CHECK VALVES IN NEUROLOGICAL APPLICATIONS

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Abstract. *Hydrocephalus is a pathophisiology of adults and children caused by congenital malformations, brain anomalies, tumors, inflammations, infections, encephalitis, intracranial hemorrhages, subdural or epidural hematoma, abscess, traumatisms and other. Hydrocephalus can be followed by significant rise of intracerebral pressure (ICP) due to the excess of production of cerebrospinal fluid (CSF) over the absorption, resulting in permanent brain injury and death. Following the diagnosis of hydrocephalus, there are few options other than surgery for treatment. A procedure involves the placement of a ventricular catheter into the first cerebral ventricles to bypass the CSF flow draining to other place. The channel the CSF from the cerebral ventricles to a bag outside of the body is a provisory treatment known as external ventricular drainage (EVD). A permanent treatment is also possibly utilizing an implanted valve in order to promote the CFS drainage to other body cavity -more commonly the abdominal cavity - (IVD internal ventricular drainage). In both cases, (EVD or IVD) several precautions should be employed in order to minimize the reverse flow preventing an accidental return of the drained CSF to the brain. In the present effort of work one-way valves (also named check valve) utilized in CSF IVD systems have been tested in order to verify the occurrence of reverse flow (or regurgitation) while submitted to a wide range of adverse pressure gradients levels. Experiments have been carried out in an apparatus for testing complete shunt systems or part of shunts revealing acceptable regurgitation levels.*

Keywords*: Hydrocephalus, Cerebrospinal fluid, CSF, Ventricular drainage, ventriculo-peritonial shunt*

1. INTRODUCTION

The cerebrospinal fluid (CSF) provides mechanical support of the brain and acts like a protective water jacket. CSF control too brain excitability by regulating the ionic composition, carries away metabolites (because the brain has no lymphatic vessels), and provides protection against pressure changes (Waxman, 2010). Normal CSF is clear, colorless and odorless and presents a chemical composition very close to ultra filtrated plasma. The internal portion of the cerebral spinal fluid system (CSFS) consists of two lateral ventricles, the interventricular foramens, the third ventricle, the cerebral aqueduct and the fourth ventricle, in accord to Fig. 1 - left side. The external part of CSFS consists of the subarachnoid spaces and cisterns (the subarachnoid space is a cavity that cover the brain and spinal cord, bounded externally by a fine arachnoid membrane and internally by the surface of the brain), depicted in Fig. 1 – right side - the arrows show the CSF flow direction. Communication between the internal and external portions of CSFS occurs through the lateral apertures of the fourth ventricle (foramen of Magendie). The CSF is continually produced inner the lateral ventricles flowing to the third and fourth ventricle and after this to the external portion of the CSFS through the foramen of Magendie. In adults, the total volume of cerebral spinal fluid in all the spaces combined is normally about 150 ml. Between 400 and 500 ml of CSF is produced and reabsorbed daily. Problems due to absorption or production of CSF or an obstruction of the small cannels between the ventricles (foramens) produces uncontrolled variations of the intracerebral pressure (ICP) know as hydrocephalus. Rise of ICP to dangerous levels produces severe brain injure resulting in death and the few survivors shows several physical and mental disabilities. In order to restore a normal ICP few options other than surgery for treatment. CSF shunting permits to channel the fluid from the cerebral ventricles to other sites resulting in acceptable ICP levels. Since 1960, when cerebral shunts were first introduced, death rates associated with no controlled ICP decreased from 54 % to 5 % and the occurrence of intellectual disability has decreased from 62 % to 30 %. – Sood *et al*. (2001).

The channel the CSF from the cerebral ventricles to a bag outside of the body is a provisory treatment known as external ventricular drainage (EVD). A quasi permanent treatment is also possibly utilizing implanted valves in order to promote the CFS drainage to other body cavity - more commonly the abdominal cavity - (IVD internal ventricular drainage). A special catheter implanted inner the lateral ventricle drainage the exceeded CSF out the brain. Several types of mechanical valves positioned in the end of the catheter control the flow and remain the ICP close to normal values independently of the physiological conditions of the patient. Today, drainage control valves operate only by mechanical effects without electronic control.

In both cases, (EVD or IVD) several precautions should be employed in order to minimize the reverse flow preventing an accidental return of the drained CSF to the brain. Provisory EVD systems employing membrane check valves have been intensely availed by Camilo *et al*. (2007). Membrane check valve are adequate to EVD because this relative large volumetric dimensions. Unfortunately implanted devices should present very small dimensions, no permitting the use of membrane check valves in IVD systems. In the present work, small ball check valves are test in order to estimate the regurgitation and to prevent the reverse flow for IVD system applications.

