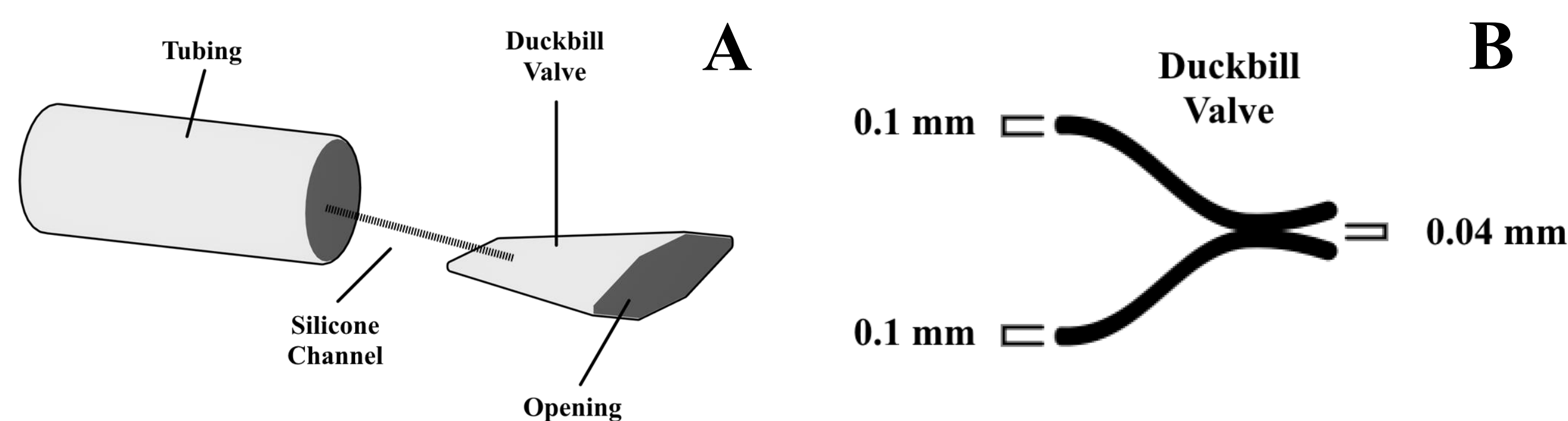


Fig 1. Diagrams showing one-way duckbill valve, neither are to scale. A) 3D model diagram with labelled components. The silicone channel is 3 mm in length, with an outer diameter of 0.6 mm and inner diameter of 0.4 mm. B) 2D Sagittal view of the duckbill valve's opening, showing how the valve's lips do not connect at end of opening. Each lip is 0.1 mm thick, and the distance between the lips at the end is 0.04 mm.

