Advancements in the Management, Treatment, and Rehabilitation of Hydrocephalus: A Comprehensive Literature Review on Cerebrospinal Fluid Shunt Systems and Associated Complications

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Abstract:
Background: Hydrocephalus is a condition characterized by an abnormal accumulation of cerebrospinal fluid (CSF), leading to increased intracranial pressure and neurological deterioration. CSF shunting remains the primary treatment, though complications such as infection and shunt failure present significant challenges. Rehabilitation is crucial for optimizing functional recovery and improving patient quality of life.
Methods: This review synthesizes recent studies on hydrocephalus epidemiology, etiology, pathophysiology, diagnosis, management, and rehabilitation. It focuses on CSF shunt systems, their classifications, failure mechanisms, infection-related complications, and rehabilitation strategies.
Results: Advances in hydrocephalus management have improved patient outcomes, yet shunt-related complications persist. Standardized surgical protocols and antibiotic-impregnated catheters have reduced infections, but issues like obstruction and mechanical failures remain prevalent. Emerging technologies such as programmable shunts and endoscopic third ventriculostomy (ETV) show promise. Rehabilitation, including neurocognitive therapy, motor and speech therapy, and psychosocial support, plays a vital role in long-term recovery.
Conclusion: Despite advancements in hydrocephalus treatment, long-term complications continue to affect morbidity and mortality. Rehabilitation is essential in addressing cognitive, motor, and psychosocial challenges. Future research should focus on optimizing infection control, improving shunt materials, refining surgical techniques, and expanding rehabilitation interventions to enhance patient outcomes.
Keywords: Hydrocephalus, Shunt Infection, Risk Factors, Rehabilitations

Introduction

Hydrocephalus is a neurological disorder characterized by an abnormal accumulation of cerebrospinal fluid (CSF) within the brain's ventricular system, leading to increased intracranial pressure (ICP) and progressive neurological deficits. This condition can be congenital or acquired and affects individuals of all ages, with significant implications for morbidity and mortality. Without timely and appropriate intervention, hydrocephalus can result in severe cognitive and physical impairments, or even death.

The primary treatment for hydrocephalus involves surgical CSF diversion through shunt systems

or, in selected cases, endoscopic third ventriculostomy (ETV). While these interventions have significantly improved patient survival and neurological function, shunt-related complications, including infections and mechanical failures, remain prevalent. Such complications necessitate frequent surgical revisions and prolonged hospitalizations, posing a substantial burden on both healthcare systems and patients.

Beyond surgical management, rehabilitation plays a crucial role in improving outcomes for individuals with hydrocephalus. Cognitive, motor, and psychosocial impairments are common in affected individuals, requiring a multidisciplinary approach that includes neurocognitive therapy, physical rehabilitation, speech therapy, and psychosocial support. Effective rehabilitation strategies can enhance functional recovery, improve quality of life, and reduce the long-term impact of the condition.

This literature review aims to provide a comprehensive analysis of hydrocephalus, focusing on its epidemiology, pathophysiology, clinical presentation, and current management approaches. Special attention is given to CSF shunt systems, their mechanisms, associated complications, and the role of rehabilitation in optimizing patient outcomes. By synthesizing current evidence, this review seeks to identify gaps in knowledge and propose future directions for research and clinical practice.

Hydrocephalus

Hydrocephalus is a physiological disorder of cerebrospinal fluid (CSF) that causes abnormal accumulation of CSF in the ventricular system, resulting in abnormal dilation of part or all of the cerebral ventricles. Hydrocephalus is generally accompanied by increased intracranial pressure (Kahle et al., 2016; Rekate, 2009). Hydrocephalus in children is a surgical disorder and can result in progressive neurological disorders and death if not treated properly (Isaacs et al., 2018; Vinchon et al., 2012).