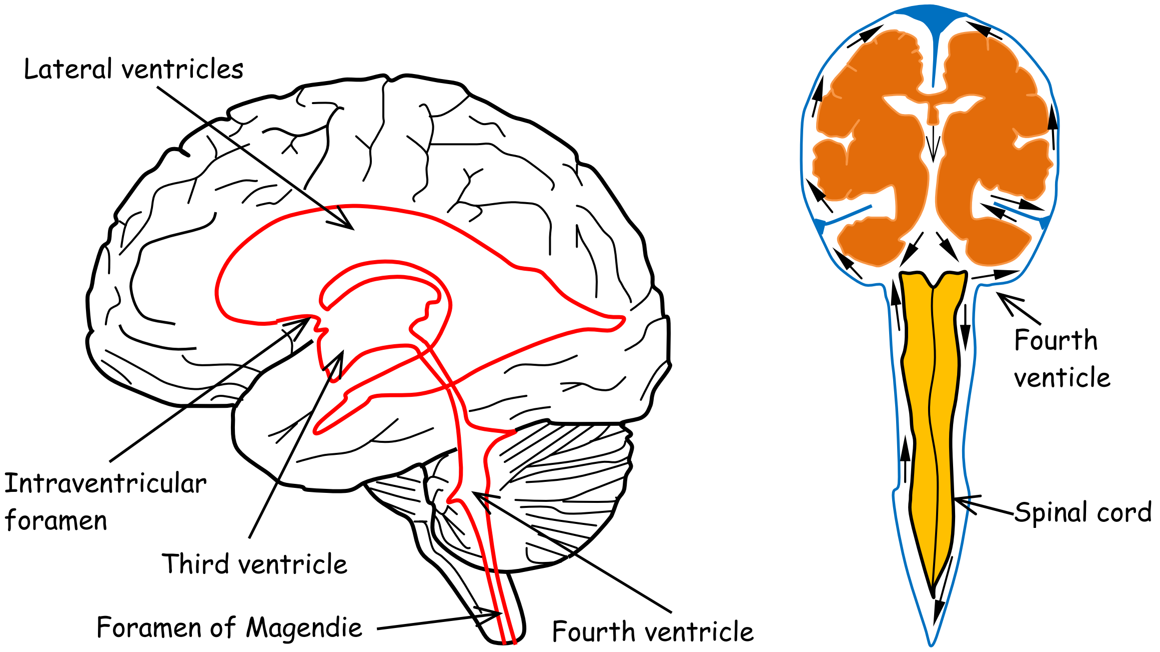


Figure 1. Schematic representation of the cerebral spinal fluid system, adapted of Martin, (2003).

2. EXPERIMENTAL APPARATUS

Several apparatus for testing shunt systems can be found in technical literature showing several conceptions of devices to performing test in valves shunts involving sophisticated devices utilizing infusion pumps and electronic measurements of pressure and volumetric flow. The work of Camilo (2005) shows several shunt test systems. The test device, sketched in the fig. 2, has been utilized in the present effort of work, and is composed by an elevating mechanism (A) to apply vertical movement to a platform (B) with controlled velocity by means a pass motor (C) interlinked to a micro computer (D). The flow is drained to a reservoir discharge localized in the platform (B). A drain permits to evacuate the reservoir previously to begin of the test. A digital balance (E) - Mars Balanças model AS 2000 - with ±0,005 g of measured accuracy equipped with a RS232C interface permits a continuum record the mass drained with the time of the reservoir. The reservoir is a well know Mariotte bottle, an ingenious device able to keep the pressure output constant independent of the liquid level inside the bottle. The Mariotte bottle supplies the liquid flow dependent only of the loss of pressure. Constructive details about Mariotte bottle and other details of the present device can be found on the work of Camilo (2005). For small flow rates the digital balance and the Mariotte bottle can be substituted by an infusion pump.

The physical characteristics of CSF, especially the density, are near to ultra centrifuged plasma. In the present work we employed bi-distillated water in ambient temperature as work fluid. The present device permits to obtain reliable measurements of the mass flow internal to the ball check valve in function of the differential pressure and data acquisition is automatically realized. This automated test permits to obtain rapid and precise results.

