CEREBROSPINAL FLUID DRAINAGE DEVICES: EXPERIMENTAL CARACTERIZATION

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Abstract. *The hydrocephalus is a pathophisiology that due to the excess of cerebrospinal fluid in brain ventricles, and it can be caused by birth defects, brain abnormalities, tumors, inflammations, infections, intracranial hemorrhage and others. Hydrocephalus can be followed by significant rise of intracerebral pressure due to the excess of production of cerebrospinal fluid over the absorption, resulting in a weakening of intellectual functions, serious neurological damage (decreased movement, sensation and functions), critical physical disabilities and even death. A procedure for treatment involves the placement of a ventricular catheter into the cerebral ventricles to divert/drain the cerebrospinal fluid flow to a bag outside of the body - provisory treatment known as external ventricular drainage (EVD). Another option is the permanent treatment, internal ventricular drainage (IVD), that promote the cerebrospinal fluid drainage to other body cavity, being more commonly the abdominal cavity. In both cases, EVD and IVD, it is necessary to use of several types of neurological valves in order to control the flow of cerebrospinal fluid. So in the present work proposes the experimental hydrodynamic study about Harkey Roberts one way neurological valve, to verify their behavior when subjected to various pressure gradients found in the human body. The results showing a hydrodynamic feature specific.*

Keywords*: Hydrocephalus, Cerebrospinal fluid, Ventricular drainage.*

1. INTRODUCTION

Cerebrospinal fluid is also known as CSF, is an aqueous fluid and has characteristics be colorless, odorless and low concentration of cells and proteins. According to Adam *et al*. (2001), the cerebrospinal fluid fills the spaces intra and extra cerebral brain showing a stable ionic composition. Around 20% of all CSF the body be in foramen and in ventricles - intracerebral space and the other 80% is located in areas outside the brain, around the brain and the spinal cord, in accord to Fig. 1.

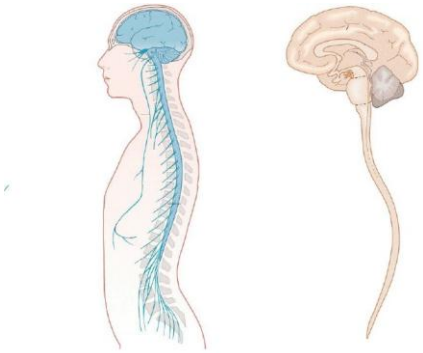

Figure 1. Structure of the brain and spinal cord in the human body (Adapted from Waxman, 2010).

Adam *et al.* (2001) e Irani (2009) show that the main purpose of cerebrospinal fluid is to protect the brain and the spinal cord from mechanical shocks, to regulate the ionic composition and too plays an important role in the biological protection of the nervous system, distributing nutrients, proteins and agents of defense against infections and carries away metabolites residues.

Healthy adult presents about 150 ml of CSF total volume flowing throughout its body in a continuous daily production rate between 400 and 500 ml (Carlotti Jr, Colli & Dias, 1998).

In accord to Camilo (2005), the cerebrospinal fluid is continually produced by a tissue called the choroid plexus situated in the lateral cerebral ventricles. Most of the cerebrospinal fluid is produced by first and second ventricle (called lateral ventricles - one in each hemisphere of the brain), where having a large fraction of the choroid plexus. The Figure 2 illustrates the path of the cerebrospinal fluid. After being produced, and fill the lateral ventricles, passes into the third ventricle through a small aperture called the foramen of Monro (very small brain orifice). Thus, the third ventricle (single cavity situated in the center of the brain) is filled with liquid deposited and joins a small volume produced locally. After, the CSF flows, continuing its path by the aqueduct of Sylvius into the fourth ventricle (small cavity on the back of the brain). The fourth ventricle also has the choroid plexus, but very low, their importance is the fact contain the foramen Lushka and Magendie, which are the output openings of all cerebrospinal fluid produced in the brain. Next, the CSF bathes the outer surface of the brain (with its several cavities) and spinal cord. After this long way, from the interior to the surface of the brain, the fluid is absorbed in small structures called arachnoid granulations (venous absorption).

