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Hydrocephalus: An Overview

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1. Introduction

Hydrocephalus is a condition where an abnormal build-up of cerebrospinal fluid (CSF) fluid causes an increase in pressure in the ventricles or subarachnoid space of the brain. It can be caused by either the blockage of CSF flow (i.e. obstructive/non-communicating hydrocephalus) in the ventricular system or by inadequate re-absorption of CSF fluid (i.e. non-obstructive/communicating hydrocephalus). These features result in enlargement of the ventricles (i.e. ventriculomegaly) or subarachnoid space and increase intracranial pressure (ICP). The severity of ICP can compress surrounding brain parenchyma, manifesting into identifiable acute or chronic symptoms depending on the age of onset.

Major developments in the treatment of hydrocephalus have occurred since the 20th century, with the use of shunts and neurosurgical interventions being the most successful. Currently, no cure has been found for hydrocephalus.

2. Types and classification

Hydrocephalus can be grouped based on two broad criteria: 1) pathology and 2) etiology. Pathology can be grouped as either obstructive (non-communicating) or non-obstructive (communicating). Etiology can be grouped as congenital or acquired. Additionally, there is a form of hydrocephalus called normal pressure hydrocephalus (NPH), which primarily affects the elderly population.

Congenital hydrocephalus is present at birth, and can be caused by Dandy-Walker malformations, porenchphaly, spina bifida, Chairi I and II malformations, arachnoid cysts, and most commonly aquaductal stenosis. Very few cases of congenital hydrocephalus are inherited (X-linked hydrocephalus). Acquired hydrocephalus may be caused by subarachnoid haemorrhage, intraventricular hemorrage, trauma, infection (meningitis), tumour, surgical complications or severe head injury at any age.

Describing hydrocephalus based on type of CSF flow (i.e. communicating/non-obstructive or non-communicating/obstructive) is preferred because of the implications for treatment. Communicating hydrocephalus is often treated with shunt surgery while non-communicating hydrocephalus suggests treatment with endoscopic third ventriculostomy (ETV). Regardless of etiology, both groups present with ventriculomegaly and elevated intracranial pressure, which are responsible for the similar symptoms seen in both communicating and non-communicating forms of hydrocephalus.

2.1 Obstructive (Non-communicating) hydrocephalus

Obstructive hydrocephalus results from the blockage of CSF circulation, either in the ventricles or subarachnoid space. This can be caused by cysts, tumours, haemorrhages, infections, congenital malformations and most commonly, aqueductal stenosis or cerebral aqueduct blockage. An MRI or CT scan can be useful to identify the point of blockage. Patients can then be treated by removing the obstructive lesion or diverting the CSF using ETV or a shunt.

2.2 Non-obstructive (Communicating) hydrocephalus

Non-obstructive hydrocephalus may be caused by a disruption of CSF equilibrium. Rarely, hydrocephalus can be caused by an abundance of CSF production, as a result of a choroid plexus papilloma or carcinoma. Hydrocephalus is typically the underlying condition when CSF absorption is impaired, and can be caused by a complication after an infection or by hemorrhagic complications. Patients are often treated using a shunt.

2.3 Normal Pressure Hydrocephalus

Normal pressure hydrocephalus (NPH), which commonly occurs in the elderly, does not fit into either obstructive or non-obstructive hydrocephalus. NPH occurs in the sixth or seventh decade of life and is characterized with specific symptoms: gait disturbance, cognitive decline and urinary incontinence (i.e. Adam's or Hakim's triad). Ventricles appear enlarged, and there is an increase in intracranial pressure compared to baseline measurements. However, it is important to note that this increase in ICP is not as significant an increase as seen in obstructive or non-obstructive cases described previously. This is why this form of hydrocephalus is called 'normal' pressure hydrocephalus. Causes may include subarachnoid haemorrhage, trauma, infection (meningitis), encephalitis, tumour, subarachnoid inflammation, or surgical complications. Often, the cause of NPH is not clear and is referred to as idiopathic (INPH). Preferred treatment for NPH is often shunt surgery.

3. Pathological findings

CSF is the fluid which acts to serve as a cushion for the brain, and plays a role in haemostasis and metabolism of the brain. It is produced by the choroid plexus, found in the body and inferior horn of the lateral ventricle, the foramen of Monroe, roof of the third ventricle and inferior roof of the fourth ventricle. The flow of CSF through the ventricles is as follows: begins in the left and right lateral ventricles → interventricular foramen of Monroe → 3rd ventricle → cerebral aqueduct → 4th ventricle and out through the two lateral apertures of Lushka or the one medial aperture of Magendi into the cisternae magna. From there, CSF will flow into the cortico-subarachnoid space and the spinal subarachnoid space.

CSF is continuously being produced by the choroid plexus at a rate of 400-500ml/day and continuously reabsorbed by the arachnoids granulations into the dural sinuses, and eventually into the venous system. At any given time, there is approximately 140ml of CSF in the adult system, of which 25-40ml is in the ventricles. The rate of absorption is proportional to the difference in intracranial pressure and dural sinus pressure. An

equilibrium between CSF production and CSF reabsorption maintains mean CSF pressure at 7-15mmHg in normal adults. In patients with communicating and non-communicating forms of hydrocephalus, the build up of extra CSF fluid within the ventricles will cause increased ICP. Clinicians can measure mean intracranial pressure either intracranially or by inserting a needle into the lumbar space. An abnormality in the mean ICP pressure or pattern of ICP changes can be indicative of hydrocephalus.

