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HYDRODYNAMIC CHARACTERIZATION OF NEUROLOGICAL VALVES

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Abstract. *Within the cerebral ventriclesi it is continuously produced a colorless liquid with low concentration of cells and proteins, termed cerebrospinal fluid (CSF). Problems in the production or absorption of CSF may induce slight changes in intraventricular pressure (IVP), yielding a pathophysiology known as hydrocephalus. Hydrocephalus can occur in adults and children as a result of congenital malformations, brain anomalies, tumors, inflammations, infections, encephalitis, intracranial hemorrhages, subdural or epidural hematoma, abscess, traumatisms and other. An increase in IVP above critical values can produce irreversible brain damage, and may even cause the death of the patient. Following the diagnosis of hydrocephalus, there are few options for treatment. One procedure involves the placement of a ventricular catheter into the cerebral ventricles to bypass the CSF flow draining to another place. The drainage of the CSF from the cerebral ventricles to a bag outside the body is a provisory treatment known as external ventricular drainage (EVD). A permanent treatment is also possible by utilizing an implanted valve in order to promote the CFS drainage to another body cavity (IVD internal ventricular drainage). In both cases, an one-way check valve is utilized to flow control. Thus in the present work it is proposed a experimental hydrodynamic study about a neurological valve, to verify their behavior when subjected to various pressure gradients found in the human body in treatment of hydrocephalus. The results show a specific hydrodynamic feature for both the models.*

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

1. INTRODUCTION

The word hydrocephalus comes from the Greek "hydro" - water, and "cephalic" - head. The popular term "brain water" is currently utilized for cerebrospinal fluid (CSF), an aqueous fluid which has characteristics of being colorless, odorless, with low concentration of cells and proteins, about 20 mg/ml of proteins and presents a chemical composition very close to ultra filtrated plasma, Davson and Segal (1996).

According to Adam *et al*. (2001), the cerebrospinal fluid fills the intra and extra cerebral spaces showing a stable ionic composition. Around 20% of all CSF the body are 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.

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 also 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.

According to Camilo (2005), the cerebrospinal fluid is continually produced by a tissue called the choroid plexus situated in the cerebral ventricles, Figure 1.

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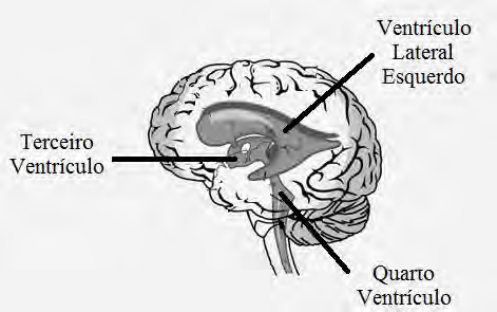

Figure 1. Cerebral ventricles.

Most of the cerebrospinal fluid is produced by the first and second ventricle (called lateral ventricles - one in each hemisphere of the brain), where there is a large fraction of the choroid plexus. After its production, and having filled the lateral ventricles, it passes into the third ventricle through a small aperture called the foramen of Monro (a very small brain orifice). Thus, the third ventricle (a single cavity situated in the center of the brain) is filled with deposited liquid 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 a very low quantity, their importance is the fact that it contains 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, Figure 2.

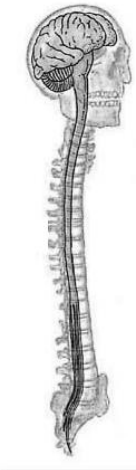

Figure 2. Structure of the brain and spinal marrow (Adapted of www.noticiasrn.com).

The cerebrospinal fluid shows an uninterrupted cycle of production, circulation and absorption. 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, Pople (2002) e Sotelo, Izurieta & Arriada (2001).

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.

Hydrocephalus occurs when there is an excessive imbalance between production and absorption of this fluid, this can happen due to a decreased ability to absorb or overproduction or when there is obstruction in the passage of liquid through the foramens (most common), causing a CSF accumulation inside the brain ventricles and consequently increasing internal brain pressure and also the intracranial pressure, Souza *et al*. (2007).

According to Carlotti Jr, Colli & Dias (1998), the intracranial pressure in a healthy person ranges from 5 to 15 mmHg and this is due to the relationship between the contents of the skull (brain, blood and CSF) and skull volume (considered constant).