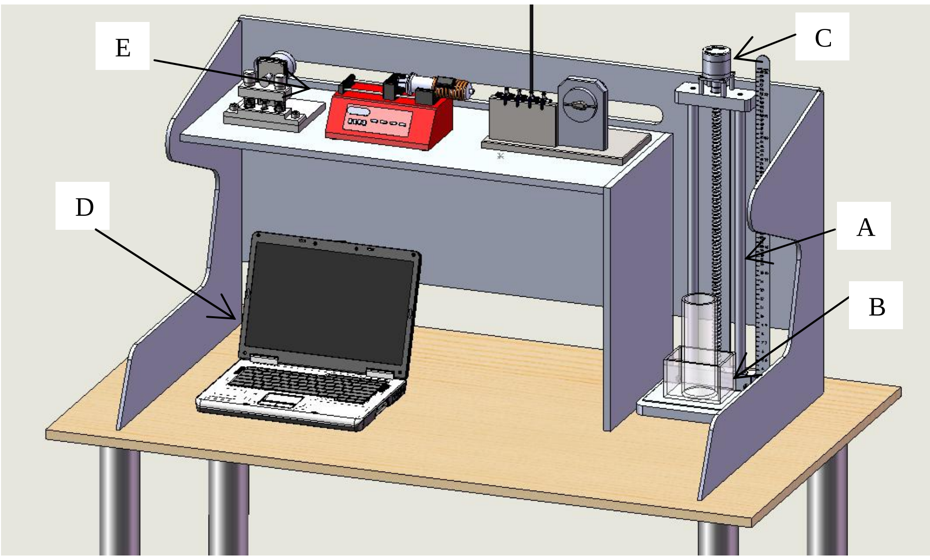
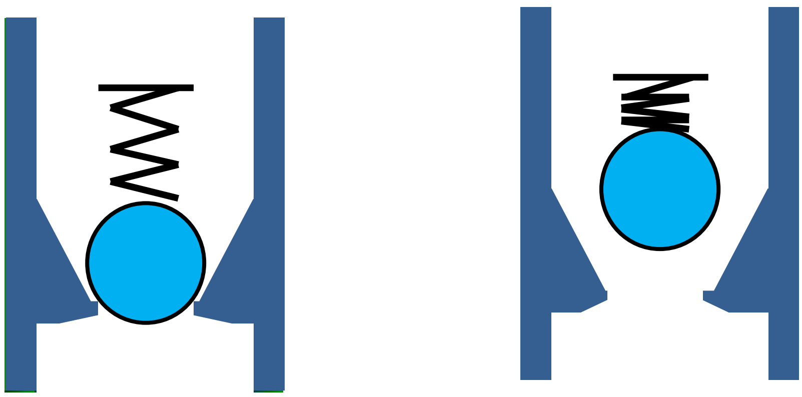


Figure 2. Schematic view of the experimental apparatus.

3. RESULTS

Several models of one-way valves (also known as unidirectional or check valve) have been available in the technical literature utilized in many types of mechanical devices in order to avoid reverse flow (reflux or regurgitation). A check valve is a mechanical device that allows the flow only in one direction. This device, generally, are composed of two-port valves, one to fluid entrance and other to fluid leaves to output. One-way valves have been many applications, since they work automatically and are not controlled by external control. Heart valves are essentially inlet and outlet check valves, since the heart ventricles act as a pump. Several design conceptions are available for one-way valves for fluid applications; the best known being the ball valves which operates with the help of a spring and a spherical ball. If higher pressure acts from downstream (non favorable pressure gradient), the spherical ball is compressed against their seat by action of the spring shutting off the valve. In opposite, if high pressure of upstream (favorable pressure gradient) the spherical ball is compressed against the spring and a small gap rise in their seat opening the valve. A scheme of a ball valve is showed in Fig. 3



Adverse pressure gradient - closed Favorable pressure gradient - open

Figure 3. typical ball and spring valve.

In consequence of their mechanical construction, in the closing process of a one-way valve necessarily regurgitation or reflux occurs. In the present word a unidirectional micro valve (only 2 mm of external diameter) has been submitted to several levels of pressure gradient (measured with 1.0 % of uncertainty) and a flow rate measured 0.12 % of uncertainty

The preliminary test, showed in Fig. 4, has been carried out utilizing a starting ICP of 50 mm of water column. The pressure upstream the micro valve is considered in this present work equivalent to ICP). The pressure downstream begin in -150 mm of water pressure and finish in +50 mm in a rapid rise of pressure (one minute of duration) showing the mass internal the Mariotte bottle measured in grams. In the Fig. 5, for ICP also equal to 50 mm of water column the pressure downstream the ball valve rises from -150 mm to + 50 mm of water column slowly in a temporal variation of 12 minutes.