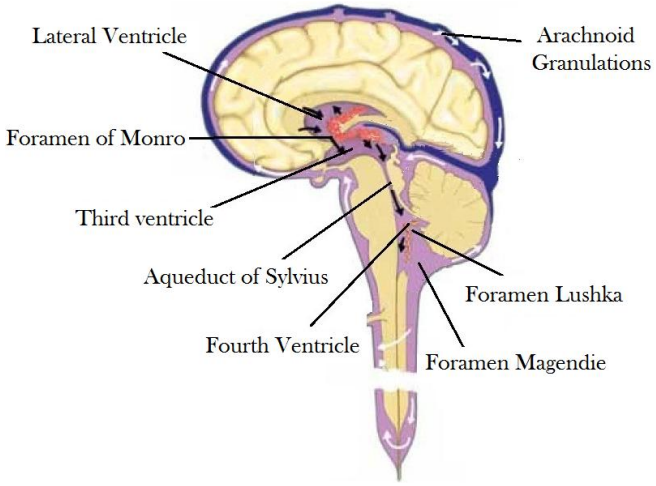

Figure 2. Path of Cerebrospinal Fluid (Adapted from Rohkamm, 2004).

There is a natural balance between production and absorption of cerebrospinal fluid, in other words, the same volume which is produced in one part of the brain should match that is absorbed elsewhere. The hydrocephalus occurs when there is a disturbance in cerebral spinal dynamics (lock in your flows, decreased ability to absorb or overproduction) implying, in general, the accumulation of CSF in the ventricles. The hydrocephalus can be followed by significant rise of intracerebral pressure (ICP) due to the excess of cerebrospinal fluid in brain ventricles (Souza et al., 2007).

Hydrocephalus is a pathophisiology that affects both adults and children, and it can be caused by congenital malformations, brain anomalies, tumors, inflammations, infections, encephalitis, intracranial hemorrhages, subdural or epidural hematoma, abscess, traumatisms and other (Camilo, 2005).

The hydrocephalus may result in a weakening of intellectual functions, serious neurological damage (decreased movement, sensation and functions), critical physical disabilities and even death.

After the diagnosis of hydrocephalus, there are some surgical options for treatment. A of the procedure for treatment involves the placement of a ventricular catheter into the cerebral ventricles to divert/drain the cerebrospinal fluid flow to a bag outside of the body - provisory treatment known as external ventricular drainage (EVD). Another option is the permanent treatment, internal ventricular drainage (IVD), that promotes the cerebrospinal fluid drainage to other body cavity, being more commonly the abdominal cavity. In both cases, EVD and IVD, it is necessary to use a neurological valve to control the flow of cerebrospinal fluid.

According to Sood, Canady & Ham (1998), since 1960, when the shunt (drainage procedure of cerebrospinal fluid) was created, the mortality rates by hydrocephalus suffered a decline of 54% to only 5%, while the loss of brain skills of patients decreased from 62% to 30%.

In this present work is study a one-way neurological valve, known as Harkey Roberts valve, designed to work outside the body - external ventricular drainage. Since that the hydraulic resistance direct influences to the valve performance, it is necessary to study its behavior at different pressure gradients, present in the human body, this way it is possible to determine the valve's coefficients of pressure loss, in order to determine the possible application in external drainage systems.

2. EXPERIMENTAL APPARATUS

There an small number of publications available in technical literature showing experimental apparatus for testing of neurological valves.

