

AN EXPERIMENTAL INVESTIGATION OF THE HYDRODYNAMIC AND BIOMECHANICAL ENVIRONMENT PRESENT IN SYRINGOMYELIA

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KEYWORDS

Syringomyelia, cerebrospinal disorders, biomechanics, Chiari malformation, hydrocephalous.

ABSTRACT

An in vitro model of the cerebrospinal fluid system with syrinx was constructed, tested, and validated to mimic the hydrodynamic conditions of the CSF system with syringomyelia.

GOAL

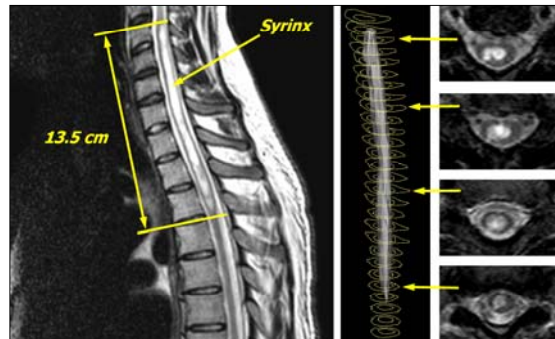
To better understand the importance of hydrodynamic forces on the initiation and progression of syringomyelia.

MOTIVATION

Occurrence of syringomyelia in the US is estimated to be higher than 1/18000. The complex relation of CSF hydrodynamics and syringomyelia pathogenesis is not fully understood.

ANATOMY

The brain and spinal cord are surrounded by a fluid called cerebrospinal fluid (CSF). This fluid moves in a pulsatile manner through the complicated subarachnoid space (SAS), spinal canal and ventricular spaces of the brain.



MR image of patient with syringomyelia.

SYRINGOMYELIA

A disorder of the cerebrospinal fluid system in which a fluid filled cyst (syrinx) develops inside the spinal cord. The cyst elongates and expands over time causing the syrinx to enlarge, destroying the center of the spinal cord.

SYMPTOMS

- pain in the head, neck, trunk, upper limbs or lower limbs.
- numbness tingling particularly of the extremities.



Picture of brain and Spinal cord, CSF is depicted in blue.

THEORIES

Craniospinal pressure dissociation (Williams): occurs due to the a ball-valve effect at the foramen magnum. "suck and slosh" theory.

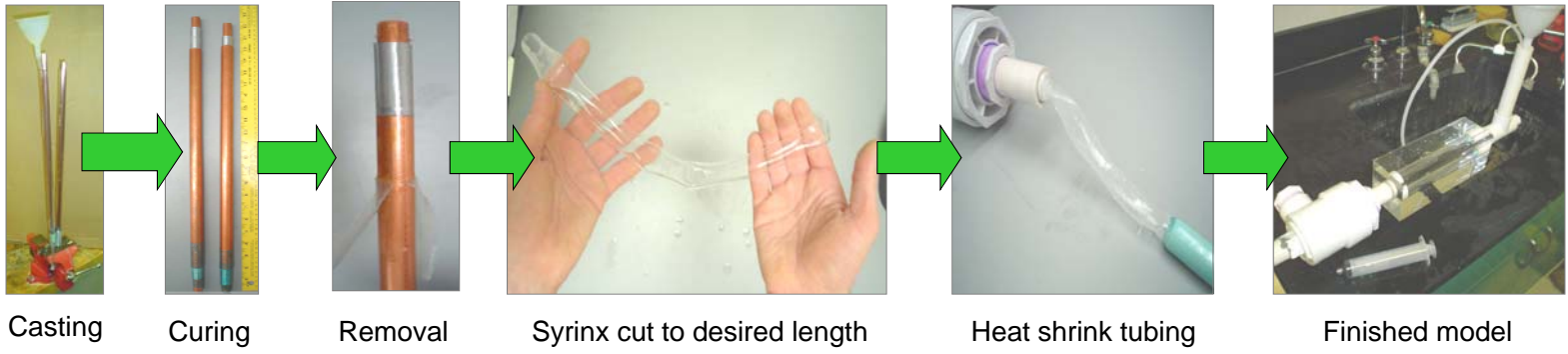
CSF from the Virchow-Robbin spaces (Ball and Dyan): CSF is forced through the Virchow-Robbin spaces into the spinal cord forming a cyst.