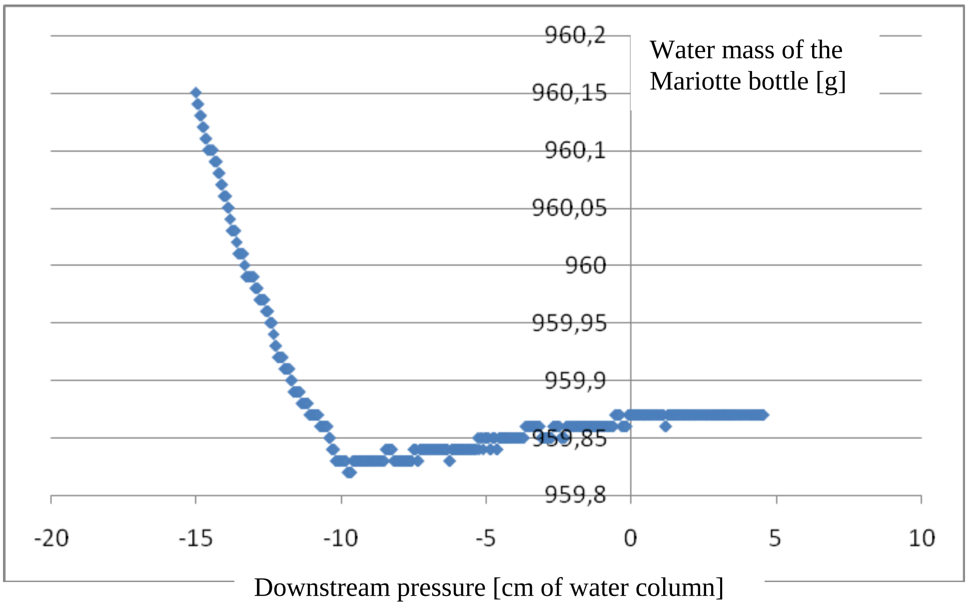


Figure 4. Mass internal the Mariotte bottle measured in grams in function of downstream pressure (cm of water column) for a rapid rise (ICP = 50 mm water column).

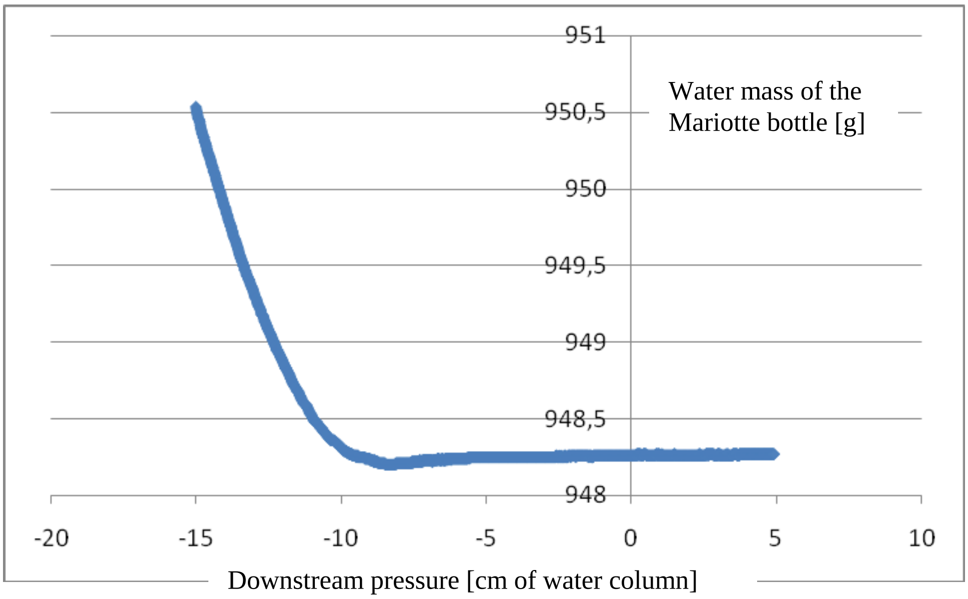


Figure 5. Mass internal the Mariotte bottle measured in grams (g) in function of downstream pressure (cm of water column) for a slowly rise (ICP = 50 mm water column).

