What Has Image Based Modelling of Cerebrospinal Fluid Flow in Chiari Malformation Taught Us About Syringomyelia Mechanisms?

Lynne E. Bilston

Abstract Chiari Malformation is a congenital disorder of the hindbrain, in which the cerebellar tonsils protrude through the foramen magnum, impeding normal cerebrospinal fluid (CSF) flow into the spinal canal. It is associated with pain, dizziness and headaches, particularly related to coughing and straining. The mechanisms by which Chiari malformation gives rise to these symptoms are not understood. In a large proportion of patients, a fluid-filled cavity develops in the spinal cord, called a syrinx. Syrinxes can cause additional neurological deficits, including sensory changes, weakness and upper limb pain. Syrinxes are associated with disturbances to normal CSF dynamics, usually as a result of obstructions in the spinal canal, but precisely how this occurs is not known. Animal studies suggest that fluid transport into the spinal cord is increased in the presence of spinal canal obstructions, likely via annular spaces surrounding penetrating arteries (perivascular spaces). Human phase contrast magnetic resonance imaging studies can quantify both cardiac driven motion of cerebrospinal fluid flow, and, more recently, respiratory and other influences. These data can be used to generate subject-specific computational fluid dynamics models of the hindbrain and spinal canal to estimate spinal canal pressure dynamics in patients with Chiari malformation, patients with syrinxes, and healthy controls. Computational models of perivascular space flow can be linked to these macroscopic models, to enable investigation of the feasibility of hypotheses about mechanisms of syrinx formation. To date, these studies have demonstrated that several popular hypotheses about Chiari mechanisms and syrinx formation are inconsistent with the mechanics of CSF flow, and generated novel mechanistic hypotheses. Subject-specific image based modelling provide a useful adjunct to human and animal experimental research into CSF flow disorders such as Chiari malformation and syringomyelia.

L. E. Bilston (✉)

Neuroscience Research Australia and Prince of Wales Clinical School, UNSW, Sydney, NSW, Australia

e-mail: L.Bilston@neura.edu.au

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