The Figure 03 shows a simplified sketch of the experimental apparatus utilized in this work, based in work of Drake e Sainte-Rose (1994), which consists of: a Mariotte bottle (A) adequately placed on a sensible digital balance (B) – Marte balance model AS 2000 – with ± 0.005 g of accuracy of read and measurement up to 5000 g. An electronic digital chronometer made by Cronobio model SW2018 with an uncertain of read of ± 0.01 s directly coupled in the balance permits to determine the instantaneous mass flow rate. The liquid inside the Mariotte bottle is continuously drained to the reservoir (D) through a stainless steel rigid tube with 2.5 mm of internal diameter and 1.0 m of length. First flow is measured for various pressure gradients (usually found in the treatment of hydrocephalus), and therewith is determined the friction factor of the rigid pipe. Posteriorly, the same procedure is realized with the presence of neurological valve (F) to determine its load loss coefficient. Throughout the process of data acquisition the temperature of the fluid is continually measured by means of a digital thermometer (E) Minipa MT 40IA with ±0.5 ^{o}C of dial indicator uncertain with a range of - 50 ^{o}C ~ 750 ^{o}C. The Mariotte bottle is a device utilized for small liquid flows able to remain a constant exit pressure, and consequently, a constant flow rate in the exit, regardless the level changes of liquid inside the bottle. All instruments utilized have been adequately evaluated in order to determine the uncertain..

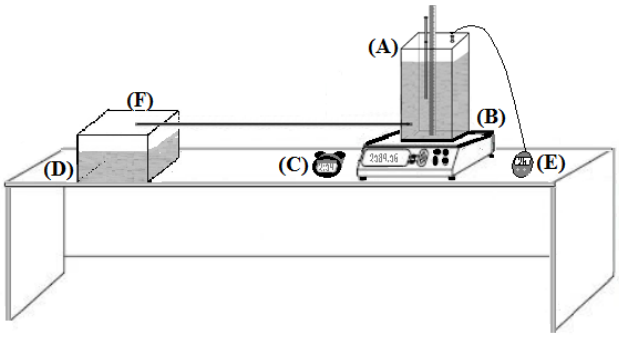

Figure 3. Schematic of experimental apparatus (Bim, 2012).

3. RESULTS AND CONCLUSIONS

Initially tests were performed using several pressure gradients equivalent to ICP, ranging from 04 to 24 cmH_2O, without the valve. Thus, it was calculated the friction factor (*f*) of the rigid pipe experimentally, using the Eq. (1), and theoretically by Hagen and Poiseuille, using the Eq. (2), valid for steady laminar flow inlet tubes (Reynolds numbers less than 2100) of newtonian fluids having a fully developed velocity profile (Fox &McDonald, 1995).

The results are depicted in Fig. 04, where the blue line represents what was obtained using the first equation and the red line represents which was obtained using the second equation. The graphic shows that there is a significant difference between the values of friction factor obtained through of equations, especially when the Reynolds number increases.

$$g\left(z_1 - z_2\right) - \alpha \frac{V_2^2}{2} = f \frac{L}{D} \frac{V^2}{2} + k_E \frac{V^2}{2} \tag{1}$$

