Updating technology of shunt valves

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Cerebrospinal fluid shunts are one of the greatest advances of modern neurosurgery and represent a shift in the treatment of hydrocephalus. The underlying physical principle is quite simple and consists of diverting the flow of cerebrospinal fluid to either intracranial structures, jugular system, right heart atrium, pleura, peritoneum or to other natural cavities, such as the omental bursa and even the bladder. All systems operate by means of a differential pressure between the proximal catheter and distal catheter and are composed of ventricular and distal catheters, and a valve, which is the device that allows unidirectional cerebrospinal fluid flow. Current valve technology allows control of the shunt through regulation of drainage pressure, flow regulation or anti-siphon devices. There are valves with low, medium and high pressure designed to open and allow the flow out of CSF when the intraventricular pressure rises above the opening pressure. In contrast to fixed pressure and programmable pressure, valves with flow regulation attempt to maintain constant flow despite changes in the fluid pressure and patient position. Anti-siphon devices are used to avoid the siphon effect and prevent under- or over-drainage of fluid. We discuss briefly the current aspects of hydrodynamics and update valve technology.

KEYWORDS: hydrocephalus; cerebrospinal fluid shunt; technology.


Received for publication on April 07 2014; First review completed on April 19 2014; Accepted for publication on May 05 2014

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INTRODUCTION

The basic principle in the treatment of hydrocephalus involves performing a bypass from a location upstream to the site of the cerebrospinal fluid (CSF) obstruction to one where it can be better absorbed1,2,3. Such a shunt may be performed by CSF diversion or by neuroendoscopy.

Shunts are the mainstay treatment of hydrocephalus, and even in patients with severe hydrocephalus, shunt insertion can have a dramatic effect on the re-expansion of the cortical mantle, particularly in children1,2,3.

CSF shunts are one of the greatest advances of modern neurosurgery and represent a shift in the treatment of hydrocephalus. It is one of the most widely used neurosurgical procedures and presents high rates of complications.

HISTORY

The modern era for the treatment of hydrocephalus began with Torkildsen4, who, in 1939, implemented materials and described the shunt from the lateral ventricles to the cisterna magna, a procedure that still appears in present day textbooks.

Matson5 reported the lomboureteral shunt in 1952. Nulsen and Spitz6 introduced the concept of ventricular - jugular bypass as well as described the first valve with a ball and spring, which was later popularized by Hakim7.

Holter developed valve systems made of silicone, which brought a significant improvement to all valve models because silicone is very well tolerated by the human body7,8. Later, in the 1980s, El - Shafei described the initial experience with a ventriculosinusal shunt9,10. In 1992 a protocol for the ventriculoperitoneal shunt was published by Choux and is widely accepted to this day11.

HYDRODYNAMICS OF CSF SHUNT

The physical principle underlying the use of CSF shunts is quite simple and consists in diverting the flow of CSF either to intracranial structures, jugular system, right heart atrium, pleura, peritoneum, or to other natural cavities, such as the omental bursa and the bladder10-17.

All systems operate by means of a differential pressure (DP) between the proximal (ventricular) and distal catheter (most commonly peritoneal)10-15. There are several physical factors involved in cerebrospinal fluid drainage, such as the pressure difference between the catheter tips, the patient’s position, the diameter and length of the tubes, and fluid viscosity10-15. This relationship can be represented by the following equation:

\[ F = \Delta P/R \]
where $F$ is the CSF flow, $AP$ is the variation of pressure between the ends of the catheter and $R$ is the resistance of the system. The Hagen Poiseuille equation correlates flow resistance in a tubular system as a function of pressure, radius, length and viscosity of the fluid:\textsuperscript{10-17}

$$F = \Delta P \pi R^4 / 8 \eta L$$

Where $F$ is the flow, $\Delta P$ is pressure difference, $R$ is radius, $\eta$ is the viscosity of the fluid and $L$ is the length of the tube. Fluid drainage is a function of $\Delta P$, but all the variable parameters, radius, diameter and viscosity play an important modulating part on shunt operation.

Stevin’s Fundamental Law of Hydrostatic postulates that in connected hydrostatic systems, and respecting the principle of communicating vessels, the pressure at a point varies with the column liquid height\textsuperscript{10-17}. Thus, if two sites are connected by a liquid pipe, the flow will be directed from the site of highest to lowest height.

