American Syringomyelia Alliance Project - Project Report
Project Title: Importance of the Mechanical Forces in the Pathogenesis of Syringomyelia

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Project statistics

Duration: 2003-2008
Papers published and submitted: 4
Thesis published: 1 M.S. and 1 Ph.D.
Conference abstracts published: 23
Presentations made: 19
Inventions disclosed: 2
Work presented at: NIH, Cleveland Clinic, Switzerland, Ireland, University of Wisconsin, Chari Institute, Imperial College, University of Chicago, and numerous conferences.
Students working on project: 2 Ph.D. students and 9 B.S. students

Highlights

- Improved understanding of the biomechanical environment present in syringomyelia
- Provided much needed data for analysis of syringomyelia theories and numerical simulations
- Built first experimental model of syringomyelia
- Obtained and analyzed numerous patient MRI data for construction of models
- Disclosed two inventions based on the work
- Developed novel MR technique for quantifying velocity wave speed in the spinal canal
- Increased collaboration with numerous experts on syringomyelia
- Introduced many to this research area through publications and presentations

Overview:

The research grant provided by the American Syringomyelia Alliance Project was instrumental in advancing our group's understanding of syringomyelia (SM) and funded the graduate work of Dr. Bryn Martin [1]. The goal of this project was to provide insight into the biomechanical environment present in SM. This was primarily accomplished through constructing and conducting detailed laboratory measurements on a physical model shown to be representative of SM based on comparison with in vivo measurements available in the literature. The model represents the first publication of in vitro modeling of SM [2]. The experimental findings have led to the publication of a number of scholarly research papers [3-5] and improved our understanding of the complex interactions present in SM. The detailed experimental results are also valuable in providing data for comparison and validation of computational models of the complex fluid structure interactions present in SM. In addition, our work led to the development and first publication of a novel MRI method capable of CSF velocity wave speed measurement in the spinal canal [3]. We benefited greatly from research discussions and interactions with physicians during the ASAP annual conferences and many other conferences.

In this document, we present the major findings of this project in the form of five studies each of which has lead to a separate journal paper. The first study examined both pressure and flow environment in the presence of a syrinx by employing an in vitro flow model of the spinal canal, spinal cord and syrinx without a blockage [2]. MR measurements were conducted on this model similar to those conducted on patients and showed the model to be representative of the in vivo case. It provided insight into how pressure waves in the spinal canal act on the syrinx to move its walls as well as the fluid within it. The second study examined the pressure environment in even greater detail using a set of SM in vitro models that more closely matched the in vivo dimensions and incorporated a blockage [5]. This study examined the importance of a flow blockage on pressure dissociation and described how these results supported or contrasted with previously described SM theories in the literature. The third study utilized the same in vitro flow models, but examined the altered pressure environment during a cough [4]. This study determined the importance of compliance in the system and how the syrinx alters this compliance. The results indicated that a "cough" type CSF pressure pulse affects the pressure environment within the syrinx in a significantly different way than with pressure pulse generated from the arterial pulsations. The fourth study was an in vivo study to determine the speed of the velocity wave in the spinal canal [3]. Measurement of compliance in the spinal canal may be helpful to assess the state of the craniospinal system however, it is difficult to quantify since pressure cannot be measured non-invasively. Velocity wave speed is known to increase with decreasing compliance. Thus, non-invasive measurement of the velocity wave speed may be a useful parameter for physicians in their assessment of SM disease severity. The fifth study examined existing literature to understand the mechanical property of tissues within the spinal canal [6]. Using measurements of wave speed and theoretical models of wave speed transmission, a measurement of overall mechanical properties can be computed which may be helpful in further understanding the state of the craniospinal system. The five studies are briefly described in the following pages through images and bullet points. More details can be found in the references.

Syringomyelia hydrodynamics: an in vitro study based on in vivo measurements [2]

Bryn A. Martin[1], Wojciech Kalata[2], Francis Loth[1], Thomas J. Royston[2], John Oshinski[3]
[1]*Department of Mechanical Engineering, The University of Akron, Akron, OH*
[2]*Department of Mechanical and Industrial Engineering, The University of Illinois at Chicago, Chicago, IL*
[3]*Department of Radiology and Biomedical Engineering, Emory University, Atlanta, GA*

