Idiopathic intracranial hypertension and transverse sinus stenosis phantom to evaluate pathophysiology: Preliminary results

Keerthi Valluru MS, Thomas Shen MS, Kevin O'Reilly BS, Henrik Haraldsson PhD, Evan Kao PhD, Joseph Leach MD, PhD, Alexandra Wright MD, Megan Ballweber BS, Karl Meisel MD, David Saloner PhD, Matthew Amans MD

Highlights of the Abstract (50 words)

We created a benchtop phantom to simulate transverse sinus (TS) stenosis that can be induced by idiopathic intracranial hypertension (IIH). We tested the efficacy of our phantom in reliably inducing a TS stenosis against several flow models to better approximate the high compliance of the cerebral veins.

Abstract (500 words)

Background: Idiopathic Intracranial Hypertension (IIH) is a pathologic elevation of the intracranial pressure (ICP) that can lead to blindness, cognitive decline, debilitating headaches, and distressing pulsatile tinnitus (PT). IIH most commonly affects overweight women of childbearing age with an incidence of 20 in 100,000. While the inciting event of IIH is unknown, transverse sinus (TS) stenoses play a critical role in its pathophysiology. Disrupting TS stenoses with venous sinus stenting (VSS) can cure IIH and the associated PT. Our experience suggests that essentially all patients with IIH and TS stenosis with an intravascular pressure (IVP) gradient measuring >8 mmHg across the stenosis will have PT resolution after VSS. However, VSS has significant relapse rates due to the development of proximal TS stenosis adjacent to the stent. An in vitro model that can mimic IIH pathophysiology and induce TS stenosis reliably in a controlled environment would allow us to evaluate the flow parameters responsible for restenosis.

Methods: We built a benchtop phantom that constitutes an interchangeable TS flow model submerged in a rigid water-filled chamber to simulate the potential effects of ICP exerted by cerebrospinal fluid (CSF) on TS stenosis. The phantom is equipped with a pressure sensor inside the chamber to record ICP and two calibrated needle gauges on either side of the TS flow model to monitor IVP gradient across the stenosis (Fig. 1A, 1B). Water is pumped through the flow model at a mean steady flow rate of 7 cc/s to simulate characteristic cerebral venous blood flow. ICP is manipulated by infusing additional water through the inlet provided on top of the phantom. Once the volume of water within the chamber reaches maximum, any further increase in ICP starts inducing TS stenosis. To better approximate the high compliance of the TS, we tested various thin-walled flow models of same size made of different materials with a range of shore hardness factors (30A - 60A) to evaluate the effects of ICP on the extent of TS stenosis as measured by IVP gradient.

Results: The IIH phantom was able to reliably induce and reproduce a stenosis in all the flow models tested (Fig. 1C, 1D). In our results, the latex flow model was found to be more compliant than silicone (Fig. 1E) but produced a stenosis with an IVP gradient of 8 mmHg at an ICP of 90 cmH_2O which is much higher than the typical lumbar puncture opening pressure of >25 cmH_2O seen in most IIH patients. Therefore, we are currently evaluating flow models manufactured with lower shore factor materials to determine the optimal TS flow model that mimics the high compliance of cerebral veins.

Conclusions: We developed a benchtop phantom that can mimic the pathophysiology of IIH and can reliably induce TS stenosis by increasing the ICP. We anticipate that the phantom with characteristic TS flow model will facilitate evaluating flow parameters that induce restenosis and will eventually allow testing of new stent designs that could provide sufficient and durable opening of the stenosis to relieve the ICP.

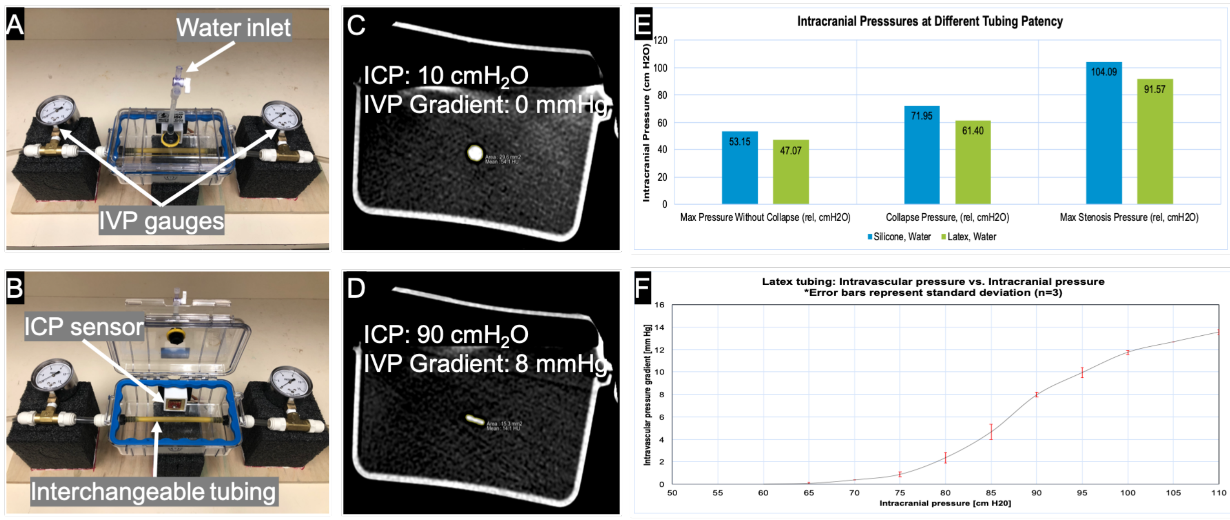

Figure 1. A) Photograph of the Idiopathic Intracranial Hypertension (IIH) phantom showing water inlet to manipulate intracranial pressure (ICP) inside the chamber. The intravascular pressure (IVP) needle gauges present on either side of the interchangeable transverse sinus (TS) flow model (with latex tubing) aid in measuring the IVP gradient across the stenosis. B) Photograph of the phantom showing internal components: The ICP sensor is affixed to the internal wall of the phantom at the same level of the flow model to record ICP exerted over the flow model that would result in TS stenosis. C-D) CT images of the phantom showing the stenosis of latex TS flow model with IVP gradient elevated from 0 to 8 mmHg as the ICP is raised from 10 cmH_2O to 90 cmH_2O. E) Comparison of silicone and latex flow models revealing that the latex model needed lower ICP (by at least 10%) to induce the same level of stenosis than the silicone model. F) Plot showing IVP gradient measured across the stenosis vs. ICP for the latex flow model: Although the latex flow model was found to be more compliant than silicone model, it produced a stenosis with an IVP gradient of 8 mmHg at an ICP of 90 cmH2O which is much higher than the typical lumbar puncture opening pressure of >25 cmH2O seen in most IIH patients.