$$f = \frac{64}{\mathrm{Re}} \tag{2}$$

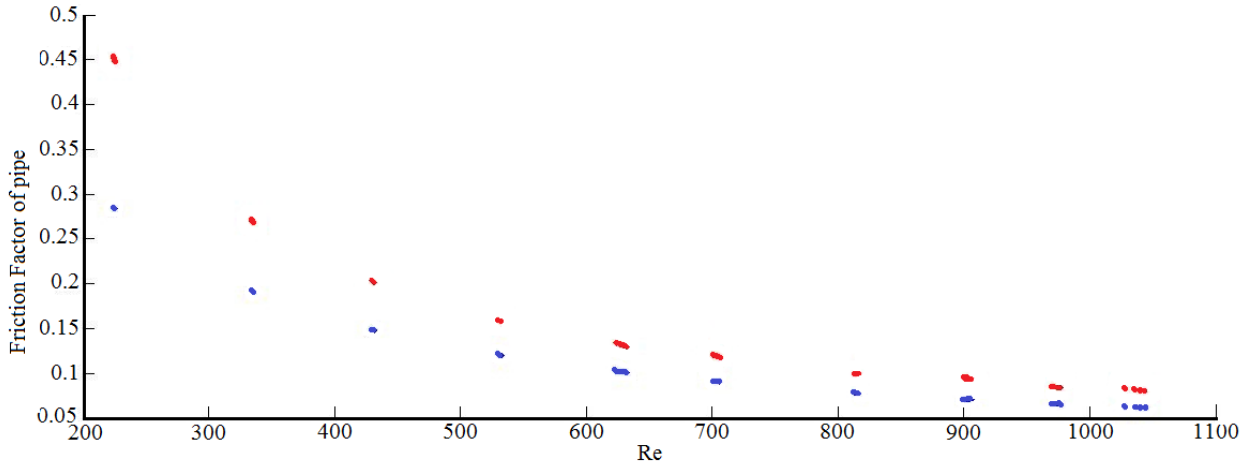

Figure 4. Friction factor of pipe *x* Re.

Knowing the friction factor of the pipe, it was possible to obtain the load loss coefficient (k_v) of Harkey Roberts valve, Eq. (3), when subjected to different pressure gradients.

The results of load loss coefficient of valve in function of log (Re) are shown in Fig. 5.

$$g\left(z_1 - z_2\right) - \alpha \frac{V_2^2}{2} = f \frac{L}{D} \frac{V^2}{2} + k_E \frac{V^2}{2} + k_V \frac{V^2}{2} \tag{3}$$

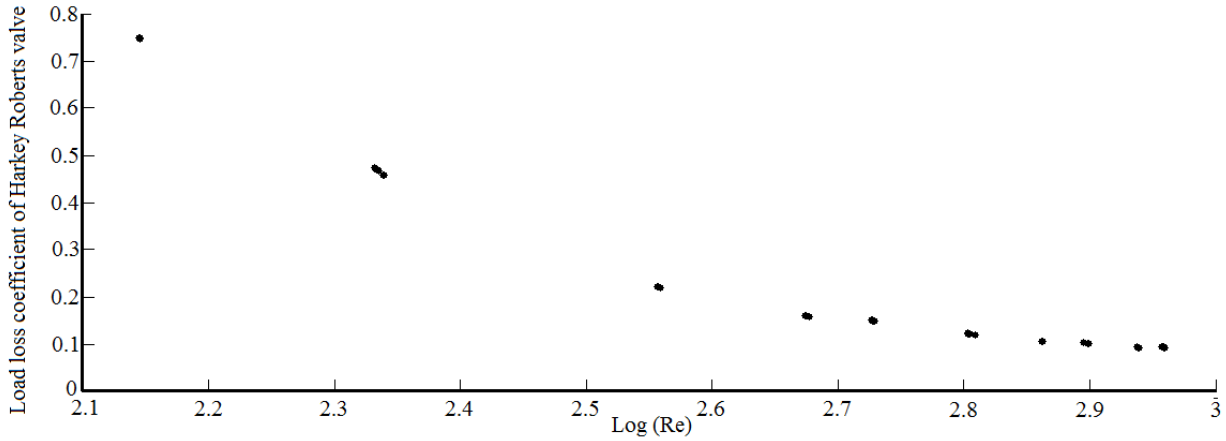

Figure 5. Load loss coefficient of Harkey Roberts valve *x* Log (Re).

Figure 6 shows the values of ΔP (pressure variation given by Mariotte bottle) in function of number of Reynolds for flow without the presence of valve (red curve) and flow with the presence of valves (blue curve). These values are used to obtain the pressure variations at the inlet and outlet of the valve (ΔP_{valve}).

With the values of the pressure variation of valve (ΔP_{valve}), shown in Fig. 6, it is possible to obtain the graphic $\Delta P/\rho$ *x* $V^2/2$, Fig 7, that allows calculating the tangent of the angle (α) of inclination of straight, obtained the value of load loss coefficient (k_v) of the Harkey Roberts valve, Equation (4).