Accomplishments

- Obtained detailed MRI measurements on a patient with syringomyelia
- Built first prototype experimental model of the spinal canal based on MRI of patient
- Built a computer controlled pulsatile pump to simulate cerebrospinal fluid flow
- Performed detailed MRI and laboratory tests on the model
- Developed novel technique coupling MRI and laboratory measurements to obtain cerebrospinal fluid wave speed in the spinal canal
- Quantified the highly complex relationship of pressure, flow, and structural motion of the spinal cord with syringomyelia

Take home points

- Experimental model was hydrodynamically similar to a patient with syringomyelia
- Interrelation of pressure wave speed in the syrinx and spinal canal were shown to be important factors which could influence fluid movement into the syrinx

Figures

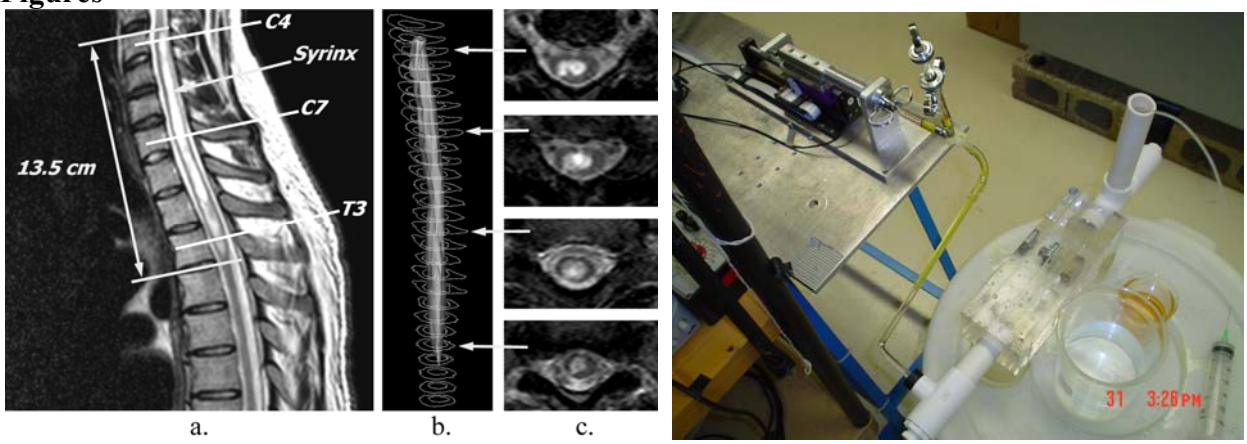

Fig. 1. Left - MRI of a patient with Chiari malformation and syringomyelia. a) Patient's lower cervical and thoracic region with syringomyelia. b) 3-D view of syrinx with contours, indicating the SAS reconstructed from axial images. c) MRI images of the spinal canal and syrinx at various axial locations. Right – Experimental model of the CSF system (video at http://www.biofluids.net/movies/1cc_sine_wav_1Hz.MPG).

Spinal Canal Pressure Measurements in an In Vitro Spinal Stenosis Model: Implications on Syringomyelia Theories [5]

Bryn A. Martin[1], Richard Labuda[2], Thomas J. Royston[3], John N. Oshinski[4], Bermans Iskandar[5], Francis Loth[1]

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Accomplishments

- Constructed four experimental models representative of conditions associated with syringomyelia (1 Chiari model w/ syrinx, 2 spinal stenosis models w/ syrinx, 1 syrinx model)
- Performed MRI and laboratory tests on each of the models

Take home points

- The Venturi effect was demonstrated when a stenosis was present in the spinal canal.
- Interaction of the syrinx and stenosis resulted in a diastolic valve mechanism which could have the effect of syrinx enlargement.
- Spinal canal flow blockage was shown to increase and dissociate pressure in the spinal canal
- Pressure in the syrinx did not dissociate.
- Results support the "suck and slosh" theory of Williams, give experimental evidence for the "milking mechanism" explained by Greitz, identify a syrinx enlargement mechanism, and provide data for validation of computational models.