Epidemiology

Hydrocephalus can occur at any age, both in pediatric and adult groups. The prevalence of hydrocephalus in newborns is estimated to be around 0.4 to 0.8 in 1,000 live births (Jamil & Kestle,

2017; Leinonen et al., 2018).

Etiology

The mechanism of hydrocephalus can generally be categorized based on disorders in the physiology of the CSS, namely disorders in the absorption of CSS and disorders in the production of CSS. The organization of the brain's ventricular system along with the general physiology of CSS consists of the production of CSS choroid plexus from the two lateral ventricles, the 3rd and 4th ventricles. CSS in the lateral ventricles collects in the 3rd ventricle through the foramen of Monro and reaches the 4th ventricle through the cerebral aqueduct(Sylvius). CSF exits the 4th ventricle through the foramina of Magendie medially and a pair of foramina of Luschka laterally to the outer surface of the central nervous system. Most of the fluid is reabsorbed in the arachnoid granulations that drain into the superior sagittal sinus (Damkier et al., 2013; M. S. Greenberg, 2005).

The majority of CSF (80%) is produced by the choroid plexus epithelium (CPE). which is a network of highly vascularized perforated capillaries, surrounded by polarized cuboidal epithelial cells connected by *tight junctions* , located in both lateral ventricles, accounts for approximately 80% to 95% of the CSF produced in the choroid plexus, and in the 4th ventricle (S. M. Greenberg, 2016; Karimy et al., 2016). CSF is one of the most efficient secretory epithelia in the human body; it produces CSF at a rate of 0.4 ml/min per gram of tissue, a rate rivaled only by the proximal tubules of the kidney and the ducts of the exocrine pancreas (Damkier et al., 2013). Most other intracranial production occurs in the interstitial spaces of the brain (S. M. Greenberg, 2016; Karimy et al., 2016). CSF is also produced by the ependymal lining of the ventricles, the spinal cord, and the dura of the nerve root sheaths. CSS production in children is approximately 20 to 25 ml/hour per day, where the rate of CSS production does not depend on intracranial

pressure (Cutler et al., 1968; S. M. Greenberg, 2016).

CSF absorption occurs primarily in the arachnoid granulations, villous structures that extend into the venous sinuses. Other sites of CSF absorption are the choroid and *glymphatic plexuses* . The rate of CSF absorption depends on the CSF pressure (S. M. Greenberg, 2016; Leinonen et al., 2018).

Impaired CSF absorption is manifested as obstructive (non-communicating) hydrocephalus and non-obstructive (communicating) hydrocephalus. Obstructive hydrocephalus is hydrocephalus that occurs due to impaired CSF flow proximal to the arachnoid granulation. Radiological examination of obstructive hydrocephalus will show partial dilatation of the ventricular system. The mechanism of non-obstructive hydrocephalus is at the level of arachnoid granulation which results in impaired CSF reabsorption in general and has an impact on dilatation of the entire ventricular system, so it is called communicating hydrocephalus (S. M. Greenberg, 2016; Karimy et al., 2016).

Another mechanism of hydrocephalus is the disruption of excessive CSS production resulting in an imbalance between production and absorption. This mechanism causes a decrease in absorption function which results in the accumulation of CSS in the entire ventricular system (S. M. Greenberg, 2016; Leinonen et al., 2018). The rate of CSS production and reabsorption must be in balance. Disruption of homeostasis can cause hydrocephalus due to CSS hypersecretion secondary to choroid plexus hyperplasia (CPH) or non-obstructive choroid plexus tumors, such as choroid plexus papilloma (CPP) (Karimy et al., 2016).

Hydrocephalus is a common manifestation found in various brain conditions, both congenital and acquired. The term congenital hydrocephalus is used to define the condition of pure hydrocephalus or hydrocephalus resulting from manifestations of other pathological conditions

found at birth or shortly after birth. Hydrocephalus acquired in children with a history of normal birth without hydrocephalus is categorized as acquired hydrocephalus (Jamil & Kestle, 2017).

a. Congenital Hydrocephalus

The majority of hydrocephalus in children is present at birth or shortly after birth. Congenital hydrocephalus is generally associated with aqueductal stenosis, Dandy-Walker malformation, holoprosencephaly, or other general malformations of brain development (Jamil & Kestle, 2017).

