A Closer Look at the Global Management of Spina Bifida: The Implementation of Endoscopic Third Ventriculostomy in the Treatment of Spina Bifida-Related Hydrocephalus in Africa

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A Senior Thesis submitted in partial fulfillment
of the requirements for graduation
in the Honors Program
Liberty University
Spring 2018

Acceptance of Senior Honors Thesis

This Senior Honors Thesis is accepted in partial fulfillment of the requirements for graduation from the Honors Program of Liberty University.

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Abstract

Spina bifida, specifically myelomeningocele, is a debilitating neural tube defect that affects patients and families throughout the world. Traditional management and treatment methods are described, followed by an explanation of why this is often inadequate in providing care for those in impoverished areas of the world, including many regions of Africa. Endoscopic third ventriculostomy is proposed as a promising alternative to traditional methods for treating hydrocephalus, an often associated condition, and the implementation of this treatment method in Africa is explored. In order to relieve Africa of the burden of spina bifida-related hydrocephalus and improve global management of spina bifida, it is imperative that the paucity of neurosurgeons in Africa be addressed and successful models for training be expanded.

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What Is Spina Bifida?

Spina bifida is a disease that results from failure of the neural tube to develop correctly in an embryo. This causes improper development of the spinal column, which can have varying levels of severity depending on the type and location of the lesion. When the neural tube develops normally, the neural plate edges fold toward the midline where they eventually meet and fuse together, giving rising to the neural tube; bone and muscle then create a barrier that protects the neural plate as it develops into the spinal cord (Northrup and Volcik, 2000). When a section of the neural plate does not fuse together, however, the growth of bone and muscle over that open segment of the developing spinal column is impeded, creating the "hole" or lesion that is characteristic of spina bifida (Northrup and Volcik, 2000). This disease affects about 3.1 children and adolescents per 10, 000 in the United States, which means more than 24, 000 children and adolescents are living with this disease in the United States alone; overall, spina bifida is slightly more prevalent in females than males (Shin et al., 2010).

Types of Spina Bifida

The mildest and most common form of spina bifida is known as spina bifida occulta ("hidden"). This occurs when development of the vertebrae is incomplete, but the skin covering the defect is still intact (Castillo and Oppenheimer, 2016). Though there is

a gap in at least one of the vertebral arches, the spinal cord and meninges do not protrude through this space but rather stay inside the vertebral canal (Northrup and Volcik, 2000). This may present itself as a small sinus between two vertebrae where they did not join correctly, and a person with this form of spina bifida may have a small dimple, hairy patch, or birth mark over the place where they have the abnormality (Northrup and Volcik, 2000). If only one vertebra is abnormal, there are usually no neurologic or clinical symptoms; this form is even considered a normal variation in the population because it occurs in the lumbar or sacral region of about 10% of people who have no other health problems (Northrup and Volcik, 2000). However, bowel, bladder, and motor problems may arise if more than one vertebra is involved (Northrup and Volcik, 2000).

The other forms of spina bifida fall under the classification of spina bifida cystica, which is the category this report will mainly focus on. These forms are more severe and involve a cerebrospinal fluid-filled cystic sac on the spinal column into which the meninges and/or spinal cord protrude. When only the meninges extend into this sac and the spinal cord and root are still in the proper position, it is known as the meningocele form of spina bifida (Northrup and Volcik, 2000). Although this type of lesion does not involve nerves, it can still be accompanied by hydrocephalus and abnormalities of the central nervous system (Castillo and Oppenheimer, 2016). However, when both the meninges and spinal cord protrude into this sac, it falls under the myelomeningocele

category (see Figure 1).

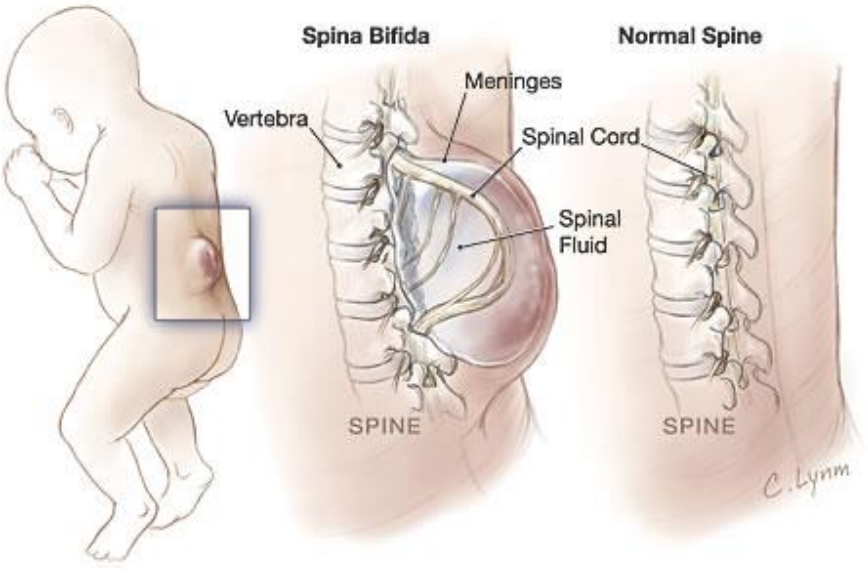

Figure 1. Anatomy of Spina Bifida.