$$tg\alpha = k_v = \frac{y_2 - y_1}{x_2 - x_1} \tag{4}$$

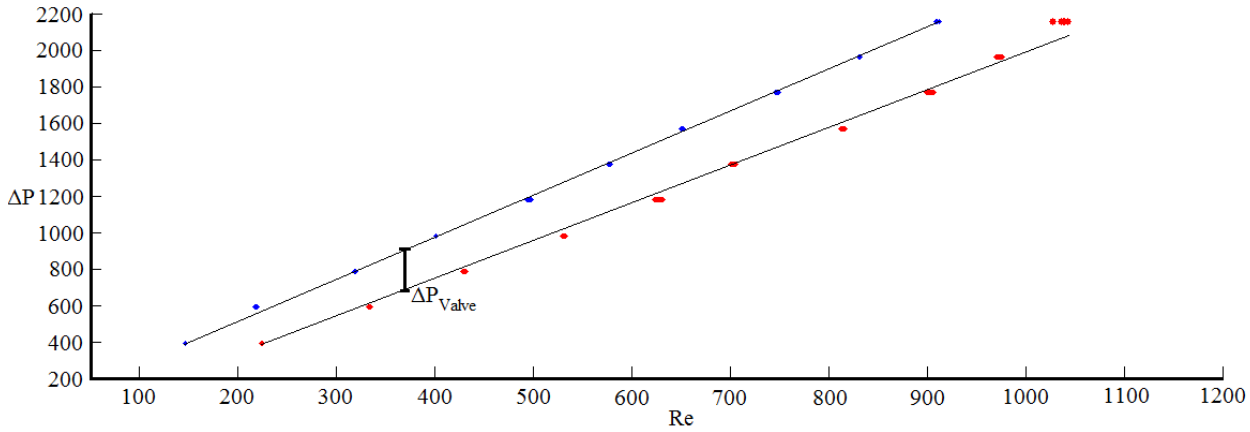

Figure 6. Pressure variation (ΔP) *x* Re.

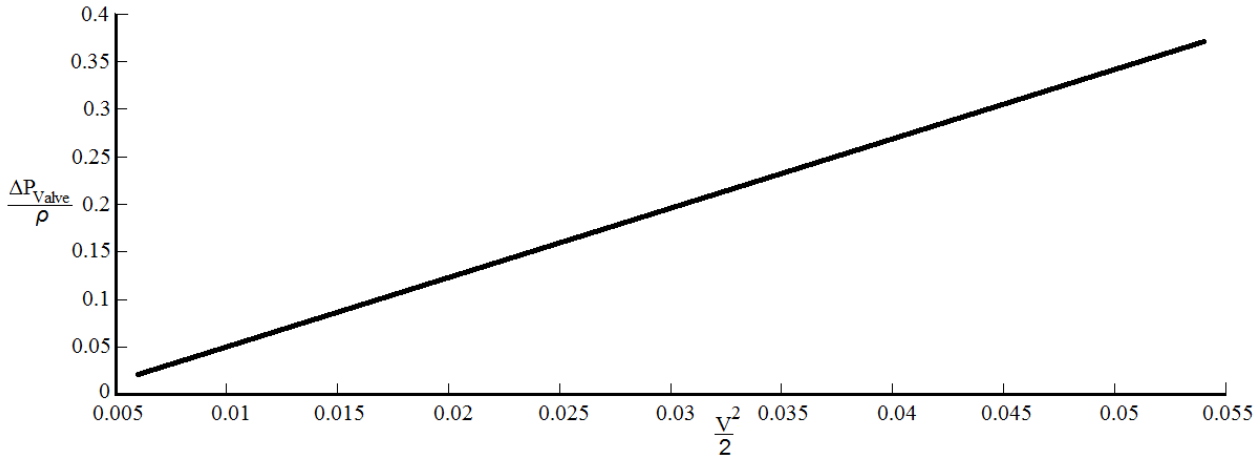

Figure 7. $\Delta P_{valve}/\rho$ *x* $V^2/2$ of the Harkey Roberts valve.

The value obtained of the load loss coefficient (kv) of the Harkey Roberts valve, by Eq. (4), was 7,1. This value is considered of quality for external drainage of CSF. Therefore, the results showing a hydrodynamic feature specific of the valve Harkey Roberts, where your behavior determine that is possible application in external drainage systems.

4. ACKNOWLEDGEMENTS

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