Fig. 4 and 5 is relative to an ICP (upstream pressure) only of 50 mm of water column and the downstream pressure change from -150 mm to +50 mm of water column. In Fig. 4 the pressure downstream rise in relative rapid velocity (about 1 minute of duration) and several instabilities can be visualized in the mass internal the Mariotte bottle resultant in an appreciable regurgitation. In opposition, in Fig. 5 for a slowly velocity of pressure rise the regurgitation is very small and the valve is closed without instabilities.

In Fig. 6 and 7, experiments have been carried out utilizing an equivalent ICP of 100 mm of water column. The pressure downstream begin in -150 mm of water pressure and finish in +50 mm in a rapid rise of pressure less than 2 minutes of duration showing the mass internal the Mariotte bottle measured in grams (Fig. 6). In the Fig. 7, the pressure downstream the ball valve rises too from -150 mm to + 50 mm of water column slowly in a temporal variation of 26 minutes.

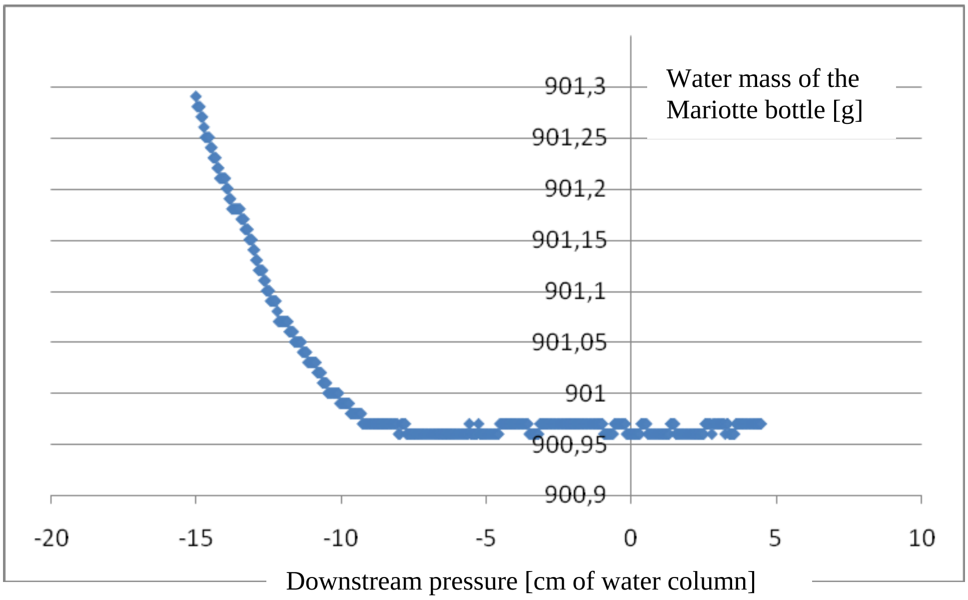


Figure 6. Mass internal the Mariotte bottle measured in grams (g) in function of downstream pressure (cm of water column) for a rapid rise (ICP = 100 mm water column).

