Current Management Strategies of Hydrocephalus in the Child With Open Spina Bifida

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Symptomatic hydrocephalus is a common condition associated with myelomeningocele (open spina bifida). Traditionally, hydrocephalus was treated with insertion of a ventriculo-peritoneal (VP) shunt. This has been the standard of treatment since the introduction of the Holter shunt valve for the VP shunt in the late 1950s. Now there are other treatments that offer alternatives to VP shunt diversion for hydrocephalus. This article is a review of hydrocephalus associated with myelomeningocele and its treatment options. Treatment in the form of a VP shunt, endoscopic third ventriculostomy (ETV), and conservative management are discussed.
Key words: *hydrocephalus, spina bifida, surgical management, ventriculo-peritoneal (VP) shunt*

In the United States, approximately 3,000 pregnancies are affected by neural tube defects (NTDs) per year.[1] Geographical location, ethnicity, and socioeconomic status contribute to variations in the prevalence of NTDs.[2] Myelomeningocele (or open spina bifida) is the most common NTD and the most severe birth defect compatible with long-term survival. In the early 1950s, the survival rate for individuals with myelomeningocele was about 10%.[3] Today, many children born with myelomeningocele are surviving into adulthood because of advances in the management of several important health issues associated with this complex disease, such as hydrocephalus, tethered spinal cord, and neurogenic bladder.[4-6]

One major complicating factor for infants born with myelomeningocele is the development of hydrocephalus. Hydrocephalus is the abnormal progressive accumulation of cerebrospinal fluid (CSF) within the ventricles of the brain. Hydrocephalus is a major cause of morbidity and mortality for individuals with myelomeningocele.[4] The introduction of the Holter valve for the ventriculo-peritoneal (VP) shunt opened up the possibility for long-term survival in infants with open spina bifida.[3] The VP shunt has been successful in extending the life span of individuals with hydrocephalus, but a high degree of maintenance is required to avoid shunt-related complications. Shunt failure is common in patients with hydrocephalus. In our reported 25-year outcome in patients born with open spina bifida, 95% of the 86% of patients requiring shunt placement have undergone at least one shunt revision.[4] Shunt infections were also common within this cohort: 22 (19%) patients had at least one shunt infection, and 12 (10%) patients had an infection with gram-negative bacteria.[4]

Today, other procedures are being implemented as alternatives to the VP shunt. Endoscopic third ventriculostomy with choroid plexus cauterization and conservative management of relatively stable ventriculomegaly are alternatives to VP shunt placement.[7-10]

Hydrocephalus is only one complicating factor associated with open spina bifida. Optimal treatment of children born with this complex disease requires multispecialty care to prevent, monitor, and treat a variety of potential health issues that impact function, quality of life, and survival.[11]

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The aim of this paper is to review the etiology and management of hydrocephalus in infants born with myelomeningocele.

Hydrocephalus and the Chiari II Malformation

The most common and severe neural tube defect associated with long-term survival is myelomeningocele. Like other forms of spina bifida, myelomeningocele is characterized by the incomplete closure of the spinal column, but its unique characteristic is the extrusion of the spinal elements into the fluid-filled sac. Patients with myelomeningocele commonly have an associated brain anomaly known as the Chiari II malformation, which includes the herniation of the developing fetal cerebellum upward into the middle fossa and downward in the cervical spinal canal. The Chiari II malformation encompasses a broad constellation of developmental brain abnormalities and is associated with the development of hydrocephalus in patients with myelomeningocele.[12] To a large extent, it is the severity of the Chiari II that determines the outcome for patients with myelomeningocele. In the absence of a Chiari II malformation, many patients with open spina bifida would have an outcome similar to patients with closed dysraphism.[13]

The etiology of hydrocephalus in patients with open spina bifida has been the subject of many studies, yet its pathogenesis is still unclear.[12,14,15] The most widely accepted theory for the development of hydrocephalus in patients with open spina bifida was proposed by McLone and Knepper in 1989.[12] Their hypothesis, known as the unified theory, proposed that the embryological basis of the Chiari II is the loss of cerebrospinal fluid (CSF) through the open spinal defect. With continual leakage of CSF through the spinal opening during early gestational life, there is impairment in the development of the brain and normal CSF pathways, which ultimately allows for the caudal descent of the hindbrain and subsequent hydrocephalus development.