Spina bifida is a disease characterized by improper development of the spinal column due to a defect in neural tube development. There are varying severities of the condition depending on the type and location of the lesion. Shown above is the myelomeningocele form, in which the spinal cord and nerves protrude through an opening in the spinal column. (Figure reprinted from Pace, B. and Lymn, C.: JAMA Patient Page: Spina Bifida. **JAMA 285(23):**3050, 2001. DOI:10.1001/jama.285.23.3050, with permission from the American Medical Association.)

This form is the most severe and is more common than meningocele defects (Northrup and Volcik, 2000). The level of the lesion on the spine also affects the severity of this disease. In general, the higher the lesion the more severe the symptoms due to proximity to the brain; with myelomeningoceles, there is usually paralysis from the location of the lesion down, along with urinary and fecal incontinence, skin anesthesia, and hip, knee, and feet abnormalities (Northrup and Volcik, 2000).

Spina Bifida Etiology

The exact etiology of neural tube defects in general is not perfectly understood, but there are several factors that appear to contribute to the formation of spina bifida. One of the strongest risk factors that has been established for spina bifida is having a family history of spina bifida or anencephaly, another type of neural tube defect that involves the brain itself (Mitchel et al., 2004). When a couple has already had a child with spina bifida, the risk for spina bifida in subsequent siblings is higher than in the general population, ranging from 3% to 8% (Mitchel et al., 2004).

It has also been shown that not taking in enough folate before and during early pregnancy leads to increased risk of the fetus having spina bifida. In fact, the United States Public Health Service recommends that all women in the United States who are capable of having children take 0.4 mg of folic acid a day in order to reduce the risk of having a child affected by spina bifida or another neural tube defect (CDC, 2004). Research using vitamin supplements has demonstrated that not consuming adequate folic acid increases the risk of the child having spina bifida by two-fold to eight-fold (Mitchel et al., 2004). Though the mechanism explaining this association has not been determined exactly, it is known that folate plays a part in two metabolic pathways that are very important to the developing embryo; one pathway contributes to nucleic acid synthesis, and the other is involved in a variety of other methylation reactions (Mitchel et al., 2004). The concentration of homocysteine levels can also increase when folate metabolism is disrupted, which in some animal models is known to be teratogenic to the neural tube (Mitchel et al., 2004). Other known teratogens are anticonvulsant drugs such as valproic

acid and carbamazepine, which are associated with an increased risk in fetal spina bifida when taken by the mother (Hernández-Díaz et al., 2001). It is estimated that up to 1% to 2% of fetuses who are exposed to valproic acid end up developing a neural tube defect (Koren and Kennedy, 1999). The mechanism by which these drugs affect the development of spina bifida is also unknown, though there are several theories, including that it affects the metabolism of folate (Mitchel et al., 2004). Some other factors include a genetic predisposition for the disease, whether mothers have pregestational diabetes (increased risk when mothers do have it), and the presence of malformation syndromes due to chromosomal abnormalities and single gene disorders (Castillo and Oppenheimer, 2016).

Diagnosis of Spina Bifida

Many neural tube defects are able to be detected before the baby is born. A screening test can be performed between the 16th and 18th week of gestation in which the alpha-fetoprotein is measured in the maternal serum; increased levels of this protein can be an indicator of the presence of a neural tube defect (Castillo and Oppenheimer, 2016). However, this test is not highly specific or sensitive and is therefore not conclusive alone (Cameron and Moran, 2009). Following this screening test, amniocentesis may be performed in which a sample of the amniotic fluid is obtained and the fetal DNA can be analyzed for genetic abnormalities (Nicolaides et al., 1986). However, this option carries a small risk of miscarriage, and a less invasive alternative to examine those with a high serum alpha-fetoprotein is to perform a detailed ultrasound examination (Nicolaides et al., 1986). The ultrasound is capable of showing the U-shaped open neural arch and any

myelocele or myelomeningocele that may be present (Nicolaides et al., 1986). These ultrasound examinations can be as sensitive as 96% and as specific as 99.9% when the spine is examined by a very skilled ultrasonographer (Nicolaides et al., 1986). There are several cranial and cerebellar signs that are telling and easy to identify in determining the presence of open spina bifida that helps improve the accuracy of these ultrasound examinations (Nicolaides et al., 1986). The use of ultrasound has for the most part surpassed the use of alpha-fetoprotein in screening for neural tube defects since it has such a higher level of specificity (Cameron and Moran, 2009). Some centers also use MRI to detect spina bifida prenatally; this can help estimate the level of the lesion, as well as analyze intracranial pathology and other potential structural abnormalities (Castillo and Oppenheimer, 2016). Even if spina bifida is not detected before birth, it is usually evident upon physical examination at birth as there is often a corresponding irregularity on the cutaneous level (Castillo and Oppenheimer, 2016).