Hydrocephalus can be congenital (present at neonates), due to genetic factors, brain malformation, or even by the baby being premature, and there is also acquired hydrocephalus resulting from infections, tumors, cysts, hemorrhages, meningitis, increased protein content in CSF, among other causes, Camilo (2005).

After the diagnosis of hydrocephalus, there are some surgical options for treatment, in order to drain the excess of the intracranial fluid. One of the procedures for treatment involves the placement of a ventricular catheter into the cerebral ventricles to divert/drain the cerebrospinal fluid flow to a bag outside the body - provisory treatment known as external ventricular drainage (EVD). Another option is the permanent treatment, internal ventricular drainage (IVD), that

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promotes the cerebrospinal fluid drainage to other body cavity, 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. These procedures can result in several complications; besides the risk of infection, there is also the problems such as when the liquid is not removed quickly enough, or when the amount of CSF drained from the ventricles is higher than its production.

The death rates associated with the control of ICP decreased from 54 % to 5 % and the occurrence of intellectual disability has decreased from 62 % to 30 %, Sood *et al*. (2001).

Given this, this present work studies a one-way neurological valves, known as Vernay I valve and Vernay II valve, designed to work outside the body - external ventricular drainage. Since the hydraulic resistance direct influences the valve performance, it is necessary to study its behavior at different pressure gradients, present in the human body, then 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

Despite the relatively large number of projects about neurological valves, few studies in the literature present a description of the experimental mounting used for testing CSF drainage devices. Usually the works in the area of cerebrospinal fluid drainage devices involve research about the clinical picture of patients with these implants, treatment monitoring and related features to malfunction, as can be seen in the work of Walchenbach *et al*. (2002), Kajimoto *et al.* (2000), Pudenz and Foltz (1991), Boon *et al*. (1997), Sotelo, Izurieta and Arriada (2001), Eide (2003), Murtagh, Quencer and Poole (1980), among many others that do not show anything about the experimental apparatus utilized.

Figure 3 shows a simplified sketch of the experimental apparatus, based in work of Drake e Sainte-Rose (1994), that consists in a Mariotte bottle (b) adequately placed on a sensible digital balance (a) – with ± 0.005 g of reading accuracy and measurement up to 5000 g. An electronic digital chronometer made by Cronobio model SW2018 with an uncertainty of reading of ± 0.01 s directly coupled in the balance allows determining 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 (c). Firstly, 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 the neurological valve 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 – 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 maintain 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 uncertainty.

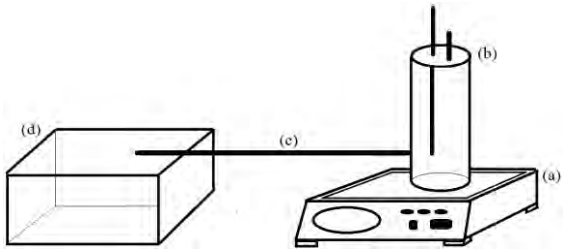

Figure 3. Schematic of experimental apparatus.

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), dimensionless, of the rigid pipe experimentally, using the Eq. (1), where the gravitational acceleration (g) is utilized as the conventional value of 9,807 m/s^2, the level difference can be calculated by $z_1 - z_2 = \Delta h$, α is kinetic energy coefficient and in the end of the tube values of α can be accepted very close to 1.0, the mean flow speed (V_1) inside the Mariotte bottle is zero and the mean flow speed in the end of the tube (V_2) can be calculated by the volumetric flow rate divided by the cross section area of the tube, L is the length and D is the diameter of the tube and the value of k (load loss coefficient) in the inlet of the tube (k_E) in accordance to Fox &McDonald (1995) is conventionally equal to 0.8.

Also was calculated the friction factor (f) of the rigid pipe, theoretically, by Hagen and Poiseuille, using Eq. (2), where Re is the Reynolds number, valid for steady laminar flow inlet tubes (Reynolds numbers less than 2100) of newtonian fluids having a fully developed velocity profile (Fox &McDonald, 1988).

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The results are depicted in Figure 4, 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 equations, especially when the Reynolds number decreases.