Recently, a trial of prenatal versus postnatal myelomeningocele closure has added support to the unified theory.[14] Participants in this National Institutes of Health (NIH)–funded trial, known as the Management of Myelomeningocele Study (MOMS), were assigned to either prenatal surgery for fetuses with open spina bifida before 26 weeks gestation or the standard postnatal myelomeningocele closure surgery. The trial found that VP shunt rates in the prenatal and postnatal repair groups were 40% and 82%, respectively. The hindbrain herniation, or Chiari II malformation, was significantly less severe in those who underwent prenatal back closure.[14] At 12 months of age, 36% of the prenatal and 4% of the postnatal group showed no evidence of hindbrain herniation. The rate of moderate-severe hindbrain herniation was higher in the postnatal group (67%) than it was in the prenatal group (25%). Other abnormalities associated with the Chiari II malformation such as brain stem kinking, abnormal fourth ventricle location, and syringomyelia were seen in higher proportions in the postnatal group.[14] The improvement in the Chiari II malformation and subsequent decrease in symptomatic hydrocephalus in the prenatal group strongly support the relationship between the continual, abnormal leakage of CSF in utero with the subsequent development of the Chiari II, and eventual hydrocephalus, as proposed previously by McLone and Knepper.

It has been observed that only 1 out of 6 patients with myelomeningocele are born with signs of raised intracranial pressure, and only 1 out of 8 are born with head circumferences that measure above the 98th percentile.[16] Following the postnatal repair of the myelomeningocele, many infants will develop some degree of ventricular enlargement, or ventriculomegaly, which causes the head to increase at a rate greater than the normal curve. This initial gentle increase in ventricular size, which then stabilizes over time and is asymptomatic, does not necessarily indicate the need for permanent CSF diversion. In patients who are neurologically stable with relatively stable ventricular enlargement and head circumference, intervention may not be required. Instead, the increase in head circumference should be followed both radiographically and clinically by a neurosurgeon to determine if and when intervention would benefit the patient.[9,10,17,18]

In infants who present with rapidly progressive and/or symptomatic hydrocephalus, surgical intervention is required.[10,17] The traditional surgical intervention for rapidly enlarging ventricles, also known as hydrocephalus, has predominantly been the insertion of a VP shunt. More recently, some medical centers have treated progressive hydrocephalus initially with an endoscopic third ventriculostomy and choroid plexus cauterization.[7]

The subsequent focus of this article is to review the different management strategies used by neurosurgeons to treat ventriculomegaly and/or hydrocephalus in infants with open spina bifida.

Conservative Management

Neurologically stable infants with stable or slowly progressive increases in ventricular size over a short period of time may be optimally managed with routine visits to their neurosurgeon.[9,10,18] Routine imaging of their ventricles via head ultrasound or rapid magnetic resonance imaging (MRI), frequent head circumference measurements, and clinical evaluation of the infant must be performed to ensure that the infant is not developing progressive hydrocephalus or symptoms of Chiari II, such as apnea, bradycardia, swallowing dysfunction, and/or other cranial nerve deficits.

Immediately after birth, the newborn is monitored in the hospital following back closure. After the neurosurgical team is comfortable that the infant has not developed any Chiari II symptoms, and the head circumference and ventricular size have reasonably stabilized, the infant may be discharged to home with close follow-up as an outpatient. The biweekly or weekly outpatient clinic evaluations by neurosurgery may continue for several weeks. In some cases, the infant's head growth will eventually slow down and follow the normal curve with a stabilization of ventricular size, usually in the moderate range.[10]

Institutions that practice the conservative method of treating asymptomatic, relatively stable ventriculomegaly in the context of myelomeningocele have stringent guidelines for shunt insertion. The criteria for shunt placement includes clinical features of raised intracranial pressure (such as bulging fontanelle, bradycardia, "sun-setting" eye movements, and/or progressively increasing occipito-frontal head circumference), rapidly increasing ventriculomegaly as documented on head ultrasound or rapid MRI, and/or worsening Chiari II symptoms (such as difficulty swallowing, apnea, stridor, abnormal eye movements). If any of these symptoms are present, the infant immediately undergoes an intervention for hydrocephalus.[10]

In 2000, our institution began the practice of conservatively managing infants with asymptomatic, stable ventriculomegaly in the setting of open spina bifida; by 2003, the VP shunt placement rate dropped from 86% to 65%.[9] At Great Ormond Street Hospital for Sick Children, London, the shunt insertion rate has been reported to be as low as 51% since its attempts to conservatively manage infants with myelomeningocele who have a stable, asymptomatic ventriculomegaly.[10]