CSF shunts

As shown in Table 1, there are over 20 choices of CSF shunts\textsuperscript{2}, each with its technical and functional peculiarities. The experience and evolution of surgical technique turned the ventriculo-peritoneal shunt into the preferred technique, due to the low potential for complications and the extensive virtual cavity for CSF reabsorption.

In spite of the market availability of a variety of CSF shunt systems, all have similar features and principles, and are also subject to similar complications. The three main components of a CSF shunt system are: proximal (ventricular) catheter, valve and distal catheter\textsuperscript{1-3}.

**Ventricular and distal catheter.** Ventricular catheters are made of silastic and inserted through a frontal or parieto-occipital approach, usually on the right (nondominant) hemisphere. A burr is made in the skull and the tip of the catheter is placed in the anterior horn of the lateral ventricle. This region is chosen due to its decreased amount of choroid plexus, decreasing the chance of a clogging of the ventricle. This region is chosen due to its decreased amount of choroid plexus, decreasing the chance of a clogging of the lateral holes in the catheter\textsuperscript{1-3}. A distal catheter is also made of silastic and its tip is placed in different sites.

**Valves.** The second component of the drainage system, the valve, maintains unidirectional flow (craniocaudal) and acts by regulating CSF drainage\textsuperscript{18-29}. This control occurs mainly through pressure regulation (pressure regulators), flow regulation (regulatory flow valves) and anti-siphon mechanisms (anti-siphon devices). Table 2 presenst valves currently available.

### Table 1 - Possible distal sites for ventricular shunts

| 1. EXTERNAL | INTRACRANIAL | Subarachnoid space/ Subdural space/ Superior sagittal sinus |
| 2. INTERNAL | EXTRACRANIAL | Subgaleal space/ Mastoid antrum/ Duct of salivary gland |
| CERVICAL | Duct of salivary gland/ Common facial vein |
| THORACIC | Right atrium/ Superior vena cava/ Pleural cavity/ Thoracic duct/ Spinal epidural space/ Bone marrow |
| ABDOMINAL | Peritoneal cavity/ Omental bursa/ Stomach/ Gallbladder/ Urinary bladder/ Ureter/ Ileum/ Uterine tube |

### Table 2 - Available valve types

<table>
<thead>
<tr>
<th>Principle</th>
<th>Valve type</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure differential (fixed pressure)</td>
<td>Silt</td>
<td>Codman Holter</td>
</tr>
<tr>
<td>Mitre</td>
<td>Mueller Heyer Schulte</td>
<td></td>
</tr>
<tr>
<td>Ball and Spring</td>
<td>Cordis Hakim</td>
<td></td>
</tr>
<tr>
<td>Diaphragm</td>
<td>Codman Medos Hakim</td>
<td></td>
</tr>
<tr>
<td>Diaphragm + anti-siphon device</td>
<td>Mueller Heyer Schulte</td>
<td></td>
</tr>
<tr>
<td>Anti-siphon device</td>
<td>Flow control</td>
<td></td>
</tr>
<tr>
<td>PS Medical</td>
<td>Codman Accu-flo</td>
<td></td>
</tr>
<tr>
<td>Medos</td>
<td>PS Medical Delta</td>
<td></td>
</tr>
<tr>
<td>Variable resistance</td>
<td>Sophysa</td>
<td></td>
</tr>
<tr>
<td>Progav</td>
<td>Strata</td>
<td></td>
</tr>
</tbody>
</table>

The pressure at which the valve opens is called the set pressure. There are valves with low, medium and high pressure in each category, referring to opening pressures of about 5, 10, and 15 cm H$_2$O respectively. Most valves are designed to open and allow the flow of CSF when the intraventricular pressure rises above the opening pressure\textsuperscript{18-29}. Once the proximal pressure drops below the closing pressure, the valve closes and CSF flow ceases.

In contrast to fixed and programmable pressure valves, flow regulated valves maintain constant flow despite changes in the CSF pressure and patient position\textsuperscript{18-29}.

Anti-siphon devices are used to avoid the siphon effect and its complication, namely over-drainage of CSF. The siphon effect is a phenomenon that occurs due to the increased flow of CSF from the ventricles drained after postural changes such as standing up after sitting. This phenomenon is due to the increased hydrostatic pressure and perfusion pressure of the drainage system. In the vertical position, additional hydrostatic pressure increases the pressure differential and the CSF flow through the valve. One of the critical pressure regulators is that they are subject to this phenomenon in the vertical position\textsuperscript{18-29}.