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

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

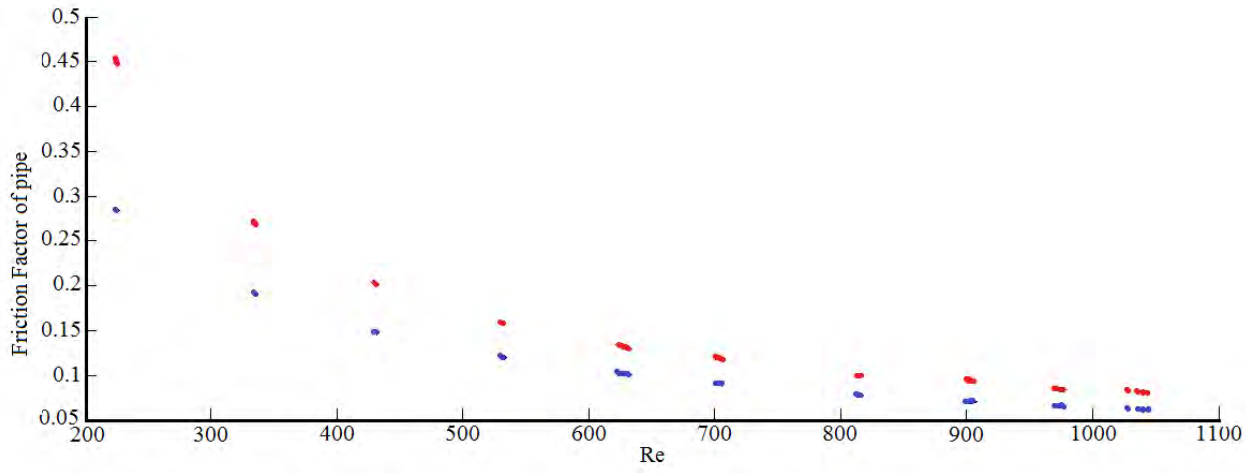

Figure 4. Friction factor of pipe *x* Re.

The Figure 5 shows the values of friction factor (*f*) of the rigid pipe also calculated experimentally, Eq. (1), and theoretically by Hagen and Poiseuille, Eq. (2), in function of the pressure dimensionless, Eq. (3). The results shows a large difference between the equations experimental and theoretical.

$$P_{ad} = \frac{\Delta P}{\rho V^2} \tag{3}$$

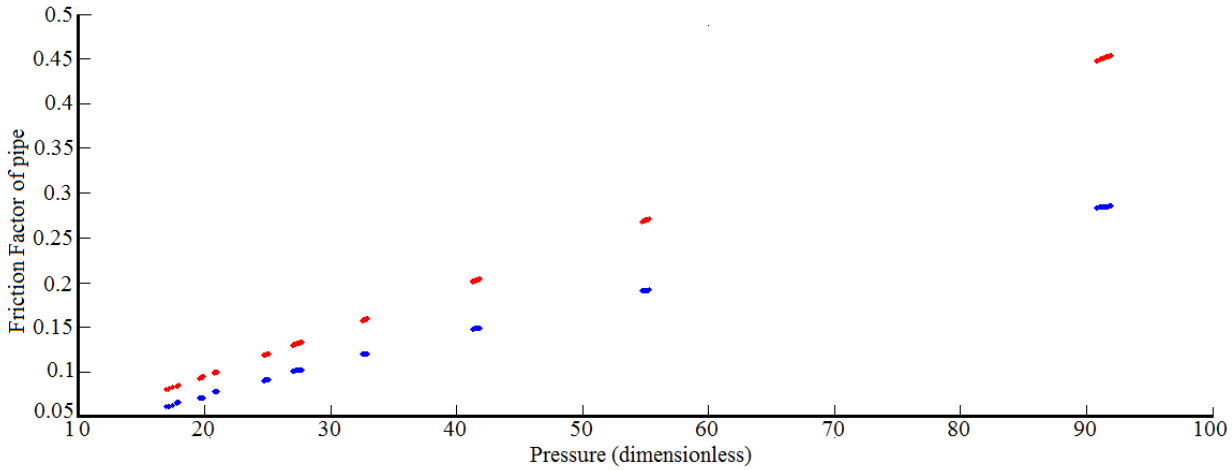

Figure 5. Friction factor of pipe *x* Pressure (dimensionless).