Spina Bifida Management

Once a baby with spina bifida is born, a multidisciplinary team is essential in providing the appropriate care and treatment required. The first issue that must be dealt with is the lesion itself. Novel surgical techniques have actually made it possible to address this while the baby is still in the womb. One study done by Olutoye and Adzick reported success in repairing a large myelomeningocele in a fetus at 23 weeks with open fetal surgical intervention (Olutoye and Adzick, 1999). For myelomeningoceles, this in utero surgery removes the cystic membrane of the lesion, disconnects attachments of the meninges, and allows the spinal cord to fall into its proper place in the spinal canal

(Northrup and Volcik, 2000). An acellular dermal graft is put between the skin and spinal cord to prevent it from tethering, and then the skin is closed up over the area (Northrup and Volcik, 2000). Research suggests that if this procedure is performed early enough (before the 24th week of gestation ends), the young fetus's regenerative properties will be able to help heal the wound and potentially prevent damage to the spinal cord later on in pregnancy, as well as possibly resolving some secondary conditions associated with spina bifida (Olutoye and Adzick, 1999). However, traditionally the lesion is repaired as soon as possible after birth, usually within the first 24 to 48 hours (Philips et al., 2017). Further tests can then be performed to determine the extent of secondary conditions.

Urological management. Urological management is another important facet of care for spina bifida patients. The nerves of the bladder originate in the thoracic, lumbar, and sacral spinal cord, so bladder function in spina bifida patients is almost always affected (Castillo and Oppenheimer, 2016). The level of the lesion is not always a precise indicator of bladder function, but generally the higher level lesions cause the bladder to retain urine, while lower level lesions cause it to leak urine (Castillo and Oppenheimer, 2016). When the bladder does not empty properly, there is an increased risk for urinary tract infections, as well as complications with and damage to the kidneys due to the high pressures from poor emptying (Phillips et al., 2017). Bladder management involves clean intermittent catheterization, as well as medication to help control bladder spasms (Phillips et al., 2017). For babies the goal of management is simply to maintain normal bladder pressure and keep the kidneys safe, but as children

grow older social continence is also a goal and can usually be achieved by catheterization, although surgery is sometimes necessary (Phillips et al., 2017).

Bowel management. Because the sacral nerves also innervate the rectal sphincter, most children with myelomeningocele (about 90%) will have a neurogenic bowel that will require management (Phillips et al,. 2017). Spina bifida patients with a lesion at the thoracic level often face difficulty in bearing down, whereas patients with sacral level spina bifida often have a hard time attaining proper stool consistency; the goal of bowel management is for a patient to be able to empty their bowel of soft, formed stools regularly and consistently each day (Castillo and Oppenheimer, 2016). Bowel emptying techniques are an essential tool in management and include rectal stimulation, suppositories, behavioral training, and enemas; surgical intervention may be required if the patient is not able to achieve fecal continence with these techniques (Castillo and Oppenheimer, 2016).

Orthopedic management. Spina bifida patients will also require orthopedic management. Ambulation is strongly dependent on the level of sensorimotor function, which is the main factor in determining lumbar and sacral lesions, and independent mobility is probable in almost all cases of these lesions (Castillo and Oppenheimer, 2016). However, for lesions above L2, independent mobility is not likely and a wheelchair will probably be necessary (Castillo and Oppenheimer, 2016). Unfortunately, as children age their ability to ambulate can deteriorate as weight and orthopedic deformity increase, making walking more difficult, and a wheelchair often becomes a more efficient option at that point (Castillo and Oppenheimer, 2016). Orthopedic

management involves the prevention or correction of deformities in order to help patients achieve the highest level of mobility and independence that is realistic for them (Thomson and Segal, 2010). A wide range of abnormalities, including a tethered cord, hip disorders, knee, foot, or ankle deformities or problems, scoliosis, and kyphosis, may need to be addressed (Thomson and Segal, 2010). Physical therapy from an early age is essential to achieving optimal motor function, and should aim to normalize experiences, help improve posture for sitting or standing, manage orthotics, and keep the skin from breaking down (Castillo and Oppenheimer, 2016). Orthotics can be helpful in preventing contracture, as well as encouraging independent mobility, and walkers, braces, standers, and parapodiums may also be used to help with support and mobility (Castillo and Oppenheimer, 2016).

Developmental and cognitive management. There is a wide range of developmental outcomes for children with spina bifida. In general, a higher level lesion is associated with more severe abnormalities of brain development, which in turn result in more serious neurobehavioral impairments (Fletcher et al., 2005). Children with spina bifida often have specific learning disabilities, but a majority of them, about 80%, still have intelligence within the normal range (Castillo and Oppenheimer, 2016). They are generally stronger in language, such as reading and spelling, and weaker in perceptual, motor, and math skills (Castillo and Oppenheimer, 2016). Routine neuropsychological and psycho-educational evaluations are helpful in identifying learning issues and can aid in developing an appropriate educational plan for the child with spina bifida (Castillo and Oppenheimer, 2016).