3.1 Normal Pressure Hydrocephalus (NPH)

Dr. Hakim first identified NPH over 4 decades ago, and a clear pathological model has not yet been proposed to explain the triad of clinical symptoms and the development of the paradoxical nature of near-normal intracranial pressure and ventricomegaly observed in NPH patients. Evidence suggests ventricomegaly is caused by impaired CSF absorption at the arachnoid granules or impaired CSF conductance through the subarachnoid space.

One theory suggests ICP increases due to accumulation of CSF as a result of reduced conductance and absorption. This causes an initial phase of ventricle enlargement, which then normalizes after the initial expansion. This theory has been supported by various experimental models of hydrocephalus.

Hakim hypothesized a transient increase in ICP was sufficient to initiate ventricular dilation. Using Pascal's law (force = pressure x area), if force were to remain constant, as ventricular area increased, the (intracranial) pressure could decrease and normalize, thereby explaining the paradoxical 'normal pressure' presenting in NPH patients. The transient increase in NPH patients is not detected in patients because they are examined in a clinical setting after ventricles have enlarged and ICP has normalized.

Other theories suggest ventriculomegaly develops as a combination of increased mean CSF pressure, and the increased frequency of CSF pressure waves. (Eide & Sorteberg, 2010; Madson et al., 2006)

4. Epidemiology

The true incidence of hydrocephalus in children and adults is unknown. It has been estimated that it affects 0.9 to 1.5 per 1000 births. When congenital abnormalities are included (e.g. spina bifida, myemeninocele), hydrocephalus can affect 1.3 to 2.9 per 1000 births. (Rizvi & Anjum, 2005) Due to the increased practice of pregnant females taking folic acid to reduce neural tube defects, it has been reported that the incidence of hydrocephalus in children has decreased over the recent decades. (Drake, 2008; Bullivant et al., 2008; Kestle, 2003) Without a central registry of hydrocephalus cases, however, it is difficult to accurately know the incidence of acquired cases of hydrocephalus.

Similarly, the incidence of NPH remains uncertain as well, mainly due to variability in diagnostic criteria between different centres. As well, many cases of NPH may be misdiagnosed as other common elderly diseases. Current reports estimate rates of 1.3 per million to 4 cases per 1000; variability due to different diagnostic criteria for NPH and sample populations. A recent study surveying 49 centers in Germany known to care for NPH patients estimated 1.8 cases per 100 000 people. (Krauss and Halve, 2004)

5. Clinical presentation of hydrocephalus

As noted earlier, irrespective of etiology, patient symptoms will present in a similar manner. However, depending on the type of hydrocephalus, age of onset, and severity, symptoms will vary greatly.

5.1 Infants (0-2 years)

In infants, the accumulation of CSF, enlargements of ventricles and increase in intracranial pressure (ICP) will manifest in an increase of head circumference (since the fontanelles have not yet fused), bulging fontanelles, and bulging scalp veins, which occurs especially when the infant cries. These are often the first presenting signs of hydroceaphlus in infants. The shape of the head may also indicate the location of an obstruction. For example, an occipital prominence is seen in Dandy Walker malformations and a larger forehead in comparison to the rest of the skull is seen in aqueductal stenosis. Other signs include an enlarged fontanelle and full anterior fontanelle. Also an infant will often present with signs of irritability, lethargy, fever, and vomiting.

As hydrocephalus worsens, the infant may suffer from 'sunsetting eyes'. This symptom is characterized by the child's inability to look upward, as the eyes are displaced downward due to the pressure on the cranial nerves controlling eye movement. As a result, the infant appears as though it is looking at the bottom lid of its eye. Vision may also be affected in advanced hydrocephalus due to compression of the optic chiasma as a result of a dilated 3rd ventricle. Stretching of periventricular structures can cause abducent nerve paresis, presenting in nystagmus and random eye movement.

Infants with advanced hydrocephalus may also present with increased deep tendon reflexes and muscle tone in lower extremities, growth failure, delayed neurological development, and limited control in the head and trunk regions. Left untreated, this can progress and can result in seizures and/or coma.

5.2 Children and adults

Children presenting with hydrocephalus, may have had a pre-existing and unrecognized hydrocephalus and may have normal or delayed neurological development. These children have slightly enlarged heads, optic atrophy or papilloedema caused by increased ICP. These children also have abnormal hypothalamic function (i.e. short stature, gigantism, obesity, precocious puberty, diabetes insipidus, amonerrea), spastic lower limbs and hyperreflexia. In school, they may present with learning difficulties, and often have lower performance IQ than verbal IQ.

When hydrocephalus occurs in children and adults (after fontanelles have fused), hydrocephalus will manifest with different symptoms. Affected individuals will have normal head size and present with headache, vomiting, irritability, alerted consciousness, lethargy and ventriculomegaly. Papilloedema, absucens nerve pareis, and lower limb hyper reflexia are also seen. The stretching of cranial nerves that are responsible for eye function may lead to impaired or dysfunctional eye movement and/or tunnel vision.

Toddlers may present with loss of previously gained cognitive and motor abilities, delays in reaching milestones (e.g. walking, talking, etc.), poor coordination and decreased bladder

control. Older children often complain of headaches as their primary symptom (due to increased ICP), feel sleepy and lethargic, and also show a decline in school performance. Adult symptoms may vary from weakness to spasticity, difficulties with balance, poor motor control, headaches and nausea.

If an individual with suspected hydrocephalus is left untreated or poorly managed, the chronic increase in intracranial pressure may lead to convulsions, mental retardation, gait disturbances, dementia and personality changes in adults. In young girls, it may also lead to early onset puberty.