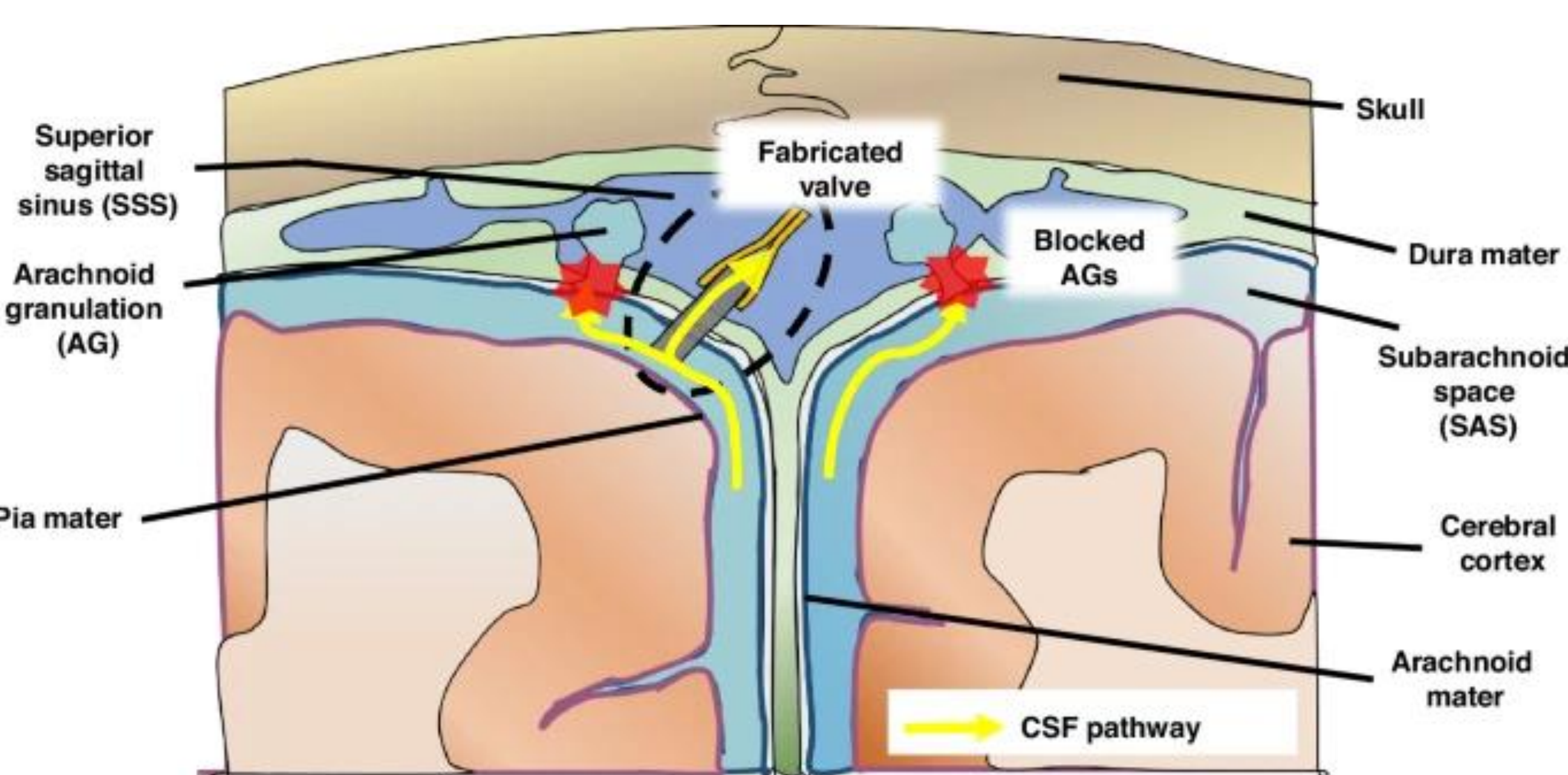


Fig 2. The fabricated valve and channel are inserted into CSF buildup location, bypassing the blocked AGs while minimizing amount of foreign material implanted.

Experimental Design

We want to measure the one-way duckbilled valve's total deformation & time to deform as fluid passes through it.

- ❑ **Syringe Pump:** 'Harvard Apparatus Infuse / Withdraw PHD 22/2000'. Five samples were taken with a flow rate of either 0.1, 0.3, 1, 5, or 20 mL / min.
- ❑ **Syringe:** 60 mL dose syringe, filled with distilled water.
- ❑ **Tubing:** Made of silicone.
- ❑ **Tubing Support:** A petri dish was used to bring the tubing to camera-level & prevent unwanted movement. Tubing was hot-glued to petri dish, and the petri dish was hot-glued to bottom of bin.
- ❑ **Valve:** Same as shown in 'Device Concept'.
- ❑ **Camera:** 'Elikliv EDM9 Microscope Camera'. Was secured in place with magnetic clamp and connected to a computer for recording.
- ❑ **Light:** Illuminated valve's opening for better capture on microscope camera.
- ❑ **Bin:** Filled with distilled water such that valve would be fully submerged.