Systolic pressure theory (Oldfield): The brain expands during systole causing a pressure wave to travel down the SAS. Tonsils are forced to distend causing the syrinx to enlarge.

Differential-pressure-propagation mechanism (Greitz et al): The cord is filled with extra-cellular fluid that slowly circulates through the spinal cord.

Mathematical representation of fluid concentric filled coaxial tubes (Carpenter): Movement is shown to be largely dependant on the ratio of the cross-sectional area of the tubes. Assumes axis-symmetric quazi-one dimensional wave propagation.

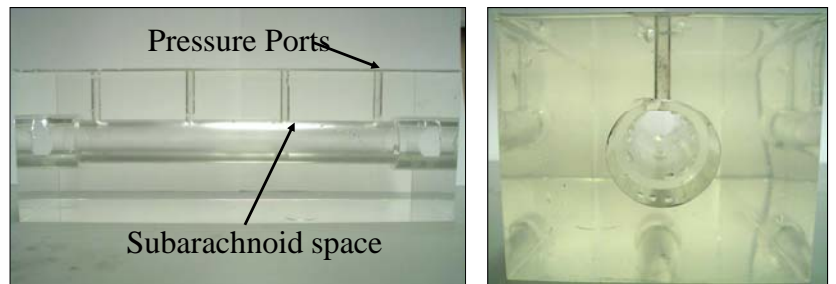
IN VITRO MODEL



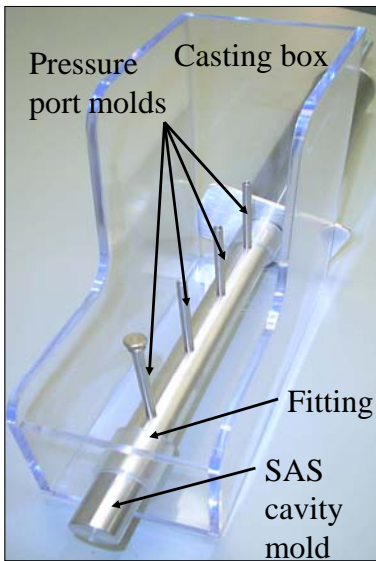
Assembly of the CSF system flow model

SAS CONSTRUCTION

Casting technique is used to obtain SAS geometry. The casting box is made up of a SAS cavity mold, pressure port molds and end fittings as shown.



Finished SAS cavity with pressure ports (left = side view, right = end view)



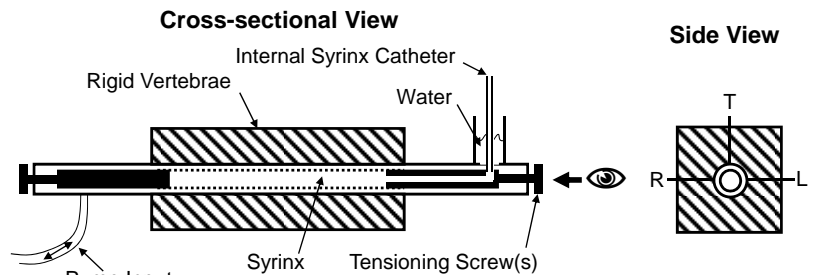
SAS molding cavity

MODEL ASSEMBLY

The flexible syringe is attached to an end pin made of PVC pipe. The end pins have screw fittings to tension the syringe. An internal syringe catheter enables filling of the syringe externally. The entire model is void of ferrous materials so that it can be tested by MRI. Figure 10 indicates the overall schematic of the assembled CSF system phantom model.

SYRINGE CONSTRUCTION

The syringe is cast around a copper pipe with an exterior confinement of heat shrink tubing. The model is then cured for one week at room temperature and carefully removed with soapy water. This process is shown in Figure 7 steps one, two, and three.