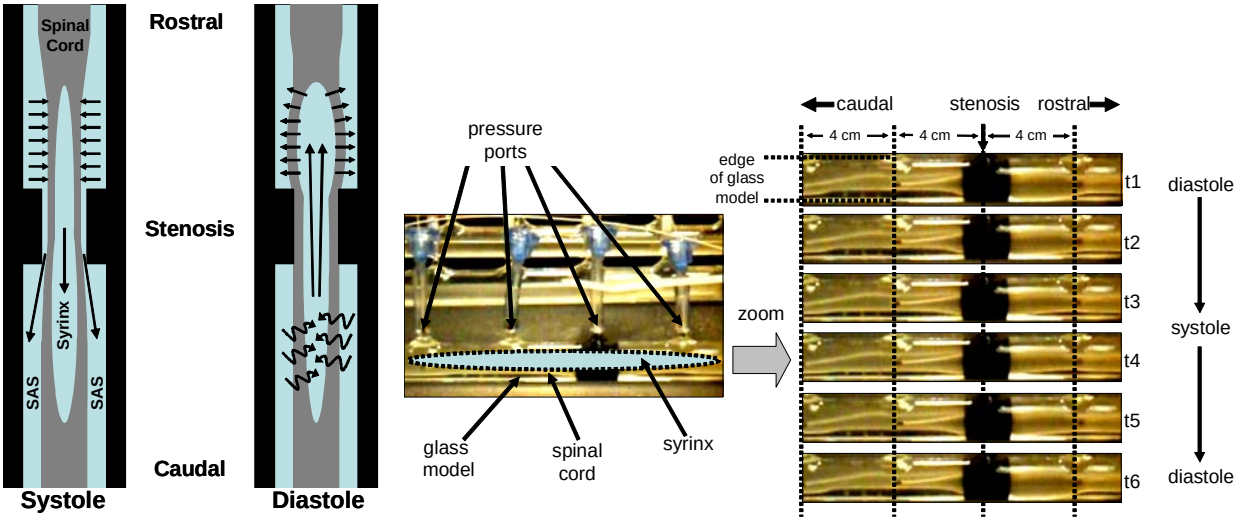

Fig. 2. Left - Diastolic valve mechanism of the syrinx and stenosis. Right - Images from the SSE model video (movie is at http://www.biofluids.net/movies/20080610_SSE_model.avi). Note, the outward ballooning of the syrinx can be seen best in the 4cm region rostral to the stenosis during diastole. Syrinx contraction can be best observed during systole in this region.

The Influence of Coughing on Cerebrospinal Fluid Pressure in an In Vitro Syringomyelia Model with Spinal Canal Stenosis [4]

Bryn A. Martin[1], Francis Loth1[1]
[1]*Department of Mechanical Engineering, University of Akron, Akron, OH.*

Accomplishments

- Conducted "coughing" type tests on four models representative of various conditions associated with a spinal canal stenosis.
- Quantified the complex pressure environment in the spinal canal under coughing conditions

Take home points

- Models were shown to have similar pressure environment as patients
- Spinal canal geometry and compliance had large influence on pressure during coughing
- Pressure wave speed in the spinal canal was shown to be indicative of spinal canal compliance and pathology (stenosis and presence of the syrinx)
- Identified future areas of research including; the influence of the vasculature (veins and arteries), SC compliance, piston action of the brain, and cerebrospinal fluid waveform (cough type).

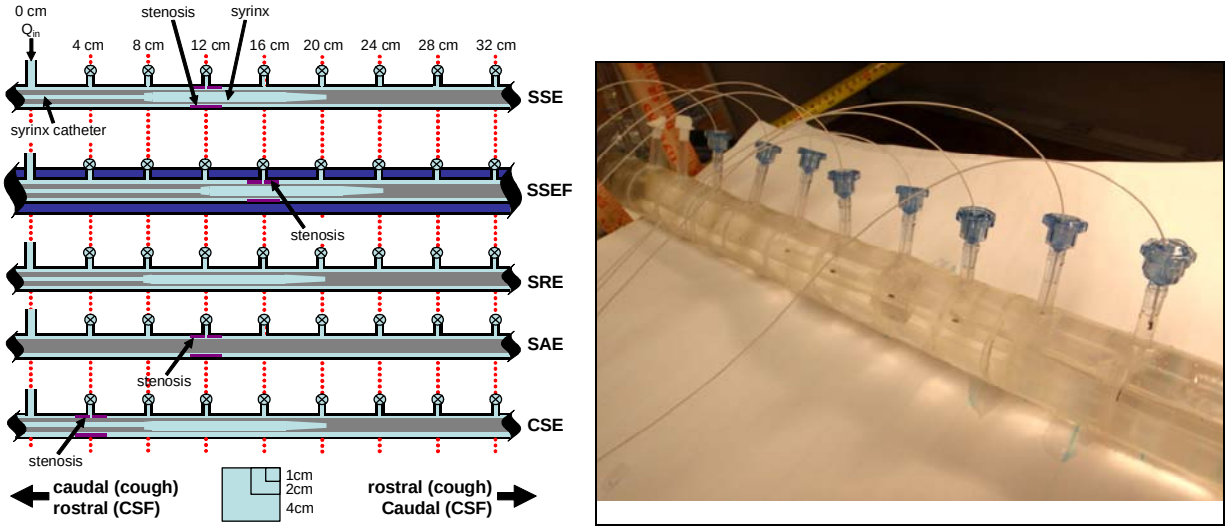

Fig. 3. Left - Schematic diagram for the coughing experiments. Right - Syrinx with stenosis experiment with flexible spinal column (SSEF).