Neurosurgical management. Neurosurgical management is a very important aspect of providing care for spina bifida patients. Children with spina bifida usually also have a Chiari II malformation, but this is only addressed with surgery when it is symptomatic enough, which only occurs in about 15-35% of cases (Castillo and Oppenheimer, 2016). A Chiari II malformation usually forms because the fourth ventricle did not develop sufficiently, creating a small posterior fossa which can cause the brain to be displaced caudally with the cerebellum and brainstem extending through the foramen magnum (Phillips et al., 2017). Surgical intervention may be needed if patients cannot regulate their breathing, lose the normal function of their vocal cords, have a hard time swallowing, or are weak in their arm or hand (Phillips et al., 2017).

Another neurological problem patients with spina bifida often face is a tethered spinal cord. This happens when the end of the spinal cord is tethered to the spine by scar tissue, creating tension as the child grows and stretches (Phillips et al., 2017). Almost all children with a repaired myelomeningocele will have this, but it is usually asymptomatic and left untreated because it will often just re-tether (Castillo and Oppenheimer, 2016). Nevertheless, if a patient experiences back or leg pain, leg spasms, weakness, deterioration in gait or sensation, or increased constipation or urological irregularities, an untethering procedure should be considered (Phillips et al., 2017).

In addition to these issues, the initial closing of the lesion in the spine often disrupts the pathway of the cerebrospinal fluid, creating a condition known as hydrocephalus in which the cerebrospinal fluid accumulates in the ventricles of the brain and causes them to swell (see Figure 2). At least 70-85% of children who have

hydrocephalus related to spina bifida, if not more, end up needing to have a shunt placed in order to maintain normal intracranial pressure (Philips et al., 2017).

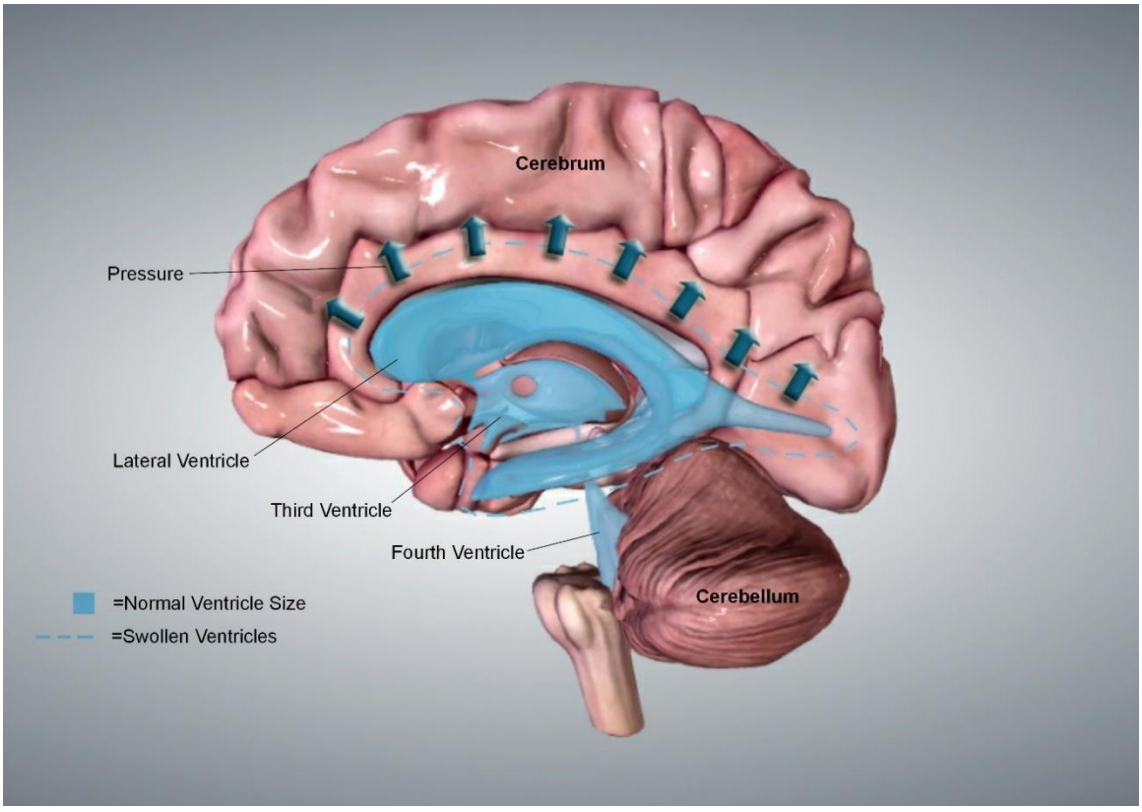

Figure 2. Anatomy of Hydrocephalus.