Schematic of assembled CSF system phantom model

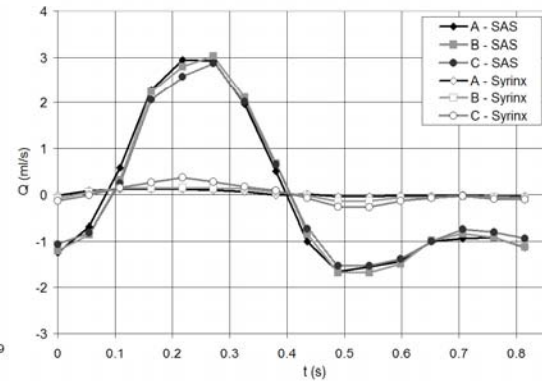
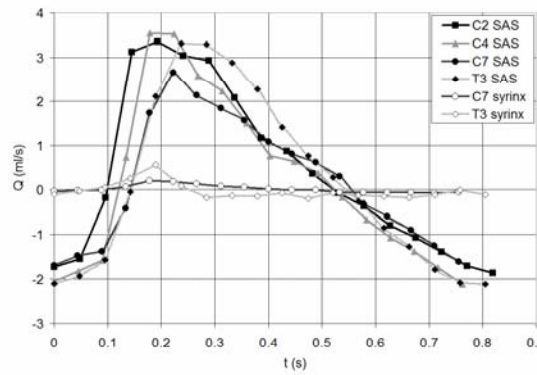
MRI FLOW RESULTS

OBSERVATION

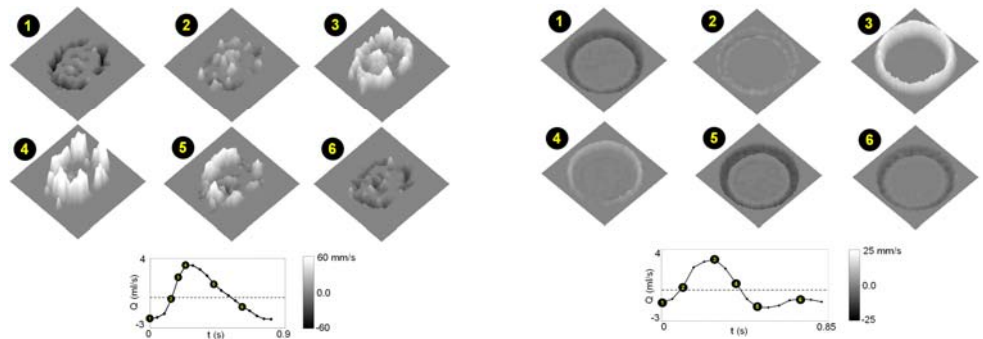
A fundamental difference in flow results when the syringe is open or closed to the external environment. When the syringe is open, the internal and external fluid motions are in phase with one another. When the syringe is closed, the syringe flow occurs out of phase. In a patient the internal and external flow waveforms are in phase with one another.

COMPARISON

Flow waveforms in SAS and syringe are closely matched in amplitude and shape in vivo and in vitro. CSF flow velocities in the SAS and syringe are smaller in vitro than in vivo.