5.3 Adult normal pressure hydrocephalus

Normal pressure hydrocephalus results from a decrease in CSF absorption, and ICP may range from normal to high depending on the time of day. It is often characterized by Hakim's triad of symptoms: incontinence, dementia and gait disturbance. Symptoms start off mild, often beginning with gait impairment, and eventually progress in severity. Patients present with varying degrees of symptom severity, and not all symptoms may be present.

5.3.1 Gait

Gait dysfunction is the most common symptom present in adults with NPH and develops over many months or years. Enlarged lateral ventricles compress corticospinal tract fibers in the corona radiata, which are responsible for voluntary skilled movements of the legs.

Patients present with a slower, wide based gait, small shuffling steps, poor balance and a tendency to take many small steps during a turn, as well as a tendency to fall (positive Romberg test). Steps are of reduced height and small clearance, characteristic of a 'magnetic gait'. However, there is no significant motor weakness in limbs. A patient's clinical history may reveal that the patient originally presented with difficulty walking on uneven surfaces, which later developed into an increasing number of falls, needing the use of a walking stick, walker or wheelchair. The Tinetti Assessment Tool is a quick way to assess gait and balance.

Causes for gait disturbances in the elderly population can be multifactorial. As a result, it is important for physicians to rule out other possibilities or co-morbidities before a patient's diagnosis or treatment for NPH is confirmed by taking a detailed clinical history and clinical exam. A history of significant back pain, lower extremity weakness and radicular pain can be due to cervical or lumbar canal stenosis, and can be assessed with MRI. Steppage gait suggests peripheral neuropathy. Differentiation between Parkinson's disease and NPH can be challenging due to similarities in gait dysfunction: hypokinetic, smaller steps, and freezing. However, NPH is specifically associated with a wider base, outward rotated feet, an erect trunk, preserved arm swing, smaller step height, no response to levadopa treatment, and the absence of a resting tremor.

5.3.2 Urinary incontinence

Compression of sacral fibers along the corona radiata by enlarged lateral ventricles impairs inhibitory fibers to the bladder. Patients can present with a variation of urinary symptoms, ranging from urgency or increased frequency to (near) incontinence.

Since urinary incontinence is also extremely common in the elderly population, a detailed history and examination must be taken to rule out other causes of similar symptoms, such as urethral stricture (prostate hypertrophy), diuretic use, detruster instability or pelvic floor weakness leading to stress incontinence. The type of incontinence (stress, urge, etc.) and use of cystoscopy and urodynamic testing can be helpful in diagnosing patients.

5.3.3 Cognitive dementia

Patients with NPH suffer subcortical dementia, characterized by forgetfulness, disrupted visuospatial perception, psychomotor slowness, decreased attention, and preserved memory storage. A patient history may reveal the patient is incapable of daily tasks, such as shopping, or managing bank accounts. Physicians may use the Montreal Cognitive Assessment test or HIV Dementia Scale as a quick screening tool to identify subcortical cognitive dysfunction.

Cognitive decline in NPH can be similar to other common dementias seen in the elderly population, including Alzheimer's, vascular dementia, and Lewy body disease. An onset of symptoms over a few months, rather than a few years, and lack of apraxia, agnosia, aphasia and complete memory loss can differentiate subcortical dementia found in NPH from Alzheimer's. However, other types of dementia may be more difficult to differentiate from dementia due to NPH.

6. Diagnostic evaluation

6.1 Infants

Head circumference should be routinely measured in infants. Any excessive growth in serial measurements is a risk factor for hydrocephalus and should be followed up with a physician. Additionally, failure of sutures to close in a child may indicate the development of hydrocephalus, as progressive growth of ventricles in a young infant can prevent the fusion of sutures. This may also lead to a larger than normal head circumference. If hydrocephalus is suspected, x-rays of a child's head may provide further evidence such as an enlarged head, craniofacial disproportion, or elongated interdigitations of suture lines, indicating increased ICP in older children.

Hydrocephalus can be diagnosed before birth with the use of ultrasound. Also, in premature infants and very young infants with open fontanelles, ultrasound can be used to image the size of ventricles. If possible, a CT or MRI scan can be performed on the infant to assess the cause of hydrocephalus (e.g. aqudctal stenosis, loculated ventricles, tumour, etc.) and to choose appropriate follow up interventions. However, due to the invasive nature of these diagnostic procedures, it is difficult to monitor ICP in a very young infant to detect an increase ICP.

6.2 Children and adults

Children and adults presenting with symptoms of hydrocephalus need to confirm the presence of enlarged ventricles with CT or MRI. Using an MRI, Evan's ratio is defined as the ratio of the maximum width of the anterior ventricular horns to the maximum width of the calvarium at the level of the intraventricular foramen of Monroe. A ratio of 0.3 or greater

defines ventriculomegaly. CT or MRI may also reveal the presence of infection or tumours causing an obstruction and enlarged ventricles. Gating MRI to the cardiac cycle can track CSF flow and monitor movement through the ventricles to identify any blockages. Lumbar puncture can also be used to assess intracranial pressure, and screen for the presence and/or type and severity of infection.

Signs indicating non-communicating hydrocephalus include: lack of indication of obstruction on an MRI, increased CSF flow velocity in the aquaduct, rounding of lateral ventricles, and thinning and elevation of the corpus collosum on sagittal MRI images.