Patients managed conservatively will have chronic mild to moderate ventriculomegaly. The effects of this chronic condition must be further studied, but so far there has been no clear link between increased ventricular volume and neurocognitive outcome.[18-20] Studies that have researched the neurocognitive outcomes of patients with hydrocephalus have shown that shunted patients consistently score lower on their cognitive test than patients with unshunted, asymptomatic ventriculomegaly.[19,20]

Endoscopic Third Ventriculostomy-Choroid Plexus Cauterization Management

An obstruction in the normal CSF pathway may contribute to the development of hydrocephalus in patients with myelomeningocele. A common site of blockage in obstructive hydrocephalus is between the third and fourth ventricle at the level of the Sylvian aqueduct. Often, children with a Chiari II malformation have a beaked tectum (posterior midbrain), which may obstruct flow through the aqueduct. An endoscopic third ventriculostomy (ETV) is a neurosurgical procedure that creates a bypass for the CSF by creating a new opening in the floor of the third ventricle. An ETV allows CSF to pass from the intraventricular space into the

subarachnoid space to be eventually reabsorbed into the blood stream by the arachnoid villi, which are located next to the sagittal sinus.

Communicating hydrocephalus occurs when CSF is free to circulate in its normal pathway, yet normal CSF absorption does not occur. When an infant develops a Chiari II, it has been theorized that the subarachnoid space does not fully expand during in utero development, thus impeding the flow of the CSF and preventing normal absorption at the level of the arachnoid villi. Choroid plexus cauterization (CPC) is a procedure in which the choroid plexus within the lateral ventricles, which produces the CSF, is cauterized, thus limiting the amount of CSF produced. If the CSF production is sufficiently reduced, equilibrium between production and absorption may be realized.

The practice of combining ETV with CPC began as a method to treat hydrocephalic patients in Uganda after it was shown to be more effective than ETV alone on infants younger than 1 year of age.[8] Many developing countries have a high rate of neural tube defects; however, the treatment of these patients is complicated by their limited access to health care. VP shunt failures and infections are common and may ultimately be lethal. Removing these shunt-related complications is especially important for patients in developing countries, given the patients' limited access to health care.

ETV-CPC does not require the same amount of maintenance as the VP shunt and has been shown to be a safe long-lasting effective treatment of hydrocephalus in patients with myelomeningocele.[7,8,21,22] Studies have shown success rates as high as 76% of patients.[22] This combined treatment has been shown to be more effective than ETV alone. In one study by Warf et al, ETV-CPC was successful in 76% of patients younger than 1 year of age whereas ETV alone was successful in 35% of patients.[8] After 1 year of age, they noted no significant difference between ETV alone and the combined method. A preliminary study in North America of this treatment method experienced less success; nevertheless it found the method to be reasonably safe and stated that a learning curve could have played a factor.[7] The combined approach addresses both the obstructive and communicating components of hydrocephalus and may be the reason for the increased effectiveness of ETV-CPC methods over ETV alone. The ETV allows flow of the intraventricular CSF into the subarachnoid space, thereby bypassing an obstruction at the brainstem level; whereas the CPC decreases CSF production, which is useful in those with hydrocephalus secondary to decreased absorption, also known as communicating hydrocephalus. It would appear likely that both components play a role in the development and severity of hydrocephalus in children with open spina bifida, and therefore the combined method is recommended.[22]

Ventricular Shunt Management

Managing a patient's hydrocephalus with a CSF shunt has remained the predominant method of treatment for hydrocephalus secondary to myelomeningocele. The shunt is composed of 3 parts: a proximal tube that is placed in the ventricle where the CSF is building up, a valve to control the amount of CSF that is drained, and a distal tube that relocates the CSF to another part of the body. The VP shunt is the most common type of shunt. It transmits the CSF from the ventricles to the abdominal cavity or peritoneal space. If the peritoneal space is not a viable option, the shunt may also be placed into the pleural cavity, right atria of the heart, or rarely the gallbladder. Shunted patients require life-long follow-up with their neurosurgeons.