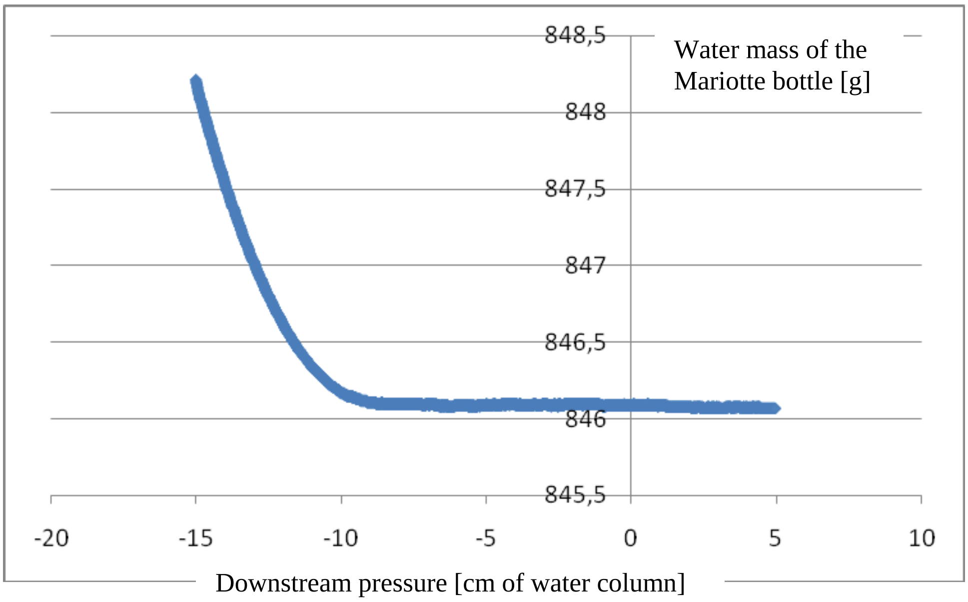


Figure 7. Mass internal the Mariotte bottle measured in grams (g) in function of downstream pressure (cm of water column) for a slowly rise (ICP = 100 mm water column).

In Fig. 6 the pressure downstream rise in relative rapid velocity (about 2 minute of duration) and several instabilities can be also visualized in the mass drained resultant in a non appreciable regurgitation. In other side, Fig. 7 for a slowly velocity of pressure rise (26 minutes) the regurgitation is practically null and the valve is closed without instabilities.

In Fig. 8 and 9, the equivalent ICP is maintained in 150 mm of water column. In the Fig. 8 the pressure downstream begin in -150 mm of water pressure and finish in +50 mm in a rapid rise of pressure less than 2 minutes of duration showing the mass internal the Mariotte bottle measured in grams. In the Fig. 9, the pressure downstream the ball valve rises too from -150 mm to + 50 mm of water column slowly in a temporal variation of 26 minutes.

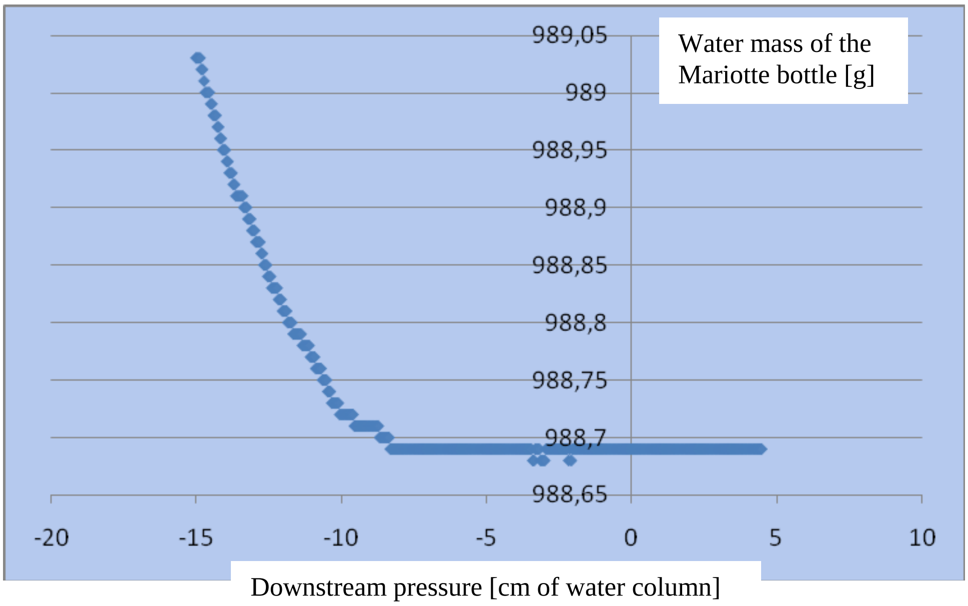


Figure 8. Mass internal the Mariotte bottle measured in grams (g) in function of downstream pressure (cm of water column) for a rapid rise (ICP = 150 mm water column).

