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THE INFLUENCE OF COUGHING ON CEREBROSPINAL FLUID PRESSURE IN AN IN VITRO SYRINGOMYELIA MODEL WITH SPINAL CANAL STENOSIS

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ABSTRACT

Five in vitro models were constructed which were representative of various pathologies of the spinal canal (SC) associated with syringomyelia (SM). The models were subjected to a cough type flow impulse while monitoring the pressure environment in the syrinx and subarachnoid space (SAS) regions of the model. The results indicated that conditions can arise during a cough which would provide pressure forces to encourage cerebrospinal fluid (CSF) movement into the syrinx cavity. The flow obstruction (stenosis) acted as an inflection point for transmural pressure (TP) in which the far region of the syrinx was expanded and the near region was compressed. In the case when a stenosis was present, but no syrinx had formed, the longitudinal pressure gradient and pulse pressures were highest on the SC. However, when a syrinx was present, the pressures were reduced, but still pathological. The primary point of pressure gradients in all of the experiments was the stenosis which caused large pressure dissociation in the system which could aid in SC ripping or tearing of the tissue. The presence of a syrinx appeared to decrease some of these forces, but without removal of the flow obstruction, a pathological biomechanical environment persists.

Keywords: Syringomyelia, Chiari malformation, cerebrospinal fluid, hydromyelia, fluid structure interaction, biofluid mechanics, biomechanics, spinal cord, subarachnoid space, syrinx, intracranial pressure, in vitro model.

INTRODUCTION

Many mechanisms have been hypothesized to explain SM pathogenesis, some of which postulate that forces in the SAS during coughing and valsalva produce a biomechanical environment contributing to syrinx formation and or enlargement and subsequent pain in the patient. It has been documented that coughing, sneezing, straining, and sitting can vary CSF pressure thereby exacerbating pain present in SM [1]. A number computational studies have examined the influence of coughing in the spinal SAS and provided detailed pressure information [2, 3, 4], but these studies have required significant simplification to the in vivo system and need further validation by comparison to in vivo data and in vitro models. However, in vivo coughing measurements are scarce and lack the detail required to fully understand the influence of coughing. Thus, in the present study temporal and spatial pressure in SM is examined through use of in vitro models. These models have been previously shown by Martin et al. to be similar to the patient and provided detailed information about the relationship of pressure, flow, and spinal cord motion [5], and the pressure environment resulting from the interaction of the syrinx and stenosis [6].

METHODS

Four models representative of various conditions associated with SM were constructed (Fig. 1). A spinal *stenosis and syrinx experiment (SSE)* was conducted to be representative of a SM patient with a SAS stenosis located near the midsection of the syrinx cavity. A *stenosis removed experiment (SRE)* was conducted having an identical syrinx to the SSE, but without a spinal stenosis. Another model was designed to be representative of a *stenosis alone experiment (SAE),* having a spinal stenosis, but lacking a syrinx cavity. An additional model was constructed to form a *spinal stenosis and syrinx experiment with flexible spinal column (SSEF).* The SC portion of the SSE, SRE, and SAE models was constructed with an elastic polymer, and the spinal column of these models was formed by a rigid glass tube with pressure ports (Fig. 1). TP across the syrinx cavity was obtained by subtracting adjacent internal-external sensor signals (syrinx minus SAS). In SSE,

SSEF, and SAE, a ~ 2 cm length annular shaped stenosis was fitted into the spinal canal blocking > 90% of the total SAS area. Each of the models was connected to a computer controlled pulsatile pump and subjected to a 5 ms pressure impulse at the flow input port (Fig. 1). All results are shown relative to initial pressure.