Since the introduction of the shunt valve, patients with myelomeningocele have had an opportunity to live into adulthood.[3] A cohort of 117 patients was studied long term and showed a 39% survival rate to the age of 40.[23] Studying this aging population has offered insight into what factors play a role in the long-term outcomes. Sensory level tested at birth has been shown to be more closely related to long-term outcomes than motor level, and it remains stable over time. Patients who had sensation down to at least their knees had a 61% survival rate at 40 years, while patients with no sensation below their umbilicus had a 17% survival rate.[24] Patients with a more severe neurological deficit were also more likely to require CSF diversion. This study showed that patients without a shunt or who had never required a shunt revision were more likely to live independently, drive a car, and be a community walker.[24]

As a result of shunt-related complications, many neurosurgeons have become more reluctant to shunt their patients. Shunt failures are common, especially in patients with hydrocephalus secondary to myelomeningocele.[25-27] Shunt failure can manifest in a number of ways: inappropriate drainage, occlusion, valve failure, catheter migration, and other less commonly encountered complications. The risk of infection is also high (12.3%) for this group of patients.[28] As a result of these failures and infections, patients can spend weeks to months in the hospital. These extended hospital stays are a significant burden to both the patient and their family.

Studies in adults have demonstrated a correlation between life-time shunt revisions with increased mortality, achievement, memory, and quality of life.[5,29-31] A relationship has also been shown between the number of shunt revisions and cognitive outcome in a large adult cohort.[32] According to Barf et al,[32] patients with open spina bifida who had multiple shunt revisions were subsequently shown to have a lower cognitive outcome.

Conclusion

Early and aggressive shunt insertion and care, which has been the standard of practice since the 1960s, has increased the life span of this patient population, but there have been drawbacks. All patients with a VP shunt have a daily risk of malfunction and/or infection. As this patient population has grown older, neuro-psychological issues related to these shunt complications have become more evident. Consequently, neurosurgeons are reluctant to insert shunts as a first line of therapy. Instead, many centers are initially addressing hydrocephalus in spina bifida patients with ETV-CPC. A few centers, ours included, have attempted to avoid all neurosurgical interventions for relatively stable, asymptomatic ventriculomegaly. If either of these treatment paradigms fail, the infant undergoes placement of a VP shunt. Fortunately, the rate of shunt placement has decreased with the increased prenatal closures and the early use of ETV-CPC. It is our hope that the long-term mortality and morbidity associated with this complex disease will be improved with more selective use of the VP shunt in future generations of children born with myelomeningocele.

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REFERENCES

1. Williams J, Mai CT, Mulinare J, et al. Updated estimates of neural tube defects prevented by mandatory folic acid fortification–United States, 1995–2011. *MMWR Morb Mortal Wkly Rep.* 2015;64(1):1-5.
2. Carter CO. Clues to the etiology of neural tube malformations. *Dev Med Child Neurol.* 1974;16(32):3-15.
3. Laurence K. Effect of early surgery for spina bifida on survival and quality of life. *Lancet.* 1974;1:301-304
4. Bowman RM, McLone DG, Grant JA, et al. Spina bifida outcome: A 25-year prospective. *Pediatr Neurosurg.* 2001;34(3):114-120.
5. Oakeshott P, Hunt GM. Long-term outcome in open spina bifida. *Br J Gen Pract.* 2003;53(493):632-636.
6. Hunt GM, Oakeshott P. Outcome in people with open spina bifida at age 35: Prospective community based cohort study. *BMJ.* 2003;326(7403):1365-1366.
7. Kulkarni AV, Riva-Cambrin J, Browd SR, et al. Endoscopic third ventriculostomy and choroid plexus cauterization in infants with hydrocephalus: A retrospective Hydrocephalus Clinical Research Network study: Clinical article. *J Neurosurg Pediatr.* 2014;14(3):224-229.
8. Warf BC. Comparison of endoscopic third ventriculostomy alone and combined with choroid plexus cauterization in infants younger than 1 year of age: A prospective study in 550 African children. *J Neurosurg Pediatr.* 2005;103(6):475-481.
9. Bowman RM, Boshnjaku V, McLone DG. The changing incidence of myelomeningocele and its impact on pediatric neurosurgery: A review from the Children's Memorial Hospital. *Child's Nerv Syst.* 2009;25(7):801-806.
10. Chakraborty A, Crimmins D, Hayward R, et al. Toward reducing shunt placement rates in patients with myelomeningocele. *J Neurosurg Pediatr.* 2008;1:361-365.
11. Kaufman BA, Terbrock A, Winters N, Ito J, Klosterman A, Park TS. Disbanding a multidisciplinary clinic: Effects on the health care of myelomeningocele patients. *Pediatric Neurosurg.* 1994;21(1):36-44.