Acknowledging the friction factor of the pipe, it was possible to obtain the load loss coefficient (k_v), dimensionless, of the neurological valves, Equation (4), when subjected to different pressure gradients (04 to 24 cmH_2O).

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The results of load loss coefficient of valves in function of log (Re) are shown in Figure 6 and Figure 7 being, respectively, of the Vernay I valve and Vernay II valve.

$$g\left(z_1 - z_2\right) - \alpha \frac{V_2^2}{2} = f \frac{L}{D} \frac{V^2}{2} + k_E \frac{V^2}{2} + k_V \frac{V^2}{2} \tag{4}$$

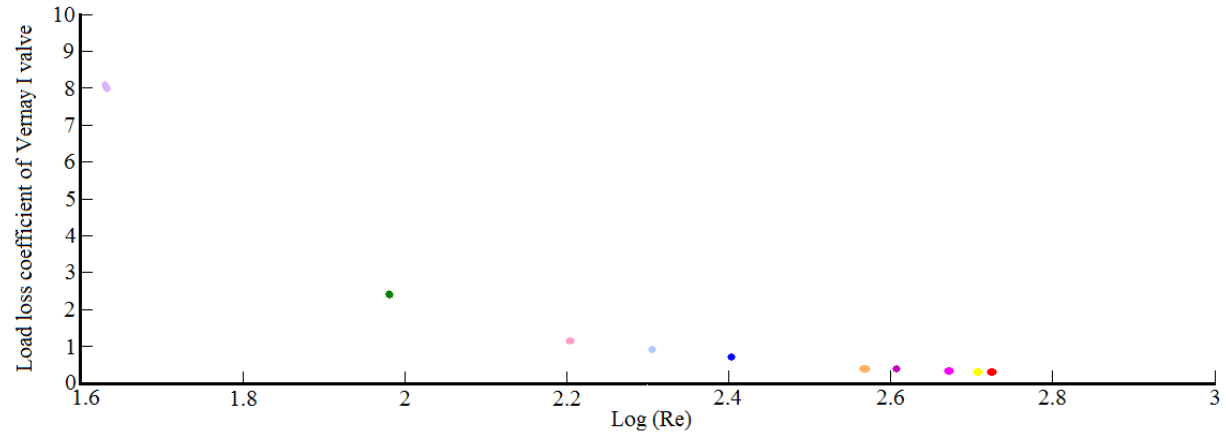

Figure 6. Load loss coefficient of Vernay I valve *x* Log (Re).

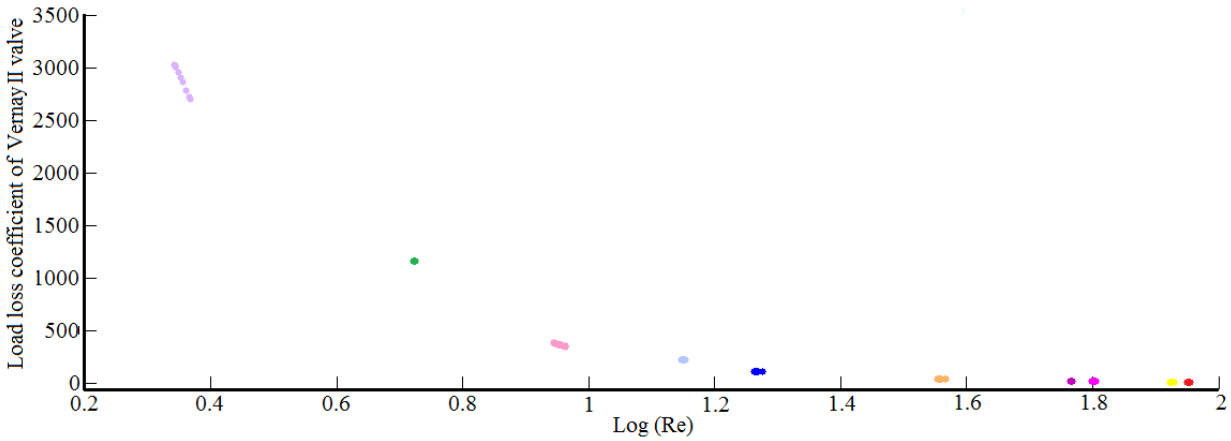

Figure 7. Load loss coefficient of Vernay II valve *x* Log (Re).