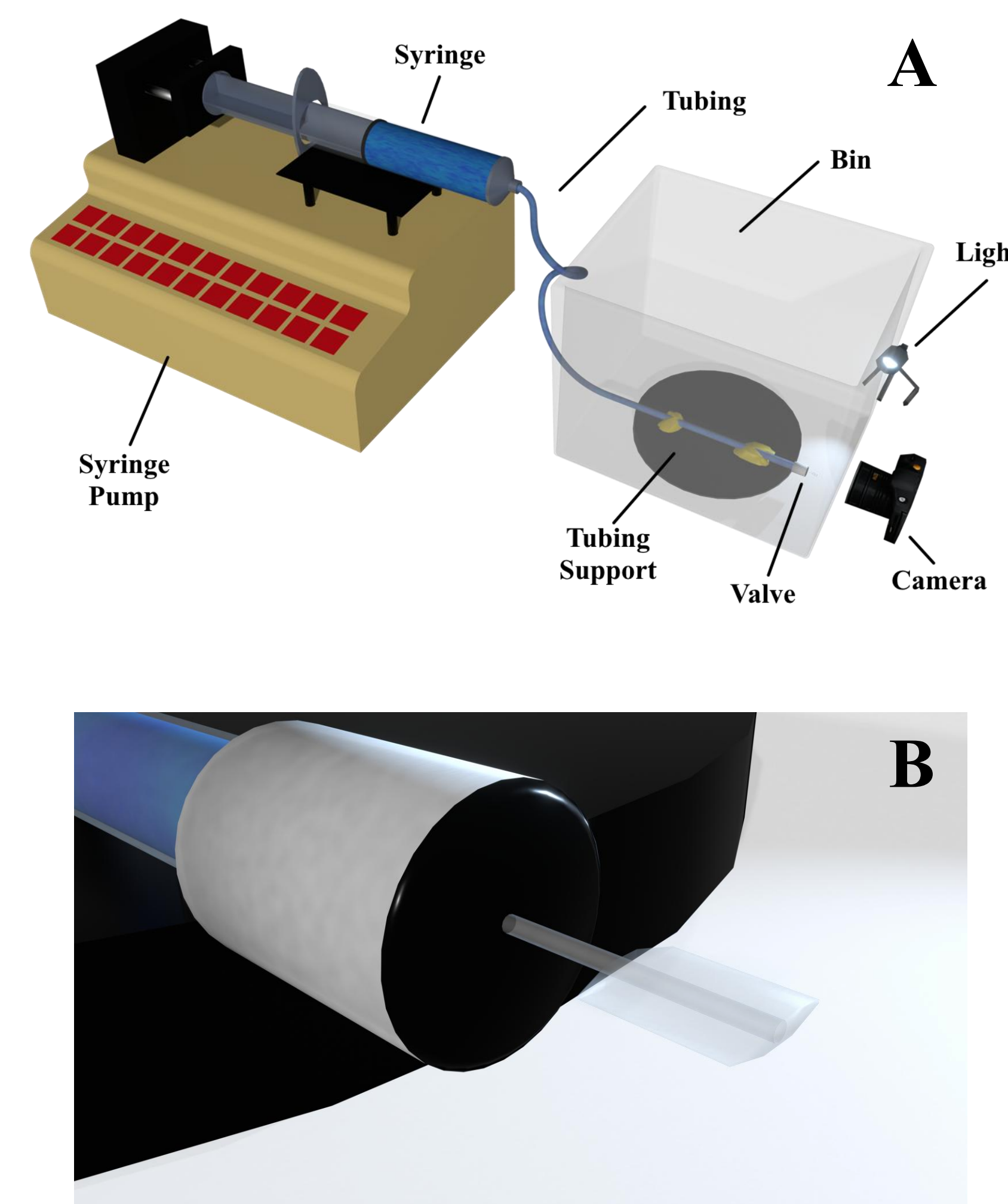


Fig 3. 3D model of real-world CSF drainage system created in Blender 4.1. A) Overall setup with labels. B) Close-up view of channel and valve.

Results

- ❑ Individual recordings were taken of the five samples for each of the flow rate tests of 0.1, 0.3, 1, 5, or 20 mL / min.
- ❑ The raw video footage was processed into separate colored and high contrast variants.
 - ❑ Colored = Contrast +0.1, Brightness +0.25, Saturation +0.15, Sharpness +0.2
 - ❑ High Contrast = Contrast +1.0, Brightness +0.2
- ❑ When the deformation reached its maximum in the video, the valve's opening was screenshotted. Then in Photoshop, the valve had its inner (blue) and outer (red) deformations measured in two different locations.
- ❑ These were compared against a 0 mL / min color or high contrast reference that had a single inner and outer measurement. The pixel difference, micrometer measurement, and ratio change were then calculated for each test and averaged.