Children with spina bifida often develop hydrocephalus upon closure of their spinal lesion. Hydrocephalus is characterized by an accumulation of cerebrospinal fluid in the ventricles of the brain due to disruption of the cerebrospinal fluid pathway. This can be seen in their enlargement compared to the ventricles of a normal brain. This buildup of cerebrospinal fluid then results in brain compression due to the pressure exerted by the swollen ventricles. (Figure created using BioDigital Human software.)

Global Management of Spina Bifida

Clearly, a considerable amount of skill and effort are required when caring for patients who have spina bifida and providing the treatment and management they need to

live a quality life. Unfortunately, this care can be difficult to deliver in places of the world that are lacking in resources, such as many impoverished regions of Africa. Though the exact incidence of this disease is not known for these regions, most likely it is as high as that reported for any other area of the world (Warf, 2011). This means that at least one child in every 1, 000 live births is affected with myelomeningocele; still, the number of individuals affected is probably higher compared to developed countries due to higher birth rates (Warf, 2011). Of the children affected by neural tube defects, about 80-90% develop the associated condition hydrocephalus (Warf et al., 2008). As mentioned previously, the traditional treatment for this condition is the placement of a ventriculoperitoneal shunt. However, this treatment brings with it an array of challenges, especially in poverty-stricken contexts.

Challenges with Traditional Treatment

Shunts are known to have a high rate of failure and complications, and numerous studies have demonstrated this unfortunate phenomenon. In a study by Dakurah and his colleagues, 37 of their patients who received shunts developed complications associated with the shunt (Dakurah et al., 2016). An 86% shunt failure rate was reported for the spina bifida population of a study by Steinbok and his coauthors (Steinbok et al., 1992), while another study by Tuli and his colleagues yielded a 64% failure rate of the spina bifida population (Tuli et al., 2003).

Numerous problems can occur when a shunt is placed. The most common complication is the development of a shunt infection; according to Idowu and his colleagues, a shunt infection can lead to a higher risk of seizure disorder, as well as

decreased intellectual performance and an increase in mortality rate long-term (Idowu et al., 2009). They also point out that these infections are potentially fatal, especially if the child is brought in late for treatment, which is often in the case in this context (Idowu et al., 2009). Another potential complication is migration of the shunt, which requires another surgery to correct its placement; over time shunts can also become leaky, obstructed, or disconnected (Dakurah et al., 2016). These all contribute to the high failure and complication rates of shunts, which in turn accounts for the high likelihood of subsequent revisional surgeries. In adult patients with myelomeningocele, a life-time dependence on a shunt has even been associated with decreased survival (Davis et al., 2005).

In developed countries, these complications and failures can be dealt with and tolerated because emergency neurosurgical care facilities are more readily accessible. However, this is not the case in many regions of Africa where hospitals are few and far between and poverty and poor infrastructure also contribute to lack of access (Warf, 2011). On top of all this, children in developing countries are often malnourished and therefore already predisposed to infection (Laeke et al., 2017). This has prompted the search for a different approach to treating hydrocephalus, one that is more appropriate for less developed contexts.

A Promising Alternative

What is ETV? Endoscopic third ventriculostomy (ETV) is a surgical procedure that offers hope as an alternative to traditional shunt placement. In ETV, holes are made in the floor of the third ventricle of the brain to allow for the drainage of the accumulated

cerebrospinal fluid (CSF) into the normal CSF pathway for reabsorption into the body (see Figure 3).

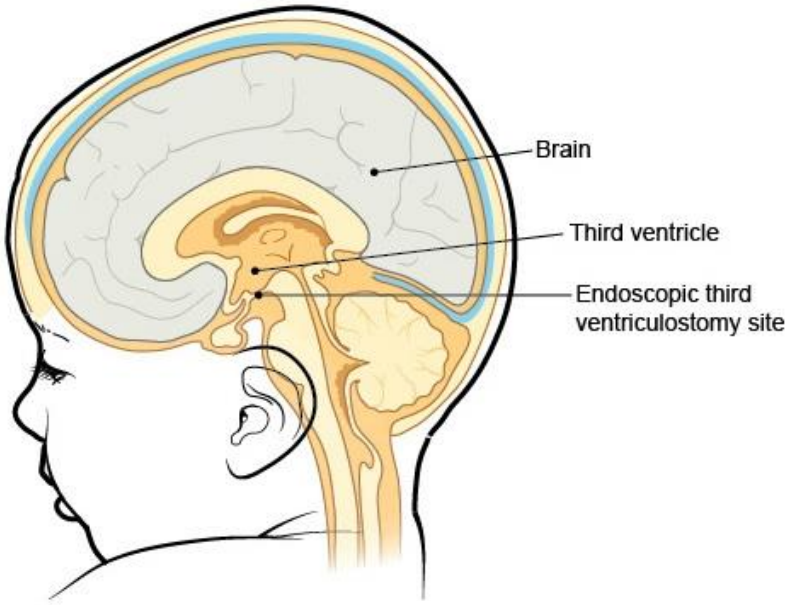

Figure 3. ETV location.