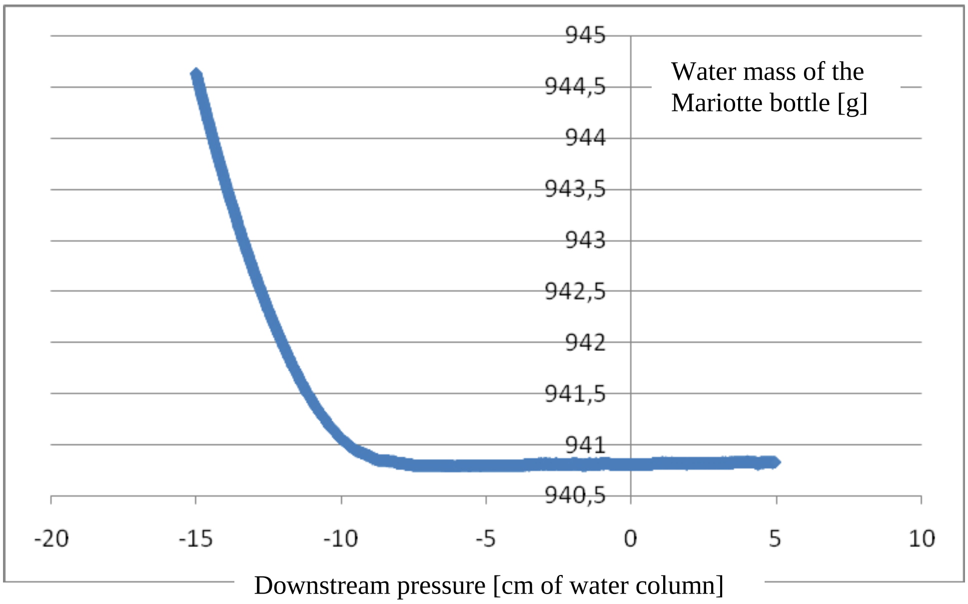


Figure 9. Mass internal the Mariotte bottle measured in grams (g) in function of downstream pressure (cm of water column) for a slowly rise (ICP = 150 mm water column).

Fig. 8 and 9 is relative to an equivalent ICP (upstream pressure) of 150 mm of water column and the downstream pressure change from -150 mm to +50 mm of water column. In Fig. 8 the pressure downstream rise in relative rapid velocity (about 2 minutes of duration) and non appreciable instabilities can be visualized in the mass internal the Mariotte bottle resultant practically no regurgitation. In opposition, in Fig. 9 for a slowly velocity of pressure rise the regurgitation is very small and the valve is closed without instabilities.

Finally, in Fig. 10 and 11, the equivalent ICP is maintained in 200 mm of water column. In the Fig. 10 the pressure downstream begin in -150 mm of water pressure and finish in +50 mm in a rapid rise of pressure less than 2 minutes of duration showing the mass drained measured in grams. In the Fig. 11, the pressure downstream the ball valve rises too from -150 mm to + 50 mm of water column slowly in a temporal variation of 26 minutes.

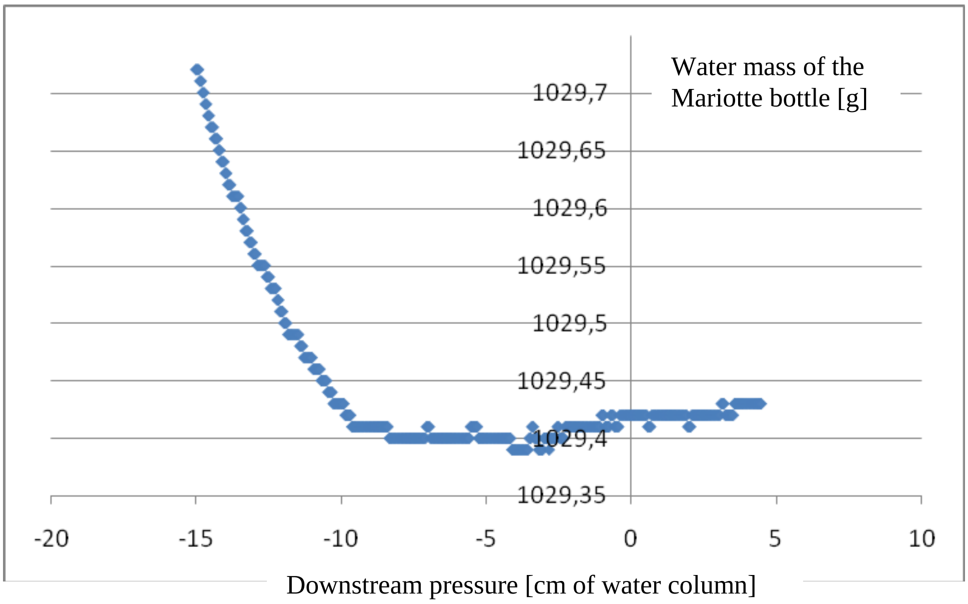


Figure 10. Mass internal the Mariotte bottle measured in grams (g) in function of downstream pressure (cm of water column) for a rapid rise (ICP = 200 mm water column).

