EXCHANGE OF FLUID BETWEEN A SYRINX AND THE STENOSED SPINAL SUBARACHNOID SPACE (WITH IMPLICATIONS BEYOND SYRINGOMYELIA)

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Abstract. Simplifying the geometry but retaining the true dimensions, we constructed in open-source software [1] an axi-symmetric poroelastic fluid/structure-interaction model [2,3] of the spinal cord and filum terminale, the pia mater, the spinal subarachnoid space (SSS) and the dura mater. A substantial fluid-filled syrinx took up part of the thoracic cord. The subarachnoid space was mostly occluded opposite the syrinx by a blockage of trapezoidal cross-section adhering to the dura. The model was excited by sinusoidal pressure applied to the fluid at the cranial end of the SSS, evoking the cyclic displacement of cerebrospinal fluid (CSF) caused by the pulsation of arteries in the head.

Because the SSS stenosis flexed, the remaining gap was slightly greater when pressure was high, and caudally-directed flow through the gap was greater than cranial. This caused greater mean SSS pressure caudal to the stenosis, and a steady streaming flow in a circuit past the gap and back via the syrinx, passing through the porous overlying tissue. Depending on details of the geometry, mean syrinx volume varied slightly from its initial value; see Figure 1. The model does not include representation of growth and remodeling, but such effects might amplify the small syrinx volume changes found.

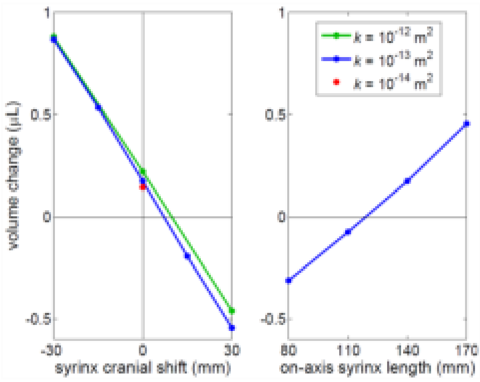

Fig. 1. Difference between initial syrinx volume and its final cycle-average value after the evolution of conditions over enough cycles to find a steady state. Left: variation with syrinx position relative to the SSS stenosis. Right: variation with the length (and therefore volume) of the syrinx. The findings vary only slightly with the value of poroelastic permeability, shown in the legend.

The SSS pulsation caused fluid to be cyclically taken up by and given up from the adjacent poroelastic tissues in a periodic swelling that was confined to a tissue boundary layer next to the SSS. The effect was particularly marked for the tissue over the syrinx, but occurred to a lesser extent everywhere along the cord, showing that there is continuous mixing of CSF and interstitial fluid in this region. The extent of the cord swelling depended on its cyclic strain, and was therefore limited by the stiff containing pia. To the extent that there is pulsatile strain of brain tissue near the subarachnoid space, the effect can be expected in the head also.

We thus describe a means of fluid ingress into a syrinx, and cord tissue in general, from the SSS that does not involve perivascular (Virchow-Robin) conduits [4,5], and a means of fluid egress from the cord that does not depend on the existence of suggested paravascular channels along basement membranes [6].

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Chris Bertram

About the Presenter: Chris Bertram graduated in 1971 (Engineering Science) and gained his DPhil in 1975 (ultrasonic measurement of arterial mechanical properties). He then worked on hemodynamics at Johns Hopkins University's Dept of Physiology. From 1977 he experimented on unsteady flow separation at DAMTP (Cambridge, UK). In 1980 he was appointed to the then Centre for Biomedical Engineering of University of New South Wales. He moved to University of Sydney in 2010. For many years he conducted experiments on self-excited oscillations of collapsed-tube flows, and these still form the most comprehensive investigation of this dynamical system. Beyond CSF, his current research is on pumping in the lymphatic system. He has been a member of the World Council of Biomechanics, and an Associate Editor of *J. Fluids & Structures*, and is on the Editorial Board of *Med. & Biol. Eng. & Comput*.