ETV is a procedure in which holes are placed in the floor of the third ventricle, labeled above, allowing excess cerebrospinal fluid to be reabsorbed into the body by the normal CSF pathway. (Figure used with permission from website article: About Your Endoscopic Third Ventriculostomy (ETV) Surgery for Pediatric Patients. **Memorial Sloan Kettering Cancer Center**, 2014.)

Surgical technique. Benjamin Warf, a leading surgeon in the advancement of ETV in Africa, describes his procedure for performing ETV in several of his articles. Patients were prepared with anesthesia and by placement in the supine position with their heads turned to the left (Warf and Campbell, 2008). This position is the same used when placing a right frontal ventriculoperitoneal shunt, allowing for a quick transition to the placement of a shunt in the case of ETV failure during the procedure (Warf and

Campbell, 2008). The incision for entry was made in the right lateral corner of the anterior fontanel; after that, the dura was opened and the cortical surface was coagulated and penetrated, allowing for the insertion of the endoscope at the right frontal horn where it could then be guided into the third ventricle (Warf and Campbell, 2008). The endoscope could then be used to view the aqueduct and floor of the ventricle so that the site for the ETV could be decided (Warf and Campbell, 2008). Then a Bugby wire was used to break through the ventricular floor, while avoiding the use of electrocautery so as not to harm the basilar artery, until the endoscope could enter the prepontine cistern and proper CSF flow was observed (Warf and Campbell, 2008).

Choroid plexus cauterization. The choroid plexus is a collection of cells that produces cerebrospinal fluid in the ventricles of the brain. Cauterizing this in conjunction with performance of ETV has been shown to improve the success rate of ETV treatment, especially in certain etiologies of hydrocephalus. In this procedure, cauterization is performed on the choroid plexus with the Bugby wire monopolar electrocautery starting at the right foramen of Monro and continuing back into the atrium; once this is done, the endoscope was maneuvered into the right temporal horn to reach the rest of the choroid plexus (Warf and Campbell, 2008). This same procedure was then performed in the right ventricle. This leaves it more shriveled and unable to continue producing excess spinal fluid that could contribute to the fluid build-up in hydrocephalus (see Figure 4).

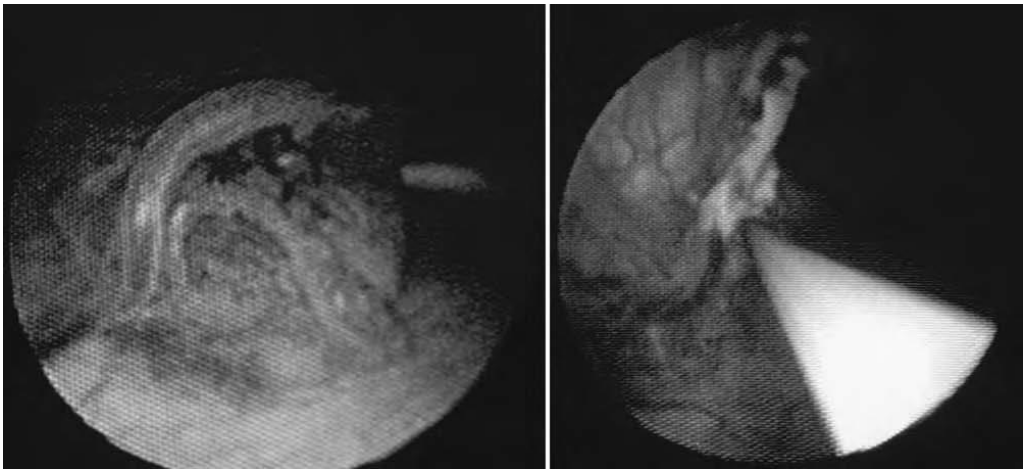

Figure 4. Choroid plexus before and after cauterization (Warf, 2005).

The normal anatomy of the choroid plexus can be seen in the image on the left. After it is cauterized by the Bugby wire, it can be seen white and shriveled in the image on the right, rendering it unable to produce excess cerebral spinal fluid. (Figure used with permission from 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 103:**475–481, 2005. DOI: 10.3171/ped.2005.103.6.0475.)