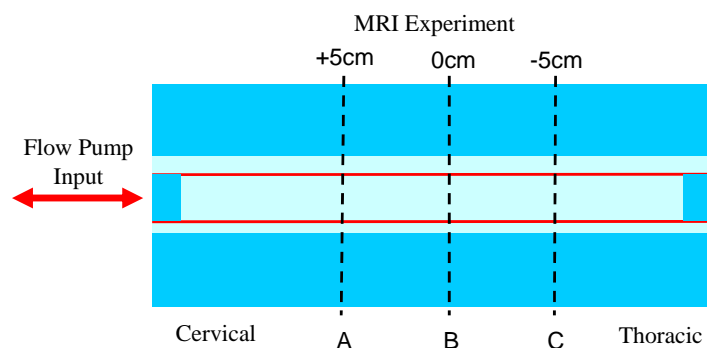
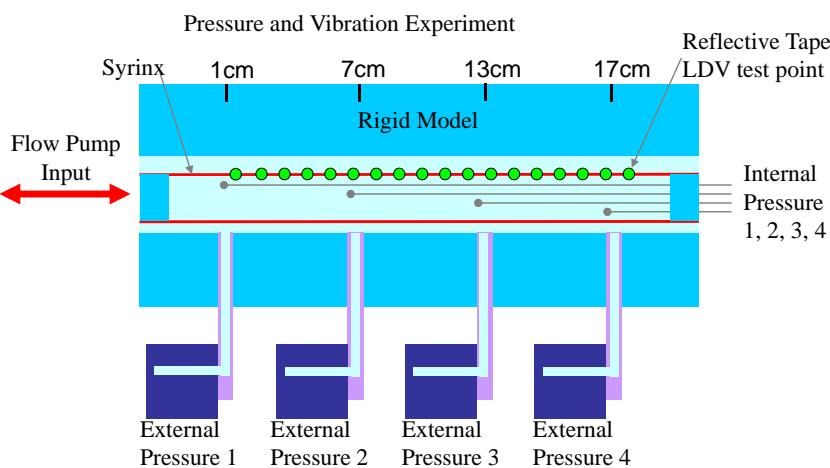


Flow in SAS and syringe at various locations (left – in vivo, right – in vitro with syringe open to environment)



Cross sectional flow in SAS and Syringe. Left figure taken at T3 in vivo, right figure at 0mm location in vitro.

IN VITRO EXPERIMENT



In vitro experiment configurations

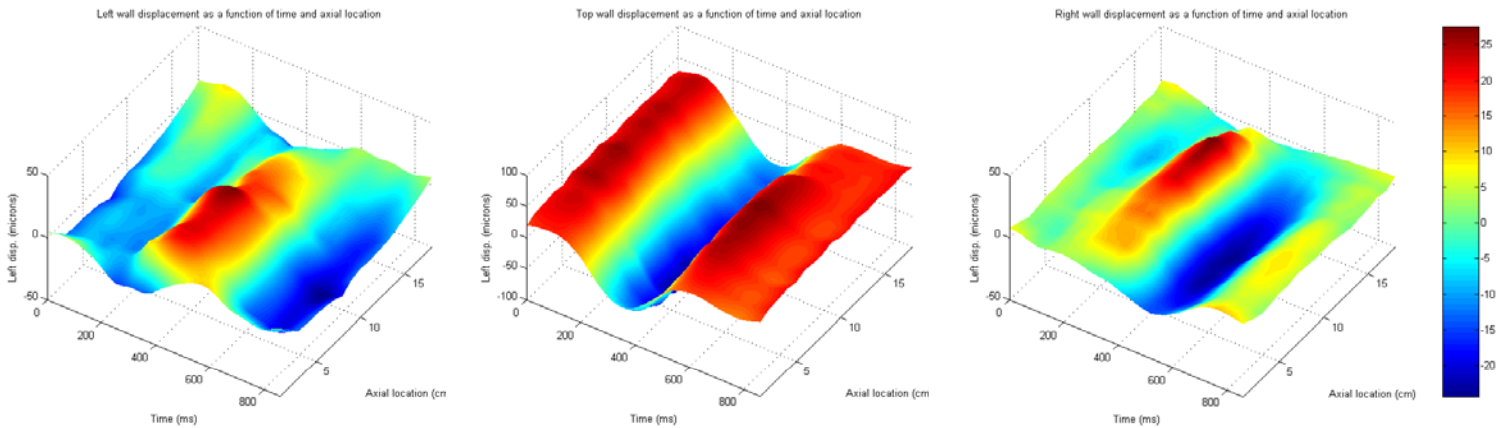
PRESSURE

Pressure measurement was acquired through using four internal pressure tip catheters (Model SPR-835, Millar Instruments, Houston, TX) and four external diaphragm pressure transducers (Model DP15, Validyne, Northridge, CA).

VIBRATION

Syringe wall motion was obtained through using non-contacting laser Doppler vibrometry (LDV) techniques. Eighteen diffuse reflective testing locations are positioned axially along the model at three polar points (Left, Top, Right).