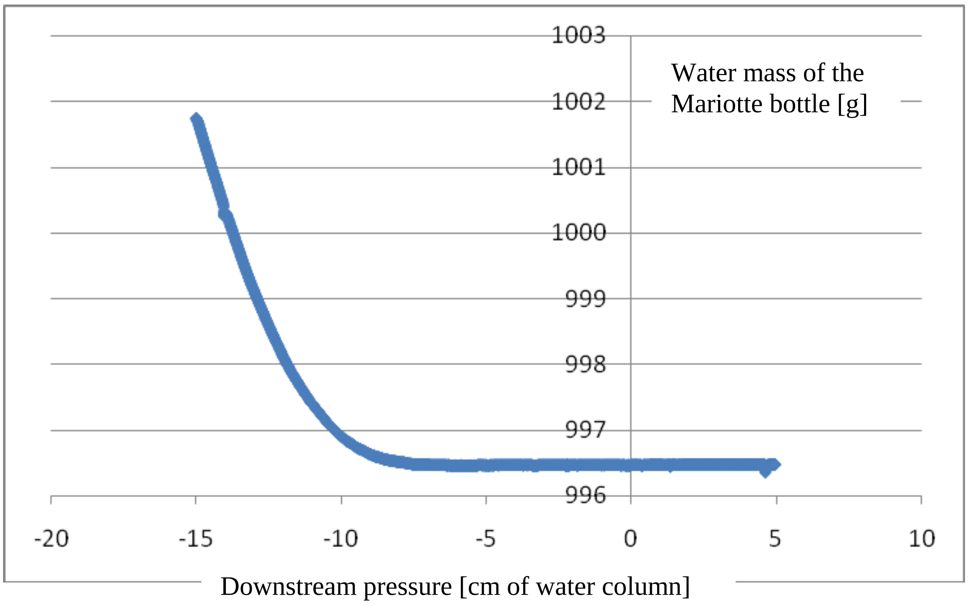


Figure 11. Mass internal the Mariotte bottle measured in grams (g) in function of downstream pressure (cm of water column) for a slowly rise (ICP = 200 mm water column).

Fig. 10 and 11 is relative to an equivalent ICP (upstream pressure) 200 mm of water column and the downstream pressure change from -150 mm to +50 mm of water column. In Fig. 10 the pressure downstream rise in relative rapid velocity (about 2minute of duration) and several instabilities can be visualized in the mass internal the Mariotte bottle resultant in an appreciable regurgitation. In opposition, in Fig. 5 for a slowly velocity of pressure rise the regurgitation is very small and the valve is closed without instabilities.

4. CONCLUSIONS

Nowadays, implantable medical devices have been widely utilized to restore body functions, improve the quality of life or to save lives. In accord to Zhou & Greenbaum, (2009), about 1 in 17 peoples in industrial countries carry some form of implanted device, like cardiac defibrillators, cochlear devices, neuromuscular microstimulators, artificial heart valves and many other apparatus.

Hydrocephalus is a pathophisiology of adults and children caused by congenital malformations, brain anomalies, tumors, inflammations, infections, encephalitis, intracranial hemorrhages, subdural or epidural hematoma, abscess, traumatisms, arachnoid cysts, aneurysms of cerebellar arteries, herniation into the foramens and other, in accord to Manto, 2010. Following the diagnosis of hydrocephalus, there are few options other than surgery for treatment. In many cases the use of implantable shunt devices is currently applicable since neonatal to old patients. The use of shunting for hydrocephalus has a long history of improvements made through basic science, as well as clinical innovations and biomedical products. The cerebrospinal fluid shunt is one of the most common surgical procedures in encephalic neurosurgery. Nevertheless, an important rate of failure (mechanical, infectious or functional) can occur in this procedure. In the engineering viewpoint, mechanical failures should be availed in details. Several engineering criterion of design should be found in order to obtain an optimized shunt operation. In some conditions reflux can occurs and reverse CSF flow is undesirable because submits the patient to infections and increases considerably the ICP.

In the present work micro check valve spring and spherical ball type has been carried out in order to estimate the regurgitation. The pressure upstream the micro check valves is considered equivalent to ICP and the pressure downstream change to -150 to +50 mm of water column. In the close process of the micro spring ball valve the mass internal the Mariotte bottle is measured and the regurgitation are estimated for a rapid and a slowly downstream pressure rise. Several instabilities have been observed for rapid process of rise the downstream pressure. But these instabilities not produced a sensible regurgitation. In other words, the present micro check valve tested shows adequate to CSF drainage applications in order to prevent reverse flow.

3. ACKNOWLEDGEMENTS

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