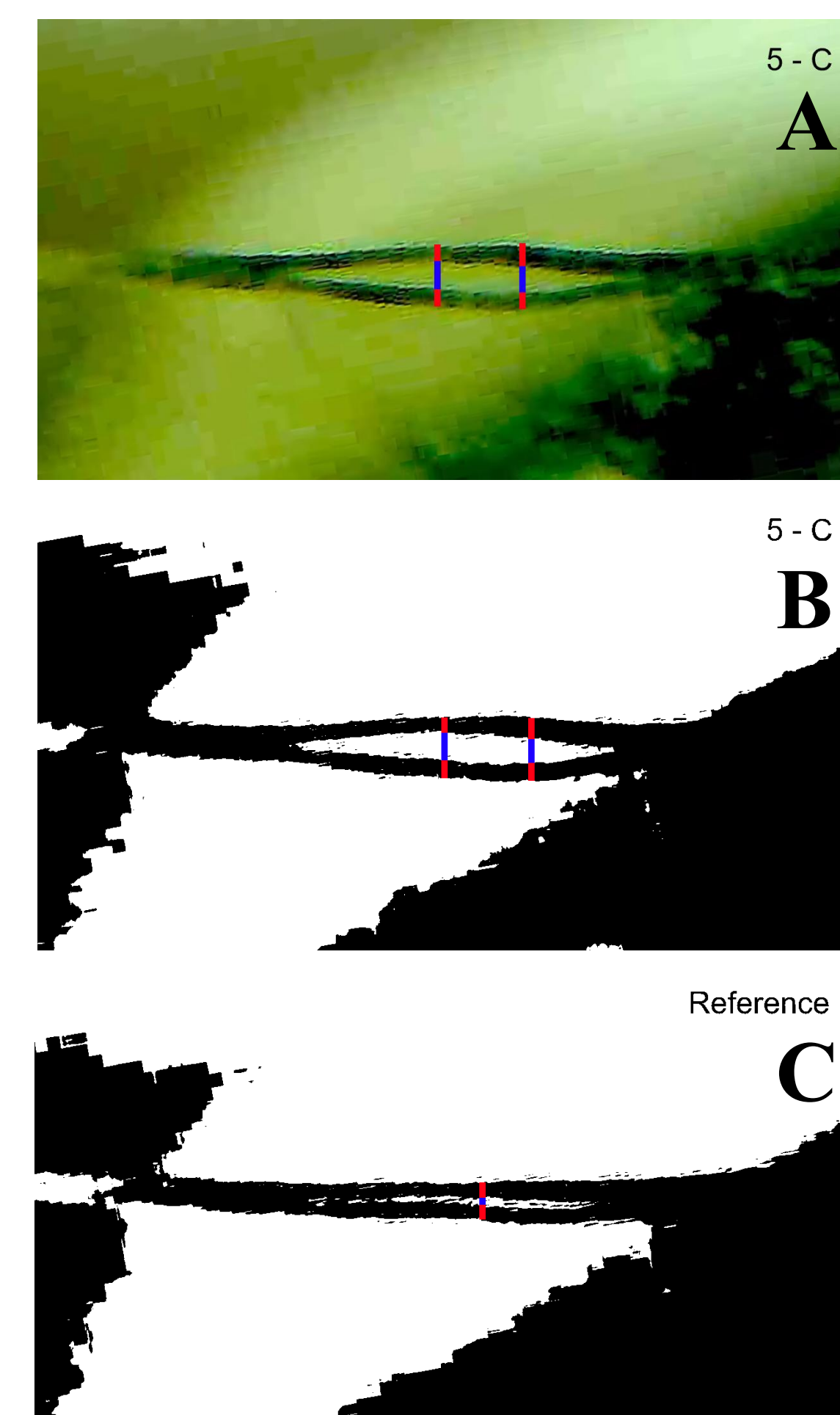


Fig 4. A) Colored screenshot of maximum deformation during test C of the 5 mL / min flow rate. B) Same 5 mL / min test with high contrast. C) A 0 mL / min high contrast closed valve reference.