Benefits of ETV. One very important benefit of ETV is that it has few complications. Contrast this with the placement of a ventriculoperitoneal shunt, which has a very high complication rate as discussed previously. Ojo and his coauthors point out the range of 23% to 25.8% for the complication rate of ventriculoperitoneal shunts, compared to a 6 to 8% complication rate with ETV (Ojo et al., 2016). Because no hardware is placed in the brain with ETV, it cannot be displaced over time, develop leaks, or become disconnected; the majority of the difficulties associated with shunts are not obstacles with ETV. Sometimes surgery needs to be performed again, but this happens on a rarer occasion than do shunt revisions (Warf, 2013). Complications with ETV have been shown to usually occur within 6 months after surgery and are easily discernible

(Warf, 2013). This makes it easy to resolve them before they can cause severe damage. Due to the fact that it has a lower complication rate, this type of surgery also requires minimum follow-up. This is very important because in many regions of Africa, it is very difficult to reach places where one can receive medical attention. Many times, families need to travel long distances to a medical facility, but this can be dangerous due to regions of poor infrastructure; poverty also inhibits traveling (Warf and Campbell, 2008). When a child has hydrocephalus, treatment is urgent. But many times, families cannot reach a medical facility in time. It is therefore a great advantage that this surgery has a low complication rate.

Another significant benefit of ETV is that it has a high success rate. In a study by Ojo and his colleagues, they found that this surgery has a success rate of 73% in their Nigerian setting (Ojo et al., 2015). This is only one example of studies that have demonstrated the high success rate for this procedure. In the beginning, there had been some concern that this procedure was not very successful in patients with hydrocephalus of certain etiologies, like myelomeningocele. However, the procedure choroid plexus cauterization described previously is a procedure that can be paired with ETV and has demonstrated better success rates for the majority of these etiologies. In a study by Warf and his colleagues, the success rate increased from 35 to 76% with the addition of choroid plexus cauterization in children with myelomeningocele (Warf et al., 2009). This discovery makes ETV a viable option for numerous children, giving it a high success rate in a wide range of etiologies.

Finally, ETV is a more cost effective procedure. Komolafe and his colleagues reported that 15.1 % of the families that need treatment for a child's hydrocephalus left before surgery against the doctor's advice due to financial limitations (Komolafe et al., 2007). Therefore, the provision of economic treatment is crucial to the service of the African population. Shunts can be very expensive; many times it is therefore not an option for many poor families. Although less expensive shunts have been developed, they have other associated costs, especially if they cause repeated problems (Idowu et al., 2009). Because ETV does not require the placement of hardware in the brain, this is not an expense for this type of procedure. This surgery is also a shorter procedure than the placement of a shunt, meaning several things. First of all, it means that this procedure requires a much shorter hospital stay. Furthermore, Idowu explains that an abbreviated procedure requires less anesthesia (Idowu et al., 2009). These factors reduce the expenses of the family considerably. Taking all this into consideration makes ETV very beneficial when it comes to treating hydrocephalus in a poor population.

The Problem That Still Stands

Although ETV has advantages over shunt placement and is a promising alternative in low-resource settings for the management of hydrocephalus, it is still not a widespread treatment option in Africa. Neurosurgical care in Africa is greatly limited by a shortage of neurosurgeons and a lack of knowledge of neuroendoscopic management of hydrocephalus. To put things in perspective, there is one neurosurgeon for every 90, 000 inhabitants in the United States; however, in East Africa (Uganda, Tanzania, and Kenya) it is estimated there is one neurosurgeon for every 10 million people (Burton, 2015). It is

also estimated that sub-Saharan Africa, not including South Africa, has fewer than 100 neurosurgeons (Warf et al., 2011).

This situation begs the question: What is being done to remedy this problem of a paucity of neurosurgeons in Africa? Because the use of ETV is still not widespread in Africa, it was not expected that many programs would be found in place with the goal of training surgeons in the endoscopic third ventriculostomy procedure. However, it was hoped that any current strategies that may provide a replicable model for expanding the training, and ultimately use, of ETV would be identified.

Method

To explore the answer to this question, A PubMed® search was performed for articles on neurosurgical management in patients with spina bifida. Articles were identified by searching for the terms "ETV and Africa and hydrocephalus." They were then read and searched for mention of efforts to train locals in performing the ETV procedure. Articles were excluded if they did not refer to the management of hydrocephalus among individuals living with spina bifida in Africa. Articles meeting inclusion criteria were classified according to management method (shunt, ETV, ETV/Choroid plexus cauterization) and whether or not they mentioned efforts to train locals in this procedure. The countries reached by the training programs were identified and several characteristics of the models were explored.

Results

A total of 47 articles were identified, of which 30 met inclusion criteria. Of these 30, only five (0.17%) referred to efforts to train local medical professionals, including surgeons and nurses, on the use of ETVs. Of these five studies, only two gave more thorough descriptions of their efforts. One article described the efforts of the Neurosurgery Education and Development (NED) Foundation. The efforts of this educational programs reached seven African nations (Kenya, Tanzania, Ethiopia, Rwanda, Uganda, Sudan, and Zimbabwe). The NED Foundation trained 72 local surgeons, 122 nurses, and 49 volunteer neurosurgeons from those seven African nations through two mobile projects (Piquer et al., 2015). The training included techniques utilizing both ETV with and without CPC for hydrocephalus associated with varying conditions including, but not limited to, infection and myelomeningocele (Piquer et al., 2015). It also underscored the need for efforts for long term follow-up (Piquer et al., 2015). In an article by Laeke and his colleagues, the results of two studies, one performed predominantly by consultant surgeons and the other performed predominantly by residents, were compared and analyzed. Although the ETV failure rate in this study was higher than reported elsewhere, the failure rate decreased from the first to second study, probably reflecting a gain in collective experience (Laeke et al., 2017). It is hoped that this trend, in combination with the application of predictive models and increased access to imaging techniques, will allow for continued improvement and decreased failure rates (Laeke et al., 2017).