7. Predictive tests for shunt surgery for NPH

Although the use of neuroimaging to identify ventriculomegaly and assessment of clinical symptoms (i.e. the presence of one or more features of Hakim's triad for INPH), can be used to diagnose NPH, additional testing must be conducted to identify patients who qualify for shunt surgery. The use of supplementary tests can help improve diagnostic accuracy and stratify patient populations into those who would be considered good candidates for surgery and those who would not.

7.1 Cisternography

In cisternography, a radioactive isotope is injected via lumbar puncture into the CSF and is allowed to distribute within the ventricular and subarachnoid system over a 1-2 day period. Flow and speed are assessed using a gamma camera. In a normal patient, the material can be seen accumulating over the cortical space. Any accumulation or reflux of the isotope in the ventricles indicates NPH. Although this method was used heavily in the past, a review in the early 1990s (Vanneste et al., 1992) concluded that this method did not improve diagnostic accuracy, and this method has been abandoned since.

7.2 Infusion methods

To examine CSF dynamics, two needles are used: one to infuse artificial CSF into the lumbar subarachnoid space, and another needle at a second side in the spine to record intracranial pressure and resistance of CSF absorption pathways in the subarachnoid space. Patients with an ICP >18mmHg/mL/min would have a good outcomes after shunt surgery (high specificity). However, certain patients still benefit from surgery, despite failure to meet the >18mmHg/mL/min cutoff, indicating low sensitivity of this test. Though this test can be quite useful to physicians recommending patients for surgery, it requires technical skill, and is currently only available at very few centers in the US.

7.3 Intracranial pressure measurement

Measuring intracranial pressure (ICP) can be done using an intraventricular or lumbar catheter. From recordings, mean pressure and systolic and diastolic pulsations of CSF can be calculated. Measurements >50mmHg for 15-20 minutes time segments on ICP recordings indicate A-waves (plateau waves). B-waves are often low amplitude waves (1-5mmHg) lasting a short period of time and have been recently explored as a possible indicator of shunt surgery outcomes. However, other studies have shown low correlation between the

incidence of B-waves and good surgical outcome. (Stephensen et al., 2004) ICP monitoring is only available at a few centers in the world, and studies have found varying results on the use B waves as a positive indicator for shunt surgery. This is likely due to the different interpretation of recordings at different centers.

7.4 CSF tap test

A CSF tap test removes 40-50ml of CSF and involves assessment of gait performance and cognitive ability before and after the procedure. The act of removing CSF simulates what would happen if the patient were to undergo placement of a shunt. The test may be done in an outpatient setting, and has low risk, low costs associated, and is a popular test to use for stratifying good surgical candidates. Although the specificity of this test is high, the sensitivity is low. Physicians should keep in mind a patient who does not respond well to this test, should not be excluded from surgical consideration. Rather the patient should be followed up with other supplementary tests, such as continuous CSF drainage before treatment is finalized. Currently, there is an ongoing European multicentre study to investigate the reliability of this test. (Malm & Eklund, 2006)

7.5 Continuous CSF drainage

Removal of large amounts of CSF over a 2-3 day period through a spinal catheter and comparison of symptoms (e.g. gait and cognitive ability) before and after this procedure has proven to be useful in consideration of shunt surgery. Factora & Luciano (2006) found at their institution, that clinical symptomatic improvement after this test was performed on patients with ideal NPH presentation (ventriculomegaly and clinical symptoms), was indicative of a high success rate after surgery.

Although this test is valuable, it is a high risk procedure. Patients may suffer from headaches, meningitis, infection, nerve root irritation, catheter blockage, as well as the associated cost of hospital stay. Additionally, the sensitivity and specificity of this test in multiple studies has been variable and only certain centers in the US specialize in this technique, suggesting continuous CSF drainage may not be best suited for widespread clinical use.

7.6 CSF flow using MRI

MRI can be used to assess CSF flow in the brain. Studies have shown increased CSF volume through the aqueduct during systole to be associated with positive outcome to shunt surgery. This technique is advantageous due to its non-invasive nature, yet further research is needed to assess reliability in a clinical setting.

7.7 Conclusion

In addition to the supplementary tests, it is important to keep in mind the likelihood of patient recovery following shunt surgery decreases the longer the NPH patients has presented with clinical symptoms.

The various ancillary tests have varied risks and benefits as well. Many studies have demonstrated that these tests also vary in terms of sensitivity and specificity. Currently, in

the absence of a true gold standard for the diagnosis of NPH, studies have highlighted CSF drainage as the best available test to indicate successful surgical outcome.

8. Treatment

Treatment of hydrocephalus is dependent on a number of factors, mainly etiology, severity, age of patient, and response to previous treatments or supplementary tests. After careful consideration and review of a patient's neuroimaging, clinical symptoms, contraindications and response to alternative treatments/tests, a physician may offer to treat a patient conservatively with pharmacotherapy or surgically with implantation of a shunt or endoscopic third ventriculostomy (ETV).

8.1 Pharmacotherapy

CSF production in choroid plexus cells is based on movement of ions on the basolateral and apical side of the cells. Carbonic anhydrase is responsible for catalyzing the following reaction: $H_2O + CO_2 \rightarrow H_2CO_3 \rightarrow HCO_3 + H^+$. The bicarbonate and hydrogen ion are exchanged on the basolateral side for Na^+ and Cl^- while on the apical side, $NaCl$, $NaHCO_3$ and H_2O are secreted to form CSF.