MATHEMATICAL MODELLING OF SPINAL CSF DYNAMICS: HUMAN AND ANIMAL MODELS OF SYRINGOMYELIA

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Abstract. Syringomyelia is a severe progressive pathological condition in which fluid-filled cavities (syrinxes) form and grow in the spinal cord. There is strong evidence that syringomyelia is linked to obstructions to the movement of cerebrospinal fluid (CSF). However, the exact mechanism of cyst formation and growth has defied explanation for decades. The lack of understanding of the origins of the condition limits the success of currently available medical treatments. Syringomyelia is often linked with Chiari malformation, a congenital condition in which underdevelopment of the skull causes the lower portion of the brain to protrude into the spinal cavity and obstruct the normal communication between the cranial and spinal CSF spaces. Syringomyelia and Chiari affect, and have the same manifestation in, both humans and animals. Some breeds of dogs are particularly predisposed; in King Charles spaniels, almost all dogs suffer from Chiari and many develop syringomyelia [1]. Consequently, this breed is an excellent model for studying the causes of syringomyelia. With the lack of clinical explanation, engineers and mathematicians have resorted to computer models to identify possible physical mechanisms that can lead to syrinx formation and growth [2]. We developed one-dimensional and semi-idealized three-dimensional models of the spinal cavity of a King Charles spaniel with a large syrinx spanning almost the entire length of the cord. The models included the spinal cord (with and without the syrinx), CSF in the subarachnoid space, dura, and the epidural space. A velocity input was prescribed at the cranial end to simulate the movement of the CSF or cord due to the communication between the cranial and spinal CSF spaces related to the cardiac cycle. To simulate the normal condition, the movement was prescribed to the CSF, and the cord was free of syrinx. To simulate the pathological condition the movement was prescribed to the cord, which was either free of a syrinx (onset of the pathology) or it had a fully developed syrinx. The results suggest that there is a mild increase in the stress experienced by the spinal cord when the blockage between the cranial and spinal CSF spaces forces the cord to move with the cardiac cycle. While the 1D model predicts an axially uniform distribution of stress, the 3D model suggests that there are regional differences due to the curvature of the spine. The syrinx seems to ultimately relax the stress in the spinal cord tissue which points to the possibility of a "homeostatic" mechanism for cavity dynamics.

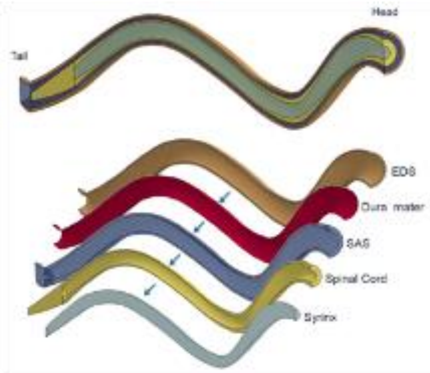

Fig. 1. Three-dimensional, semi-idealized model of the spinal cavity of a dog. The geometry was reconstructed from MR images of the spine of a King Charles spaniel suffering from a large syrinx. The model consists of the following layers: spinal cord, syrinx, subarachnoid space, dura, and epidural space. Each layer in the model was approximated to be of a circular cross-section with the radius varying axially. CSF was represented as a fluid and all other structures as (linear) elastic solids.

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Serge Cirovic

About the Presenter: Serge Cirovic obtained his PhD in Aerospace Engineering at the University of Toronto, Canada in 2001. He worked as a research consultant at DRDC-Toronto and as a research associate at the University of Sheffield before assuming a lectureship position at the University of Surrey in 2006. Dr. Cirovic is the Programme Director of the MSc in Biomedical Engineering at the University of Surrey where he teaches biomechanics to undergraduate and MSc students. His research interest is in using computer models to understand the role of mechanical stimuli in the etiology of pathological conditions. He is also interested in the therapeutic effect of high-amplitude pressure waves.