Discussion

Like most literature reviews, this review had several limitations. One was the possibility that the exact search used did not pull in every single article relating to the question at hand. It is also likely that not all efforts in low-income countries are described in the literature, and that the lack of description of training efforts could in part be due to the fact that most of the articles were surgical in nature. However, overall it is still clear that there is a gap in the education of neurosurgeons in Africa.

When looking to provide treatment for hydrocephalus in impoverished regions, it is essential that the resources and limitations of the setting are considered. That being said, it is important to note that although finding effective treatment for hydrocephalus and therefore improving spina bifida management in low-income countries is important, preventing these conditions in the first place would be the ideal alternative. As mentioned previously, folate supplementation in women of childbearing age has been shown to be beneficial in preventing the development of neural tube defects in their fetuses. However, although the regulatory agencies of more developed countries such as the United States have acted on this evidence by recommending folate supplementation as an important aspect of perinatal care, this is not something that is normally emphasized in developing countries. Warf and Campbell have suggested that the fact that neural tube defects are more common in East Africa compared to more developed regions is due in part to the lack of maternal and perinatal care, which would include measures such as folic acid supplementation (Warf and Campbell, 2008). One study reviewed the evidence for the impact of various community-based antenatal, intrapartum, and postnatal interventions on

neonatal health and survival in developing countries (Bhutta et al., 2005). Folate supplementation was identified as an important intervention to be included in a health program's antenatal care package based on the evidence gathered (Bhutta et al., 2005). In countries with limited resources, preventing neural tube defects by implementing folate supplementation would ultimately be more cost effective than managing the effects of these conditions with various expensive surgical techniques. Therefore emphasizing preventative care should be a priority even over treatment by more expensive surgical salvage techniques.

Although prevention is the preferred route for management of spina bifida, the reality is that right now many newborns in developing countries are affected by hydrocephalus. Until preventative measures are effectively implemented and their positive effects manifested in the population, hydrocephalus is still a problem that needs to be addressed. Although ETV has advantages over shunt placement in low-resource settings for the management of hydrocephalus, and efforts to train local surgeons in its use have been successful, very few institutions have developed training programs along with their outreach efforts. It is evident that training programs can strengthen collaboration among institutions from higher and lower income nations (Piquer et al., 2015). However, this benefit will not be fully realized until current efforts are enlarged and new educational programs are developed to meet the growing need of individuals living with spina bifida-related hydrocephalus in Africa.

Future Work

Because using ETV as a treatment method for spina bifida-related hydrocephalus is still a relatively new development, many areas regarding its use still need further study and development. The long-term effects it has on neurocognitive development compared to shunt placement will need further exploration. Methods for predicting success of ETV have been developed, but methods that are appropriate for settings where imaging equipment is limited should continue to be sought and developed. It is necessary that successful models for providing training on the ETV procedure be replicated and expanded to enable the spread of its implementation as a primary treatment for hydrocephalus in low-resource settings. Connections to allow for collaboration among institutions from higher and lower income nations should be established, as well as standard protocols for low-resource settings and follow-up and documentation strategies to enable the tracking of progress. Oftentimes patients were lost to follow-up before their progress could be duly noted, so this is a crucial area to be developed. The importance of community-based rehabilitation in the lives of patients with spina bifida has also been demonstrated. This is an essential aspect of providing care to this population, especially because of its role in neurocognitive outcomes for the patient. The support and care provided afterward can play just as much a role in the success of a procedure as the technique and performance of the procedure itself. Educating the community and families on how to provide that support is therefore also a vital undertaking.

ETV is a treatment method that has the potential to revolutionize the management of spina bifida-related hydrocephalus in Africa. It is highly beneficial over

ventriculperitoneal shunts in that context in large part because it does not leave the patient with a lifetime dependency on hardware in the brain that could fail at any time. When paired with choroid plexus cauterization, it is even more effective as a treatment option for an even wider range of hydrocephalus etiologies. It therefore represents a key advancement in providing care to this population worldwide. However, its full potential to revolutionize treatment will not be seen until there are more efforts made in educating both local medical professionals on how to perform the ETV procedure itself, as well as the communities and families on how to provide care to these individuals beyond the walls of healthcare facilities. If this can be achieved it will be a major advancement in the mission of providing care and the best possible quality of life to the spina bifida population across the globe.

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