In the past, in an attempt to reduce CSF production, acetazolamide, a carbonic anhydrase inhibitor was prescribed. Although this treatment has been shown to reduce CSF production slightly and mediate milder forms of hydrocephalus, it cannot be used as a long-term treatment modality. Patients who progress to more severe forms will have to either undergo a shunt placement or ETV.

8.2 Shunt surgery

Patients with communicating hydrocephalus, including adult NPH, are primarily treated with shunt surgery. As described earlier, patients offered shunt surgery as an option have typically undergone ancillary testing to determine their response to placement of a shunt.

The purpose of a shunt in a hydrocephalic patient is to divert CSF flow to another area of the body, where it can be absorbed. This allows intracranial pressure to return to normal levels and improves clinical symptoms. The procedure involves placing a proximal catheter in a ventricle through the brain or in the lumbar subarachnoid space, to drain CSF. This catheter is connected to a one-way resistance valve which controls CSF drainage and is usually placed against the skull, under the skin. The fluid then drains through a distal catheter which collects the excess fluid and drains into the peritoneal cavity (ventriculoperitoneal shunt), right atrium (ventriculoatrial shunt), or pleural space.

In addition to considering the risk to benefit ratio of the surgery, surgeons must carefully evaluate patients for specific sites of distal and proximal catheter placements, type of valve to be used, and possible co-morbidities, making shunt surgery highly individualized. Placement of proximal catheter is often in the ventricles, but in patients with specific concerns of brain injury from insertion of a catheter (e.g. patient already has left hemisphere injury, and placement of catheter in right hemisphere could result in bilateral lesions), the physician may opt to place it in the lumbar subarachnoid space. Studies have also shown that placement of the proximal catheter within the ventricles has best outcomes when placed

away from the choroid plexus. This will help to avoid catheter occlusion that would normally lead to shunt failure. The preferred location for the placement of the distal catheter is the peritoneal cavity because of ease of access and because there are typically fewer complications. If a patient has previously had an abdominal surgery or peritonitis, their ability to absorb CSF may be decreased and a surgeon may opt for a ventriculoatrial shunt. Placement of distal catheter in the heart or lung increases the risk of complications, such as: risk of emboli, pleural effusion, pneumothorax, respiratory distress, and endocarditis. Ventriculoatrial shunts also have increased and more serious risks in the long term (e.g. renal failure, great vein thrombosis).

8.2.1 Valves

There are two types of shunts used today: 1) single valve setting (fixed-resistance valves/differential pressure valves) and 2) programmable/adjustable shunts (variable resistance).

8.2.1.1 Fixed resistance valves

These valves are designed to open if the intracranial pressure is greater than the opening pressure of the valve and abdominal pressure (in VP shunt) or outlet area. This allows CSF to flow through the shunt pathway along with regular CSF pathways in the ventricles and subarachnoid spaces.

These shunts cannot be adjusted (i.e. opening pressure altered) after they are implanted and are not susceptible to alteration of function when in proximity to a magnetic field. If patient does not seem to improve symptomatically following surgery, it may become necessary to repeat the surgery and replace the shunt with a shunt that has lower opening pressure. Shunts are typically available in low, medium or high pressure.

When a patient sits upright, the hydrostatic pressure gradient may be greater than the opening pressure of the valve, and cause over drainage of the ventricles. The siphoning effect can create postural headaches (headaches which cease when patient lies down) and increases the risk of subdural hygromas and/or hematomas. Current fixed-resistance valves now have anti-siphon features to minimize disturbances when patients sit upright.

8.2.1.2 Variable Resistance Valves

The mechanism of these valves is the same as fixed-resistance valves, but they have opening pressures ranging from 20-200mmH$_2$O and can be adjusted after implantation using a magnetic device. Thus, after surgery, the valve can be adjusted to optimize benefit to the patient (i.e. as seen by best relief of clinical symptoms) and/or to avoid over drainage, and manage subdural hygromas/hemotomas.

Variable resistance valves are advantageous in comparison to fixed-pressure valves because they can be adjusted non-invasively. However they are susceptible to external magnetic fields. If a patient undergoes an MRI or comes in close contact with small kitchen magnets, the patient risks unintentionally changing the valve settings and causing unexpected changes in CSF flow. Patients are forewarned, and should visit a physician after an MRI scan to re-evaluate shunt settings.

A study looking at outcome with patients with fixed resistance vs. variable resistance valves showed no significant benefit of one valve over the other. (Pollack et al., 1999)

Selection of type of valve is dependent on the surgeon as well as the patients' etiology of hydrocephalus.

8.2.2 Complications

Implantation of a shunt can have complications that arise from the surgery itself, complications related to the shunt system or complications reflected in overall suboptimal shunt function.

The INPH guidelines list several complications, including shunt malfunction (20%), subdural hematoma (2–17%), seizure (3–11%), shunt infection (3–6%) and intracerebral hematoma (3%). (Bergsneider et al, 2005) McGirt et al. (2005) sampled 132 INPH patients, and found 7% developed an infection, 2% developed a subdural hematoma, and 1% developed an intracerebral hematoma.

8.2.2.1 Infection

Infection is a common complication resulting from the implantation of a shunt and has been reported to appear in ~8-10% of cases, most arising within the first year after shunt surgery. Evidence of infection should be taken seriously and treated immediately. The most common infection is caused by S*taphyloccoccus aureus* adhering to the shunt system, causing shunt occlusion and/or poor wound healing, and creating the risk of under drainage of CSF through the shunt. Patients experiencing an infection can present with a variety of symptoms, including fever, nausea, vomiting, lethargy and irritability. Upon presentation of these non-specific symptoms, physicians should examine patients for skin tenderness around the surgical incision and catheter and abdominal tenderness. If the entire system is infected, it must be removed surgically and replaced. As well, the patient must undergo antibiotic treatment. Current shunt catheters are impregnated with antibiotics, and have lower shunt infection rates as a result.