Results

	Inner Deformation Averages			Outer Deformation Averages		
	Pixels	Micrometers	Ratio	Pixels	Micrometers	Ratio
Color - 0.1	24	45.712	1.1428	76.7	311.976	1.2999
Color - 0.3	25.2	47.996	1.1999	80.8	328.656	1.3694
Color - 1.0	30.5	58.092	1.4523	84.2	342.504	1.4271
Color - 5.0	41.6	79.236	1.9809	97.7	397.416	1.6559
Color - 20.0	77.9	148.38	3.7095	120.1	488.52	2.0355
HC - 0.1	21.1	76.724	1.9181	72.3	299.16	1.2465
HC - 0.3	23	83.636	2.0909	74.9	309.912	1.2913
HC - 1.0	25.8	93.816	2.3454	79.5	328.968	1.3707
HC - 5.0	37.1	134.908	3.3727	93.3	386.064	1.6086
HC - 20.0	66.9	243.272	6.0818	118.3	489.504	2.0396

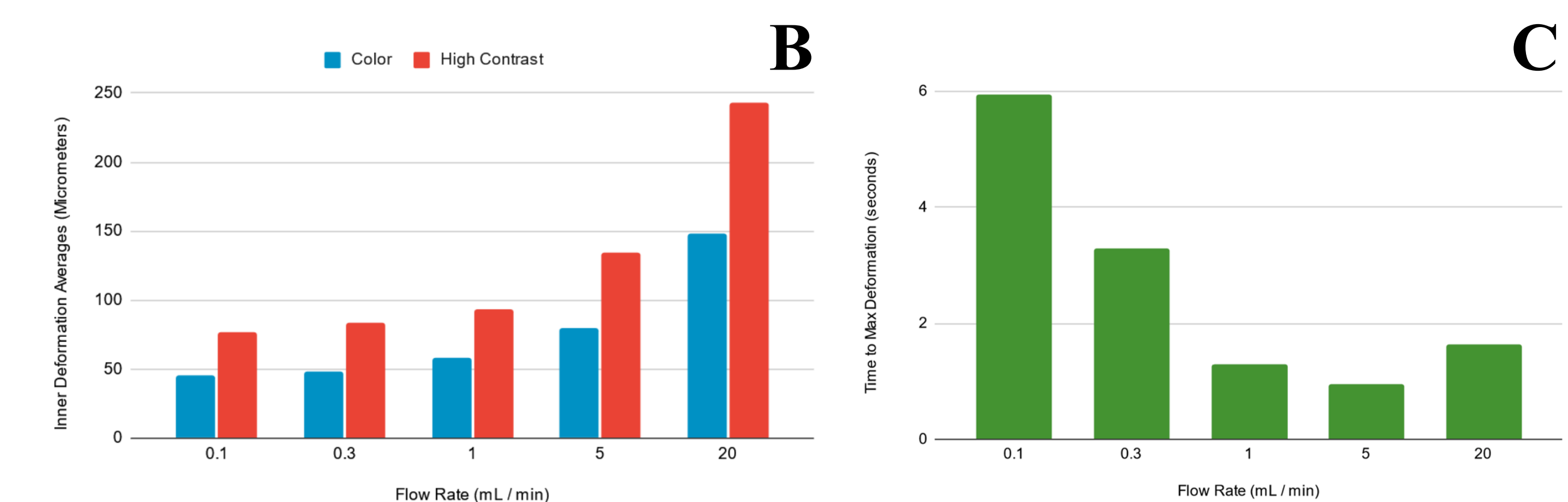


Fig 5. Measurements collected from the processed deformation screenshots. A) The average measurements of all five tests across each flow rate for both the inner and outer deformation. The pixel data is what was directly measured in Photoshop, the ratio change was calculated by comparing against the color or high contrast reference, and the micrometer measurement was the ratio multiplied by either 40 or 240 for the inner and outer deformations respectively. B) A double bar graph comparing the color and high contrast inner deformation micrometer averages. C) A bar graph showing the average amount of time each flow rate took to reach its maximum deformation.