MR Measurement of Cerebrospinal Fluid Velocity Wave Speed in the Spinal Canal [3]

Wojciech Kalata[1,5], Bryn A. Martin[2,5], John N. Oshinski[3], Michael Jerosch-Herold[4], Thomas J. Royston[5], Francis Loth[2,5]

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Accomplishments

- Developed novel MR sequence to obtain CSF velocity wave in the spinal canal
- Designed software to calculate CSF wave speed from MR CSF measurements
- Published first non-invasive MR measurement of velocity wave speed in the spinal canal

Take home points

- Velocity wave speed measurement in the spinal canal could be used as an indicator of CSF system compliance which may be indicative of disease state

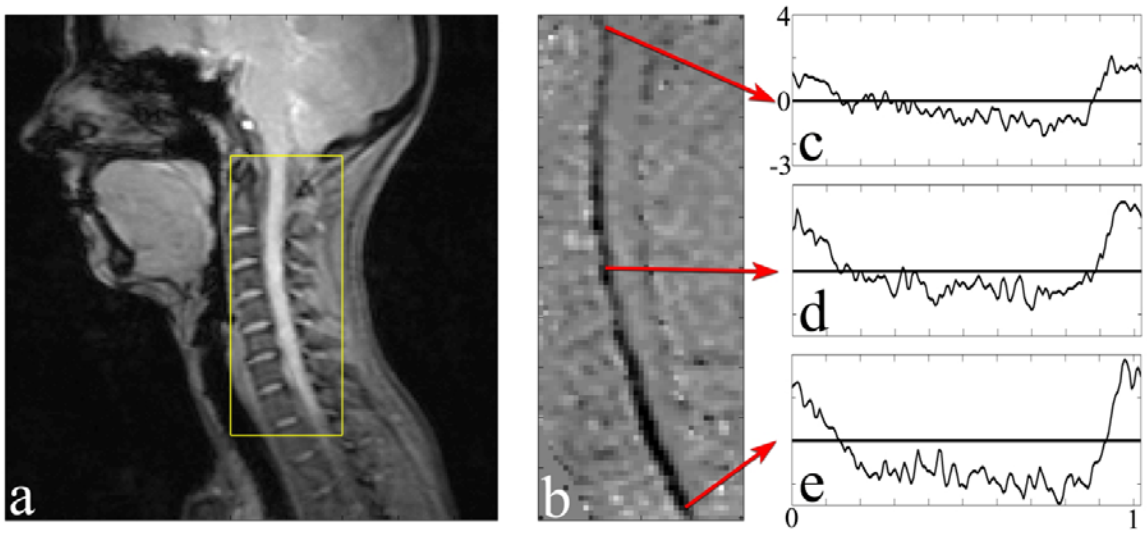

Fig. 4. Sagittal geometry image with region of interest indicated (magnitude image) (a), region of interest velocity image (phase image) as systole (T1 weighted) (b), and CSF velocity traces at various levels within center of anterior spinal canal (c-e) for patient 1.

Non-invasive assessment of elastic properties in the spinal canal [6]

Bryn A. Martin[1], Francis Loth[1], T.J. Royston[2]
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[2]*Dept. of Mechanical and Industrial Engineering, University of Illinois at Chicago, Chicago, IL*

Accomplishments

- Conducted pressure wave speed experiments on compliant in vitro models of spinal canal
- Developed theoretical model for wave speed calculation in the spinal canal
- Performed extensive literature search on mechanical properties of the spinal canal and cord
- Conducted MR studies to determine spinal canal compliance for volunteers and patients

Take home points

- Theoretical model matched experimental results, but needs improvement
- Results help researchers further develop models to non-invasively assess craniospinal system compliance