8.2.2.2 Shunt dysfunction

Shunt systems have a risk of the individual parts disconnecting or migrating, and tubing segments breaking apart. In growing children, there is a risk of the distal catheter being pulled out of the peritoneal cavity or causing 'inguinal hernias in male infants'. If there is a mechanical issue suspected with the shunt system, a series of plain X-rays should be taken to identify a break down in the system. Any shunt dysfunction can lead to excessive CSF in the ventricles, which may lead to a recurrence of original hydrocephalus symptoms.

8.2.2.3 Shunt occlusion

The most common complication with shunt surgery is occlusion of the proximal or distal catheter leading to shunt dysfunction. Occlusion may be suspected if a patient initially had a period of improvement, then a slow deterioration back to their original condition, or if there was no improvement after surgery at all.

Possible occlusion of the proximal catheter could be due to choroid plexus, and can be minimized if the catheter tip is positioned away from this region. If the distal catheter is positioned in the peritoneal cavity, occlusion and immobilization of the tip are caused by omentum or adhesions. Certain cases have reported catheter tip migration in the cavity, causing bladder or bowel perforations. Poor absorption of drained CSF flow may result in

peritoneal cysts. If this is suspected, an X-ray can be taken on separate days, and degree of mobilization of the distal tip can be assessed.

If an occlusion is suspected, a physician may conduct a patency test to check for shunt flow-through by injecting a 'radioisotope into the shunt reservoir' and noting the movement through the system. Obstruction(s) will be evident if there is a delay or restriction of the radioisotope to a certain area or no flow at all.

8.2.2.4 Over drainage

Over drainage of the ventricles may occur due to a siphoning effect, and requires the opening pressure of the shunt valve to be set higher if an adjustable valve was used, or replacement of the valve if a non-adjustable valve was used. Patients often complain of headaches when they are sitting up, which resolve when they lie down.

Excessive over drainage may result in a subdural hematoma and occurs in children and adults with completed sutures. The rapid drainage causes a compression of the ventricles, and the accompanying brain shift into space previously occupied by ventricles tears bridging veins. Prolonged overdrainage may result in slit ventricle syndrome, in which patients present with intermittent headaches and small slit-like ventricles on imaging.

8.2.3 Outcome

8.2.3.1 Children

With appropriate identification of surgery candidates, patients will often see improvement of their symptoms. Patient response to shunt surgery is variable, and there are still no tests to predict how quickly a patient will respond or to what extent symptoms will be reversed. As well, there are no tests to predict how long the improvements will last. Patients treated for infantile hydrocephalus may have complications in the long run. Often, many children will lead full, active lives, while others may still suffer from vision and motor difficulties, and learning disabilities. The majority of children are able to graduate from normal school. Routine follow-ups and management are required to ensure proper maintenance and optimal use of the shunt.

8.2.3.2 Adult NPH

Patients suffering from NPH, and who have undergone shunt surgery often show improvement, at least in one symptom, especially if shown to respond positively to pre-surgical tests. The degree of improvement and recovery time can range from immediate recovery to many months after surgery. Improvement in balance and gait are seen in the majority of patients and this symptom improves to a greater degree than other symptoms.

Marmarou et al. (2005) found improvement in at least one symptom in 90% of patients who had been selected as surgical candidates based on positive response to CSF drainage tests. Wilson and Williams (2006) selected shunt surgery candidates based on selecting surgical candidates including ICP monitoring and CSF drainage tests, and found improvement of at least one symptom in 75% of their 132 patients 18 months following surgery. Improvement in cognitive function or slowing decline in cognitive function occurs to a lesser extent in patients and can be assessed using a Mini-Mental State Exam. An international study in 2005 developed INPH guidelines, and reported "improvement rates of 30-60%"(Klinge et al,.

2005). The results of such studies indicate the variability in patient improvement, which is often due to differing criteria of patient selection, differences in postoperative assessment and variation of follow up time from surgery in various studies.

Patients may be followed up with imaging and periodic revisions to shunts. Careful follow-ups with physicians must be done to identify infection and prevent any loss in improvements of symptoms made with surgery. Patients who show no improvement in any symptoms up to 6 months after surgery should be re-evaluated for possible misdiagnosis, or shunt function.

8.2.4 Follow Up

During routine follow up visits, blood and CSF samples should be drawn for signs on infection, which is a common complication of shunt surgery. Additionally, physicians should perform routine assessments on patients to evaluate any improvement or decline in symptoms. A lack of clinical improvement after surgery may indicate a non-functional CSF shunt system (which should be evaluated for repair), a misdiagnosis, or symptoms of another developing disease. In patients with INPH, the state of disease may have reached a point in which symptoms are irreversible, thus placement of a shunt will not benefit the patient.

A patient who had previously shown improvement, but then deteriorates symptomatically may indicate improper shunt function. A patient may present with features of hydrocephalus, but not to the degree they presented prior to surgery. Thus, a follow up should include an extensive examination of the shunt system itself. If the reservoir does not refill after mechanically pumping the valve, there might be an obstruction in the proximal catheter. A proximal catheter obstruction may be due to a change in position and/or of the tip, which should be in the right frontal horn, as not to be obstructed by choroid plexus. Ultrasound can be used to examine the distal catheter position, to identify a cyst or abscess of distal tip catheter occlusion. A series of plain x-rays (i.e. shunt series) may be useful in visualizing the entire shunt system, to identify position, disconnection of components, or mechanical damage in the shunt system. Any identification of a displaced catheter would have to be fixed surgically. Shunt disconnection is usually not a problem in adults, but may present more often in children, due to increased activity, and growth.