12. McLone DG, Knepper PA. The cause of Chiari II malformation: A unified theory. *Pediatr Neurosurg.* 1989;15(1):1-12.
13. McLone DG, Dias MS. The Chiari II malformation: Cause and impact. *Child's Nerv Syst.* 2003;19(7-8) :540-550.
14. Adzick N, Thom EA, Spong CY, et al; MOMS Investigators. A randomized trial of prenatal versus postnatal repair of myelomeningocele. *New Engl J Med.* 2011;364(11):993-1004.
15. Williams H. A unifying hypothesis for hydrocephalus, Chiari malformation, syringomyelia, anencephaly and spina bifida. *Cerebrospinal Fluid Res.* 2008;5(7):1-7.
16. Tamburrini G, Frassanito P, Iakovaki K, et al. Myelomeningocele: The management of the associated hydrocephalus. *Childs Nerv Syst.* 2013;29(9):1569-1579.
17. McLone DG, Dias MS. Complications of myelomeningocele closure. *Pediatr Neurosurg.* 1991;17(5):267-273.
18. Warf B, Ondoma S, Kulkarni A, et al. Neurocognitive outcome and ventricular volume in children with myelomeningocele treated for hydrocephalus in Uganda. *J Neurosurg Pediatr.* 2009;4(6):564-570.
19. Johnson MP, Gerdes M, Rintoul N, et al. Maternal-fetal surgery for myelomeningocele: Neurodevelopmental outcomes at 2 years of age. *Am J Obstetr Gynecol.* 2006;194(4):1145-1150.
20. Fletcher JM, Bohan TP, Brandt ME, et al. Morphometric evaluation of the hydrocephalic brain: Relationships with cognitive development. *Childs Nerv Syst.* 1996;12(4):192-199.
21. Stone SS, Warf BC. Combined endoscopic third ventriculostomy and choroid plexus cauterization as primary treatment for infant hydrocephalus: A prospective North American series. *J Neurosurg Pediatr.* 2014;14(5):439-446.
22. Warf BC, Campbell JW. Combined endoscopic third ventriculostomy and choroid plexus cauterization as primary treatment of hydrocephalus for infants with myelomeningocele: Long-term results of a prospective intent-to-treat study in 115 East African infants. *J Neurosurg Pediatr.* 2008;2(5):310-316.
23. Oakeshott P, Hunt GM, Poulton A, Reid F. Expectation of life and unexpected death in open spina bifida: A 40-year complete, non-selective, longitudinal cohort study. *Dev Med Child Neurol.* 2010;52(8):749-753.
24. Oakeshott P, Hunt GM, Poulton A, Reid F. Open spina bifida: Birth findings predict long-term outcome [published online ahead of print November 25, 2011]. *Arch Dis Child.*
25. Iskandar BJ, Tubbs S, Mapstone TB, et al. Death in shunted hydrocephalic children in the 1990s. *Pediatr Neurosurg.* 1998;28(4):173-176.
26. Massimi L, Paternoster G, Fasano T, Di Rocco C. On the changing epidemiology of hydrocephalus. *Childs Nerv Syst.* 2009;25(7):795-800.
27. Tuli S, Drake J, Lamberti-Pasculli M. Long-term outcome of hydrocephalus management in myelomeningoceles. *Childs Nerv Syst.* 2003;19(5-6): 286-291.
28. Caldarelli M, Di Rocco C, La Marca F. Shunt complications in the first postoperative year in children with meningomyelocele. *Childs Nerv Syst.* 1996;12(12):748-754.
29. Hunt GM, Oakeshott P, Kerry S. Link between the CSF shunt and achievement in adults with spina bifida. *J Neurol Neurosurg Psychiatry.* 199976(5):591-595.
30. Dennis M, Barnes M. Math and numeracy in young adults with spina bifida and hydrocephalus. *Dev Neuropsychol.* 2002;21(2):141-155.
31. Hetherington R, Dennis M, Barnes M, Drake J, Gentili F. Functional outcome in young adults with spina bifida and hydrocephalus. *Childs Nerv Syst.* 2006;22(2):117-124.
32. Barf HA, Verhoef M, Jennekens-Schinkel A, et al. Cognitive status of young adults with spina bifida. *Dev Med Child Neurol.* 2003;45(12):813-820.