Moving Forward

- ❑ **Total Deformation:** In exposed air, have the valve undergo a discrete number of open and close cycles, then compare the valve's beginning & ending deformations
- ❑ **Different Solutions:** Repeat experiment with varying viscosities to better simulate CSF or simulate uncommon / harsh circumstances for the patient

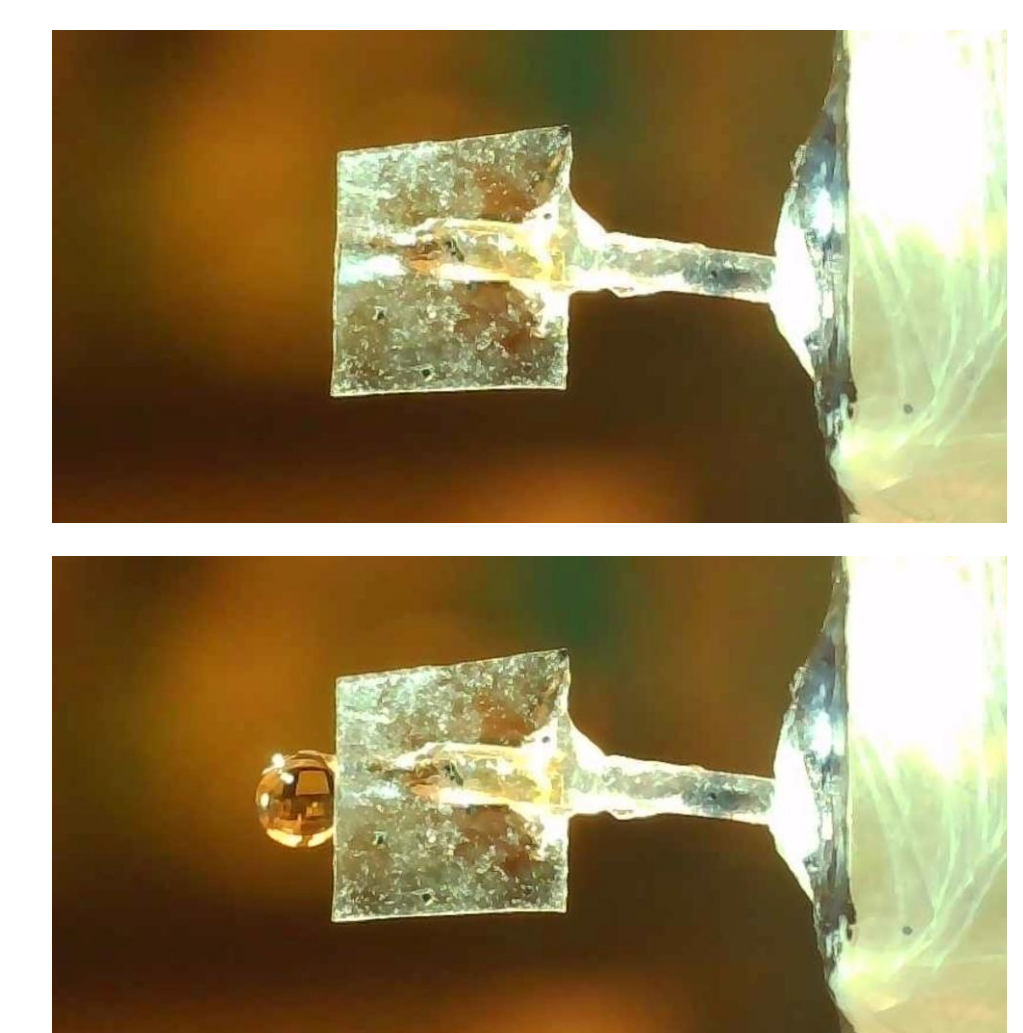


Fig 6. 'Total Deformation' example showing a single cycle being passed through the valve.

Acknowledgements

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