Shunt placement comes with the risk of over drainage and the possibility of developing subdural hematomas and slit ventricle syndrome. If a shunt was placed in a very young child, as they grow up and spend more time upright, there may be excessive drainage of CSF into the distal catheter because of the siphoning effect. Children with fixed sutures and large ventricles have a high risk of developing a subdural hematoma. (Kestle 2003) Children must have frequent follow-ups and monitoring after shunt surgery and may need contrast CT/MRI scans to visualize a hematoma. For minor subdural hematomas, a physician may choose to manage with monitoring and adjustment of valve opening pressure. However, in many cases, it is necessary to surgically remove the shunt and drain the subdural hematoma.

Slit ventricle syndrome (SVS) is a rare condition, seen in patients who have had a shunt for many years. They present with symptoms of a shunt malfunction, and with periods of recurrent headaches, and show small ventricles on imaging. Current theories suggest long

term over drainage results in smaller ventricles, and the brain to filling in any excess intracranial space. Any subsequent increases in intracranial volume presents as symptoms of high ICP. Small ventricles can also cause the proximal catheter to be obstructed. SVS occurs in a very small population of patients.

8.3 Endoscopic Third Ventriculostomy (ETV)

Endoscopic third ventriculostomy (ETV) is an alternative to treating hydrocephalus with a shunt. ETV was first attempted in the early 1920s, but the practice was abandoned in the 1950s when shunt surgery gained popularity. Increasing evidence of potential shunt complications (e.g. shunt failure, infection rates, etc.) and effectiveness in identifying patients with obstructive hydrocephalus due to modern imaging has led to an increasing popularity of ETV surgery. ETV is now considered the primary form of intervention for patients with aquaductal stenosis or tumours obstructing flow between the 3rd and 4th ventricle but also have adequate CSF reabsorption capacity in the patent subarachnoid space. Patients with minimal CSF reabsorption capacity (i.e. previous case of IVH, meningitis, myelomeningocele) may not be considered suitable for this procedure, and in studies have shown a lower success rate with ETV. (Rezaee et al, 2007)

A neuroendoscope enters through a precoronal burr to visualize the anatomy of the ventricles and the floor of the 3rd ventricle. It is guided through the cerebral mantle, through the lateral ventricle and the foramen of Monro into the 3rd ventricle. Forceps and a balloon are used to perforate a hole downward and widen a stoma in the floor of the 3rd ventricle, anterior to the mammillary bodies and bifurcation of the basilar artery, creating a passage to divert excessive CSF into the prepontine space. This diverted fluid will be absorbed through normal pathways (i.e. subarachnoid space). A pathway for excess CSF to leave the ventricles will result in normalizing the ICP, and decreasing the excessive pressure and damage of chronic systolic CSF pulsations on brain parenchyma. Cerebral blood flow and perfusion to these areas are restored, and normal CSF dynamics are restored, resulting in a reversal of symptoms.

It is important to visualize the proximity of nearby structures, namely the basilar artery, mammillary bodies, hypothalamus and thalamus prior to surgery, to avoid injury prior to surgery. However the fenestration may close in the future, resulting in a rise in ICP and a recurrence of symptoms, and the possibility of another surgery.

The lack of foreign objects in this procedure makes it a viable and suitable surgical alternative to shunt placement and current studies are examining the effectiveness of using ETV for non-communicating forms of hydrocephalus. Hadar et al. (2008) assessed the outcome of obstructive hydrocephalus patients undergoing ETV as a primary surgery or as a secondary surgery for patients who originally had shunt surgery. Results showed that those who had ETV as their second surgery had the worst outcomes overall. A similar study by Woodworth et al. (2007) showed patients who were initially treated with a CSF shunt and subsequently underwent ETV were 2.5 times more likely to suffer from treatment failure in comparison to patients who had ETV as their primary surgical treatment. Results from such studies indicate physicians should carefully select the primary surgery offered to a patient as initial treatment to avoid excessive complications later.

Treatment of NPH with ETV has been explored as well. Gangemi et al. (2004) looked at 25 patients with NPH to be treated with ETV. ETV provided symptom relief that was

comparable to shunt treatment in patients who had a short duration of symptoms and suffered primarily from gait disturbance. This suggests that a particular subgroup of NPH patients may benefit from ETV and thereby avoid shunt insertion.

8.3.1 Complications

Drake (2008) reports the overall surgical complication rate for ETV surgeries to be 10-15%.

Risks associated with ETV include hemorrage, CSF leak, and perforation of nearby structures during the procedure, including the basilar artery, hypothalamus, and cranial nerves.

If the floor of the 3rd ventricle cannot be clearly visualized, or is thin enough to see the basilar artery, a surgeon may choose to place a VP shunt to avoid risking basilar artery rupture. Injuries to the hypothalamus have been reported in the literature to manifest as hormonal disorders, such as diabetes insipidus and weight gain. Possible injury to the occulomotor nerve may result in gaze palsy as well. Bouras & Sgouros (2011) examined reports of ETV complications in multiple sites, including their home institution, and found a low percentage of complications relating to injuries to periventricular structures. These injuries were caused by an abrupt insertion of the endoscope into the lateral ventricle or through the foramen of Monroe. Other extremely rare complications included decreased consciousness, memory disorders, and hemiparesis.