A recent advance in bypass valves technology has been the introduction of programmable valves. Programmable valves can be adjusted externally using a special magnetic device that alters the position of an internal rotor and thereby modifies the opening pressure of the valve. This removes the need for a surgical procedure when the patient requires a valve with a different pressure. This type of valve tends to be well suited for handling difficult cases of over-drainage or under-drainage of CSF. It is unclear whether the benefits outweigh the increased costs of such devices in all patients\textsuperscript{18-29}.

Since the programmable valve contains a magnet, most valves need to be reprogrammed immediately after all magnetic resonance imagings (MRI). However, a programmable valve that is not altered by a magnetic field is also available. It “locks” the configuration and can be changed only with a specific magnetic programmer. Routine household equipment such as mobile phones and computers are not strong enough to affect the valve, but special care should be taken when patients are around strong magnetic sources\textsuperscript{18-29}.

Such devices include a programmable valve, Medos (Medos Codman, Le Cocle, Switzerland), the adjustable
valve, Sophysa (Sophysa, Orsay, France), the Strata valve (Medtronic, USA), and the Progav valve (Aesculap, Berlin, Germany). The adjustment after implantation is accomplished through the aid of radiography (Medos) or a compass held over the device (Sophysa, Strata and Progav) 18-29.

In order to avoid the occurrence of the siphoning effect, a variety of valve models have been developed. However, all of them generally act through additions of resistances to the drainage system, reducing in this way the flow of CSF during postural changes. The device, which is subcutaneously placed in series with the valve, holds a movable membrane that moves in response to changes in pressure across it. The outer surface is theoretically atmospheric pressure. When the pressure in the bypass drops, the diaphragm moves to occlude the lumen of the shunt. Such devices are available as separate components to insert below the valve in bypass, or can be incorporated in the valve itself, as in the Delta valve (PS Medical Corporation, California, USA) and the Sphera valve (HfBio, São Paulo, Brazil) that combine a diaphragm valve or ball-spring, respectively, and a control device siphon membrane in the body of the valve 18-29.

A different approach to the problem of the siphoning effect is seen in the Orbis Sigma valve (Cordis Corporation). In contrast to pressure regulating valves, this valve is designed to be a flow regulating device allowing a fairly constant flow rate over a wide range of differential pressures 30-34. Several level 1 studies have demonstrated a significant improvement in over-drainage complications with anti-siphon devices or the application of programmable valves or flow-regulated valves 30-34.

**CONCLUSIONS**

Shunt technology is advancing rapidly. New materials allowing better biocompatibility and even impregnated antibiotics in catheters are increasing the options for CSF shunts. Other concepts of valve systems, designed in accordance to hydrodynamic principles, are also being developed.

Neurosurgeons must implement the latest technology and highest quality care in order to insure better control of hydrocephalus and decrease complications. However one must also be aware of the scientific background and evidence for each valve.

A growing issue that also needs attention is the bias present in scientific publications. This bias can be selection, analysis and management. Many studies are sponsored by large corporations and the authors may have conflicts of interest. In a scenario where large investments are imperative to apply appropriate treatment, an independent and lucid evaluation, though challenging, is necessary.

**CONFLICTS OF INTEREST**

Authors declare no conflicts of interest.

**REFERENCES**


**RESUMO**

Derivações líquoricas são um dos maiores avanços da neurocirurgia moderna e representam uma mudança no tratamento da hidrocefalia. O princípio físico básico é muito simples e consiste em desviar o fluxo do líquido cefalorraquidiano, para estruturas intracranianas, sistema jugular, átrio direito do coração, pleura, peritônio ou para outras cavidades naturais, tais como a bolsa omental e até a bexiga. Todos os sistemas funcionam por meio da pressão diferencial entre o cateter proximal e o distal e são compostos de catéteres ventricular e distal, além de uma válvula, que é o dispositivo que garante fluxo unidirecional de líquido cerebrospinal. A tecnologia atual compreende válvulas de controle do shunt através de regulação da pressão, do fluxo, além de dispositivos anti-sífon. Existem válvulas de baixa, média e alta pressão concebidas para abrir e permitir o fluxo de LCS quando a pressão intraventricular sobe acima da pressão de abertura. Em contraste dispositivos de pressão fixa ou de pressão programável, as válvulas de regulação de fluxo funcionam para manter constante o fluxo apesar de variações na pressão de fluido e posição do paciente. Dispositivos anti-sífon são utilizados para evitar o efeito de sífon e evitar sub- ou sobre-drenagem de fluido. Discutimos brevemente os aspectos atuais da hidrodinâmica e tecnologia de válvulas de atualização.