IN VITRO RESULTS



Syrinx wall motion recorded by LDV at three polar locations left (left), top (middle), right (right)

PRESSURE

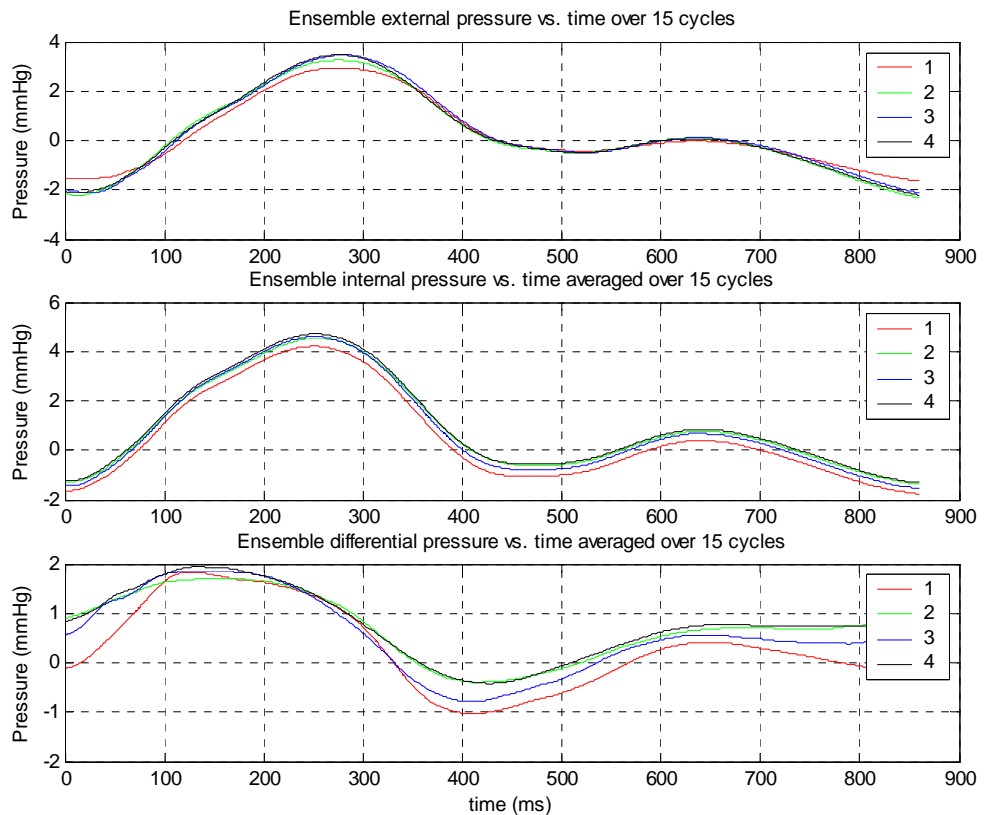
Pressure peak-to-peak amplitude in the SAS and syringe (~4mmHg) was greater than the in vivo (~1mmHg). Mean pressure in the SAS is lower than the syringe by approximately 0.5mmHg. The syringe pressure wave was found to lead the SAS pressure wave by ~40ms. Syringe pressure is less than the SAS for approximately 200ms during each 870ms flow cycle.

VIBRATION

Wall motion is non axis-symmetric. The speed of the wall motion wave is difficult to conclude. The main wall movement, "top", follows intuition. Pressure differential appears to lead wall motion by approximately 50ms.

CONCLUSIONS

- The phantom model was similar to patient with SM.
- Wall motion was asymmetric.
- Pressure differential was recorded that could provide a means for syringe development.
- Phase relation of internal and external pressure waves is important.



External SAS (top), internal Syringe (middle), and differential (bottom) pressure.

FUTURE WORK

- Further analysis of pressure and surface vibration
- Determine the importance of CSF flow waveform variations due to flow obstruction (Chiari malformation, vertebrae misalignment), breathing, coughing, and hydrocephalus.

THANKS

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For more information visit <http://www.biofluids.net>