The results show a hydrodynamic feature specific for each device, where its behavior determine that it is a possible application in external drainage systems.

4. ACKNOWLEDGEMENTS

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5. REFERENCES

Adam, P., Táborský, L., Sobek, O., Hildebrand, T., Kelbich, P., Prucha, M. & Hyánek, J., 2001. "Cerebrospinal fluid", Academic Press, Vol (36), 62 p.

Boon, A. J. W., Tans, J. T. J., Delwel, E. J., Egeler-Peerdeman, S. M., Hanlo, P. W., Wurzer, H. A. L., Avezaat, C. J. J., Jong, D. A., Gooskens, R. H. J. M., Hermans, J., 1997. "Dutch normal pressure hydrocephalus study: prediction of outcome after shunting by resistance to outflow of cerebrospinal fluid", Journal of Neurosurgery, Rolling Meadows, v. 87, n. 5, p. 687-693.

ISSN 2176-5480

Camilo, J. R., 2005. "Simulação Hidrodinâmica e Caracterização Experimental de Mecanismos Anti-sifão em Sistemas de Drenagem Externa de Líquido Cefalorraquidiano", Dissertação de Mestrado apresentado a UNESP Ilha Solteira/SP.

Carlotti Jr, C. G., Colli, B. O. & Dias, L. A. A., 1998. "Hipertensão Intracraniana", Simpósio: Medicina Intensiva, Ribeirão Preto - SP.

Davson, H., Segal, M. B., 1996. "Physiology of the CSF and Blood-Brain Barriers", 1ª ed. New York: CRC Press, 832 p.

Drake, J. M., Sainte-Rose, C.,1994. "The shunt book", Cambridge: Blackwell Science, 228 p.

Eide, P. K., 2003. "Quantitative analysis of continuous intracranial pressure recording in symptomatic patients with extracranial shunts", Journal of Neurological Neurosurgery Psychiatry, London, v. 74, n. 2, p. 231-237.

Fox, R. W., McDonald, A. T, 1988. "Introdução à mecânica dos fluidos". 3. ed. Rio de Janeiro: Guanabara, 632 p.

Irani, D. N., 2009. "Cerebrospinal Fluid in Clinical Practice", Philadelphia: Saunders Elsevier, 317 p.

Kajimoto, Y., Ohta, T., Miyake, H., Matsukawa, M., Ogawa, D., Nagao, K., Kuroiwa, T., 2000. "Posture-related changes in the pressure environment of the ventriculoperitoneal shunt system", Journal Neurosurgery, Rolling Meadows, v. 93, n. 4, p.614-617.

Murtagh, F. R., Quencer, R. M., Poole, C. A, 1980. "Extracranial complications of cerebrospinal fluid shunt function in childrenhood", American Journal of Roentgenology, Leesburg, v. 135, n. 4, p. 763-766.

NotíciasRN, 28 May 2013 <www.noticiasrn.com>.

Pople, I. K., 2002. "Hydrocephalus and shunts: what the neurologist should know", Journal of Neurological Neurosurgery Psychiatry, Vol. 73, pp. i17 - i22.

Pudenz, R. H., Foltz, E. L., 1991. "Hydrocephalus overdrainage by ventriculas shunts", Surgical Neurology, Philadelphia, v. 35, n. 3, p. 200-212.

Sotelo, J.; Izurieta, M.; Arriada, N., 2001. "Treatment of hydrocephalus in adults by placement of an open ventricular shunt", Journal of Neurosurgery, Rolling Meadows, v. 94, n. 6, p. 873-879.

Souza, H. de, Doutel, F., Borges, C. A., Azevedo, R. G. de, Oliveira Jr., W. & Ribeiro, C. H., 2007. "Hidrocefalia Aguda Essencial", Arquivos Brasileiros de Neurocirurgia, Vol. 26(2), pp. 53 - 59.

Walchenbach, R., Geiger, E., Thomeer, R. T. W. M., Vanneste, J. A. L., 2002. "The value of temporary external lumbar CSF drainage in predicting the outcome of shunting on normal pressure hydrocephalus", Journal of Neurology, Neurosurgery and Psychiatry, London, v. 72, n. 4, p. 503-506.

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