A rare, but fatal risk after ETV is late rapid deterioration. Patients will respond well after the procedure, but will then complain of headache, and rapidly deteriorate. If not given immediate care by a neurosurgeon, this condition may be fatal. A recent study collected autopsy results from patients who had late rapid deterioration, and reported the stoma of the 3rd ventricle had been closed. (Drake, 2008) Further studies in this area need to be conducted to determine if closure of the stoma precipitates the risk of late rapid deterioration.

8.3.2 Outcome

Generally, outcome after surgery in adults is good. Reports on ETV trials have claimed success rates greater than 75% (50-94%) for carefully selected patients. (Rezaee et al., 2007)

ETV offers an opportunity for children suffering from hydrocephalus to avoid a lifetime of shunt dependency. A large multicenter study (Drake 2008) showed complication rates are higher in children less than one year old, and include symptoms such as uncontrolled intraoperative bleeding. This suggests it is best to treat an infant with a shunt surgery early on, and then revaluate the patient for ETV later in life. Thus age is a critical factor in determining whether a patient would be a good candidate for ETV, and is currently under further investigation. (Bouras & Sgouros, 2011)

8.3.3 Follow Up

Patients should be tested for improvement of their specific symptoms, and possible recurrence of original symptoms, which may indicate a potential closure of the stoma. After

surgery, the size of ventricles may decrease with clinical improvement, but it has been shown that the degree of volume shrinking is not a good indicator of surgical outcome. CSF flow void via MRI can determine whether ETV function is optimal.

9. Conclusion and controversy

Current research on hydrocephalus patient populations is limited in that many cases are lumped together, irrespective of etiology and prognosis, and is likely the cause of the variable results in similar studies from different centres. Much of the issue, especially in NPH studies, is the lack of a universal set of diagnostic criteria to create homogenous control groups and patient populations, as well as standards of pre and post operative assessments. Additionally, most of the research to date has been focused on reporting any improvement or lack of improvement after surgery, instead of the degree of improvement. Specifically, there is little work looking at whether surgery on a patient with very mild symptoms would be beneficial for reversing the disease process. Focus is now aimed at identifying a set of diagnostic criteria that can be evaluated in studies to determine which set of criteria yield the highest success after shunt implantation.

Identifying a universal set of diagnostic criteria can determine the best candidates for surgery and yield the highest success rate is of key importance in this field. McGirt et al. (2005) reported having one of the highest long-term response rates (75% at 18 month follow up) for NPH patients undergoing shunt surgery. Their criteria for choosing surgical candidates included: 1) ventriculomegaly identified using imaging, 2) two or more clinical features of NPH, 3) no risk factor for secondary NPH, 4) A or B waves present during ICP monitoring and 5) improvement of clinical symptoms following a 3 day trail of CSF drainage. 93% of patients had improvement in gait, and patients who classified gait disturbance as their primary debilitating symptom, instead of incontinence or dementia, saw twice the improvement.

Much interest has been shown in using A or B CSF waves on ICP readings as a predictor of shunt surgery outcome in NPH. Increasing studies of successful surgery outcomes by incorporating pulsatile waves abnormalities in the criteria of selecting successful candidates for shunt surgery suggests possible modification of the hydrocephalus model. Incorporation of the rapid pulsations of CSF into the current bulk-flow CSF model may provide clues to the pathophysiology of NPH and may improve predictions and better cater treatment options for patients.

As previously mentioned, ETV is not routinely performed on children under a year old due to the poor outcome. Instead, infants with hydrocephalus are treated with shunts, and at a later date, may be successfully treated with ETV. One of the reasons that allow this to occur is that CSF absorption ability may be restored at an older age, after a period of shunt drainage during infancy. (Beni-Adani et al, 2006) Thus, studies are now aimed at redefining how long one should wait before offering ETV treatment (i.e. could ETV be offered before 12 months?)Although there is insufficient evidence in the literature to effectively answer this question, it is important to explore, since it could help infants avoid being dependant on shunts.

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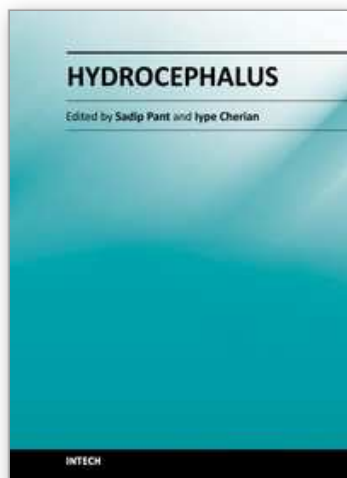
Hydrocephalus

Edited by Dr Sadip Pant

Description of hydrocephalus can be found in ancient medical literature from Egypt as old as 500 AD. Hydrocephalus is characterized by abnormal accumulation of cerebrospinal fluid (CSF) in the ventricles of the brain. This results in the rise of intracranial pressure inside the skull causing progressive increase in the size of the head, seizure, tunneling of vision, and mental disability. The clinical presentation of hydrocephalus varies with age of onset and chronicity of the underlying disease process. Acute dilatation of the ventricular system manifests with features of raised intracranial pressure while chronic dilatation has a more insidious onset presenting as Adams triad. Treatment is generally surgical by creating various types of cerebral shunts. Role of endoscopic has emerged lately in the management of hydrocephalus.

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