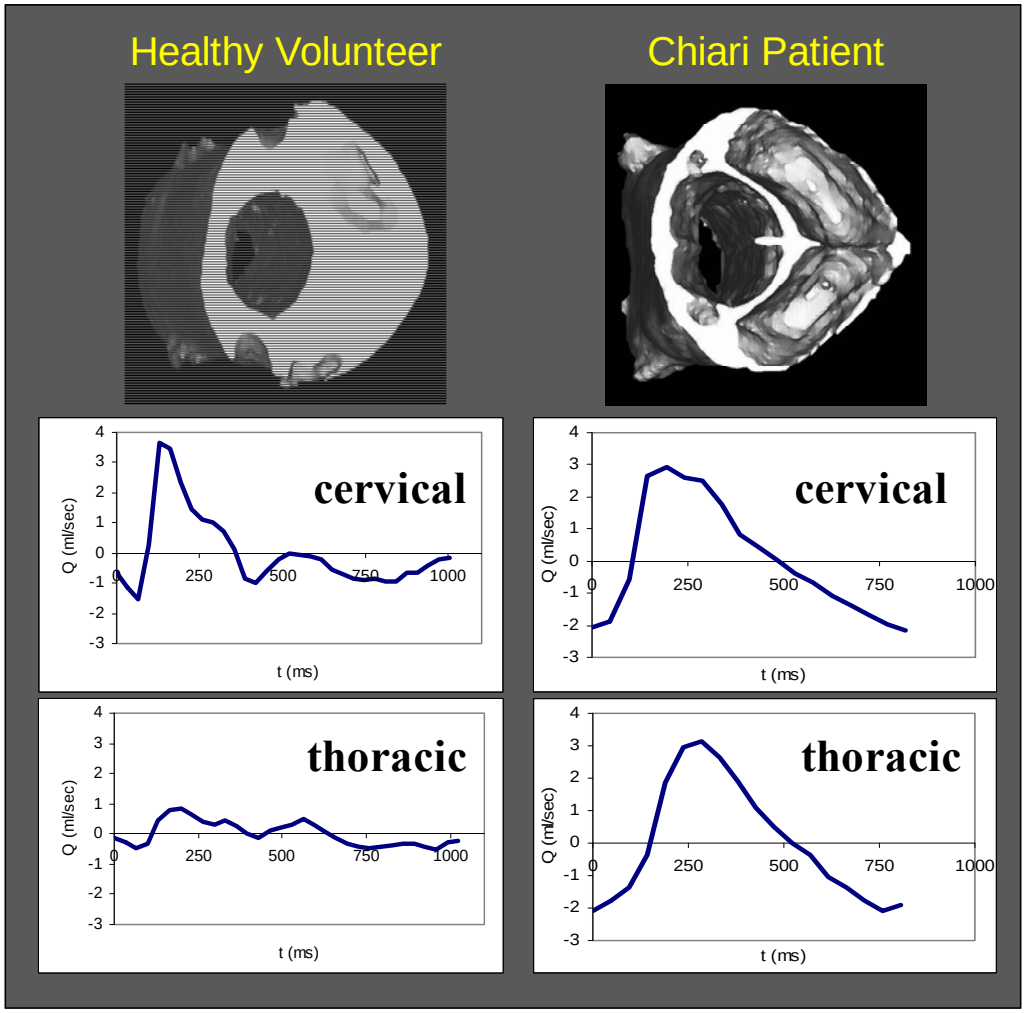

Fig. 5. Compliance study on healthy volunteer and Chiari patient through CSF flow waveform quantification of pcMR measurement at the cervical and thoracic levels

References

[1] Martin, B. A., 2008, "An Experimental Investigation of the Hydrodynamic and Biomechanical Environment Present in Syringomyelia," University of Illinois at Chicago

[2] Martin, B. A., Kalata, W., Loth, F., Royston, T. J., and Oshinski, J. N., 2005, "Syringomyelia Hydrodynamics: An in Vitro Study Based on in Vivo Measurements," J Biomech Eng, 127(7), pp. 1110-20.

[3] Kalata, W., Martin, B. A., Oshinski, J. N., Jerosch-Herold, M., Royston, T. J., and Loth, F., 2009, "MR Measurement of Cerebrospinal Fluid Velocity Wave Speed in the Spinal Canal," IEEE Transactions on Biomedical Engineering.

[4] Martin, B., and Loth, F., 2009, "The Influence of Coughing on Cerebrospinal Fluid Pressure in an in Vitro Syringomyelia Model with Spinal Canal Stenosis," Submitted February 2009.

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[6] Martin, B. A., Loth, F., Royston, T. J., and Oshinski, J. N., 2009, "Non-Invasive Measurement of Elastic Properties of the Spinal Canal," In progress.