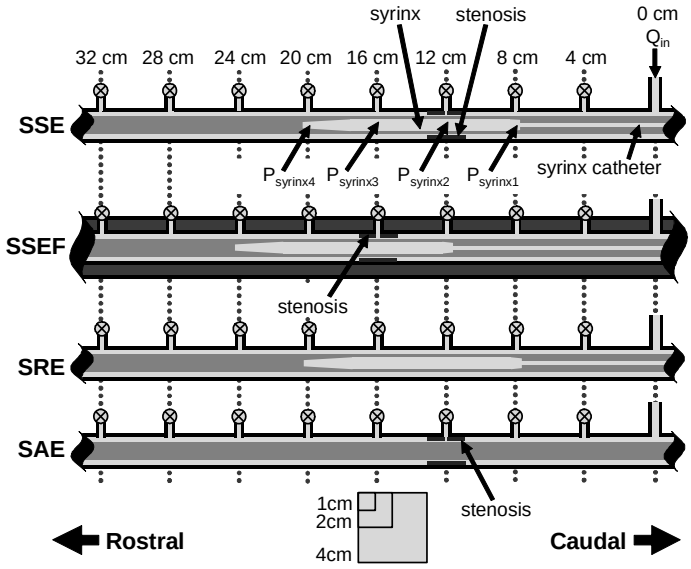

Fig. 1. Schematic diagram for each of the coughing experiments

RESULTS

The temporal and spatial pressure distribution in each of the four models varied greatly (Fig. 2). Pressure disturbances were influence by the location of the stenosis and the presence of a syrinx. The greatest pressure fluctuations occurred in SAE and the least in SSEF. The pressure wave speed varied widely between each experiment being slowest in SSEF. Interestingly, the wave speed varied moving from the rostral to the caudal side of the stenosis in all experiments, while the material properties in these regions remained the same. TP results were vastly influenced by the presence of the stenosis, which can best be observed by comparing the SSE and SRE experiment results (Fig. 3).

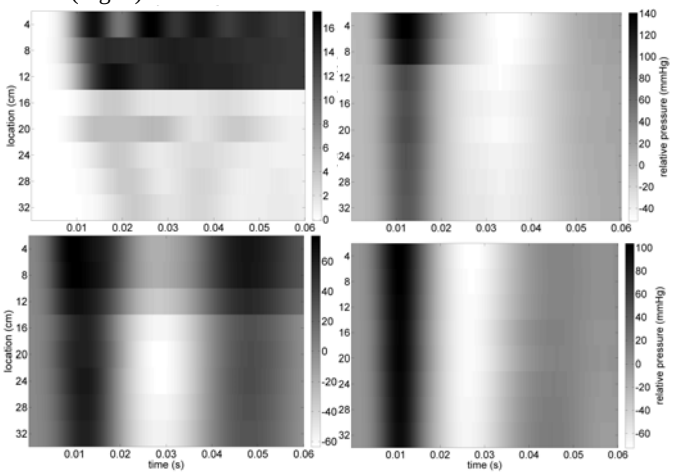

Fig. 2. Temporal pressure (SSEF, SAE, SSE, and SRE are upper left, upper right, lower left, lower right, respectively)

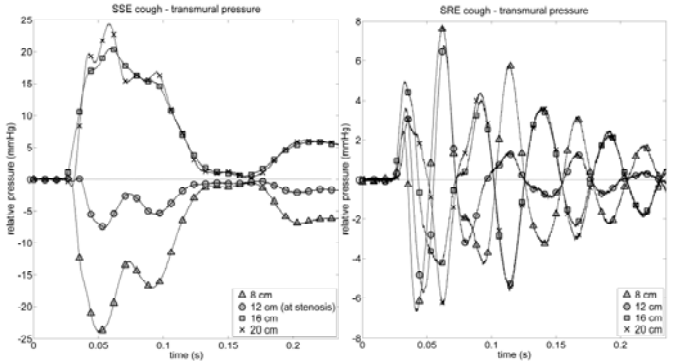

Fig. 3. Transmural pressure (relative) for SSE and SRE shown left and right, respectively.

DISCUSSION

The coughing study produced a number of important results. First, it was found that conditions can arise in which fluid would prefer to move into the syrinx cavity rather that out of it. The stenosis acted as an inflection point for TP in which the far region of the syrinx would be expanded and the near region would be compressed. It appeared that in the case when a stenosis was present, but no syrinx had formed, the longitudinal pressure gradient and pulse pressures were highest on the SC. However, the pressures were reduced for the case with a syrinx, but still substantially pathological. The primary point of pressure gradients in all of the experiments was the stenosis. The stenosis caused large pressure dissociation in the system in all cases which, by some means described, could aid in SC damage. The presence of a syrinx appeared to decrease some of these forces, but without removal of the flow obstruction, a pathological biomechanical environment persists.

CONCLUSIONS

The detailed study of the pressure environment induced by coughing in the pathological spinal SAS provides needed data for the assessment of existing SM theories and comparison to SM computational fluid structure interaction codes.

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