Intracranial dynamics: from brain elasticity to hydrocephalus

Issyan Tekaya\textsuperscript{1}, Robert Bouzerar\textsuperscript{1}, Roger Bouzerar\textsuperscript{2} and Olivier Balédent\textsuperscript{2}

\textsuperscript{1} : Physique des Systèmes Complexes – UFR Sciences –
33 Rue St-Leu - 80039 Amiens
\textsuperscript{2} : Laboratoire de Biophysique et Traitement de l’Image
CHU Amiens Nord - Place Victor Pauchet
Amiens

\textsuperscript{IV} th European Conference on Computational Solid and Structural Mechanics, Paris, France, 16-21 May 2010

We built up a physical model of the global brain dynamics taking into account the mechanical coupling of the brain strain field to both arterial and venous blood flow and the cerebrospinal fluid (CSF) flow. To deal with a more realistic view of the intracranial structure, we divided it into three compartments: the brain matter’s compartment (or parenchyma), the ventricular one and the subarachnoid spaces (SAS) [1]. Though the parenchyma consists of two components, namely grey and white matter endowed with different mechanical modulii, it is treated in first approximation as an effective homogeneous medium. Nevertheless, to stay as close as possible to the realistic situation, some of these mechanical parameters are tentatively assessed through Magnetic Resonance Imaging.

Except for these effective mechanical modulii of brain matter, our mechanical approach of the brain’s dynamics requires the knowledge of its viscoelastic properties or equivalently a characteristic relaxation time of brain strain/stresses. The abovementioned mechanical coupling of brain to the arterial (and venous) blood flow is induced by a modulated force term (heart beats). This phenomenological term, modeling the complex network of blood capillaries embedded within brain matter, acts as a source term for strain (or stresses). To bypass the structural complexity of the vascular tree, its effect is reduced in first approximation to a random distribution of “pulsatile centers” generating concentrated stresses. This concept is discussed and methods to assess that distribution through optimization techniques are proposed. This distribution is one of the main phenomenological ingredients of the model and some of its “symmetries” features such as a fractal-like scale independency are systematically investigated. The global brain’s strain evolution equation is finally derived along with some transfer function of clinical interest as the relationship arterial flow/brain’s strain.

The coupling of the parenchyma to the ventricular space and the SAS is treated in a very special way: the motion of the ependyma (thin membrane demarcating the ventricles) and of the pia-mater envelope limiting the SAS generate displacements defining boundary conditions to parenchyma’s
motion equation. This setting of the problem connects the brain’s strain dynamics with the intracranial pressure dynamics on both the healthy and pathological sides (lack of the pressure regulation). Bifurcations of the ventricles’ dynamics evidenced in a previous work [2,3] and shown to match hydrocephalic situations are reexamined within our global model. Attempts to formulate instability criteria involving the global intracranial state are discussed. More especially, the signature of any hydrocephalic state on the brain strain’s dynamics is emphasized. Because of difficulties to handle the coupled brain and ventricles’ dynamics, this last problem has been addressed from a numerical point of view. A first simplified numerical model involving spherical ventricular space and parenchyma allowed a computation of the stress (strain) field within the brain in healthy and pathological situations. The governing equations were solved using MATLAB built-in algorithms based on finite-difference schemes (explicit Runge-Kutta fourth order formula and Adams-Bashforth-Moulton Multistep solver). A comparison evidences the stress state change due to hydrocephalus. This analysis allows investigating hydrocephalus as an adaptive brain ventricles’ dilation towards a new stable configuration as was proposed by our group in earlier study [4]. Nevertheless, this highly symmetrical situation is not realistic and a deeper study needs to be held using rigorous Finite Element Analysis.


4: R. Bouzerar et al, “A theory of hydrocephalus based on bifurcations of intracranial dynamics”; submitted to CSF Research