A model of in-vivo hydrocephalus shunt dynamics for blockage and performance diagnostics

D. Schley†, J. Billingham‡ & R.J. Marchbanks†
† Department of Medical Physics and Bioengineering, Southampton General Hospital, Southampton, Hampshire. SO16 6YD UK
‡ School of Mathematical Sciences, University of Nottingham, University Park, Nottingham. NG7 2RD UK

Abstract The accumulation of excess cerebrospinal fluid in the ventricles of the brain results in hydrocephalus, a condition that is fatal if left untreated. The usual remedy is to insert a shunt into the ventricles of the brain, which drains excess fluid away, moderated by a pressure dependent valve. It is important that the system functions properly so that a reasonable intracranial pressure is maintained. Unfortunately, pressure measurements in the ventricles are highly invasive, while pressure measurements in the shunt outside the skull may not detect any blockage in the catheter inside. Here we develop a model primarily aimed at detecting in vivo a blockage and other shunt malfunction using noninvasive measurements, so that shunt valves can be adjusted accordingly. The system offers a clear insight into how currently available clinical measurements may be utilized. We then extend this to investigate the phenomenon of "chatter" (rapid opening and closing) and other mechanisms including intracranial pressure pulsatility. Although simple, the model offers a clear indication of what is required for successful regulation of both intracranial pressure and shunt flow.

Keywords hydrocephalus shunt, mathematical model, blockage detection, flow dynamics.

1 Introduction

1.1 Cerebrospinal fluid

Cerebrospinal fluid (CSF) is a watery liquid produced in the parenchyma, with approximately 60% from the choroid plexus. Normal production is at a constant rate of approximately 20ml/hr, although this varies from 14 to 36ml/hr. In healthy individuals, the CSF flows from the lateral ventricles into the third ventricles, down the audacity towards the sagittal sinus and the spinal sac. It is assumed that this is principally reabsorbed in the top of the cranial vault, through granulations near the sagital sinus, although recent studies suggest that several distinct CSF transport pathways may exist (Mollanji *et al.*, 2001). There is usually about 150ml of CSF in the intracranial space at any given time, of which 25ml is in the ventricles, 30ml in the spinal subarachnoid space and 75ml in the cerebral subarachnoid space.

1.2 Hydrocephalus

Hydrocephalus is a serious condition resulting from an excess of CSF in the ventricles of the brain. This may build up either over a long time or relatively quickly, and is usually the result of insufficient absorption (compared to production) of CSF; other causes include the blockage of drainage pathways by, for example, tumour growth . This leads to expansion of the ventricles, compression of the brain and, for non-infants, an increase in intracranial pressure (ICP), leading to the occlusion of circulation and cell death. To offset an increase