The cellular and genetic mechanisms of congenital hydrocephalus that have been found are the association of hydrocephalus with the X chromosome (*X-linked*) with the presence of *the L1-cell adhesion molecule* (L1CAM) gene located on chromosome Xq28. The L1CAM gene has implications for early brain development and brain function. The L1CAM gene gives manifestations in the form of MASA syndrome, namely mental retardation , adducted thumbs , shuffling *gait* and aphasia, and CRASH syndrome, namely *corpus callosum hypoplasia* , mental retardation, adducted thumbs , spastic paraparesis and hydrocephalus (Jamil & Kestle, 2017).

Aqueductal stenosis is one of the most common causes of congenital hydrocephalus. Aqueductal stenosis causes obstruction to the flow of CSF which results in abnormal accumulation of CSF in the ventricular system (Garne et al., 2010). Aqueductal stenosis found in males is thought to be closely related to *X-linked disorders* and generally has a worse outcome (Jamil & Kestle, 2017).

Another congenital abnormality that is also associated with congenital hydrocephalus is Dandy-Walker malformation . Dandy-Walker malformation is an abnormality in the development of the cerebellum that causes the size of the fourth ventricle to be larger than normal , elevation of the tentorium, and in some cases accompanied by hydrocephalus suspected of being due to atresia

of the foramen of Lushka and Magendie (S. M. Greenberg, 2016; Jamil & Kestle, 2017). A large fourth ventricle generally does not require special management, but progressive supratentorial ventricular dilatation should be evaluated and managed as acute hydrocephalus (Jamil & Kestle, 2017).

Hydrocephalus is commonly found in patients with myelomeningocele. Various studies have reported that approximately 90% of patients with myelomeningocele show signs and symptoms of hydrocephalus, of which approximately 80% require CSS diversion management with shunts (Jamil & Kestle, 2017).

Hydrocephalus that occurs shortly after birth is often found in patients after intraventricular hemorrhage. Intraventricular hemorrhage in neonates is often associated with prematurity and birth weight. Hydrocephalus occurs in 40 to 70% after intraventricular hemorrhage, this is influenced by the severity of intraventricular hemorrhage (Jamil & Kestle, 2017).

b. Acquired Hydrocephalus

Acquired hydrocephalus is a manifestation of hydrocephalus as a result of central nervous system abnormalities in children with a normal birth history without hydrocephalus (Jamil & Kestle, 2017). The etiology of acquired hydrocephalus can be grouped based on the underlying mechanism of hydrocephalus, namely (i) the mechanism of obstructive absorption disorders, (ii) the mechanism of non-obstructive absorption disorders, and (iii) the mechanism of excessive production disorders.

The etiology of acquired hydrocephalus with obstructive mechanisms that are commonly found is the presence of a tumor mass that interferes with the flow of CSF, especially tumors located in the area around the aqueduct (eg: medulloblastoma) (S. M. Greenberg, 2016). While the most common cause of non-obstructive hydrocephalus is infection in the central nervous system

followed by bleeding in the ventricular and arachnoid systems (S. M. Greenberg, 2016). Disorders of excessive CSF production are usually caused by choroid plexus papilloma tumors. Choroid plexus papilloma is a rare intracranial tumor that accounts for 1% to 4% of all childhood brain tumors (S. M. Greenberg, 2016; Karimy et al., 2016).

Clinical manifestations

Clinical manifestations of hydrocephalus in children can be distinguished based on the condition of the cranial sutures, namely in children with closed cranial sutures, generally in children over 18 months of age and in children with unclosed cranial sutures.

Diagnosis

Hydrocephalus is generally best demonstrated on *computed tomography* (CT) scan or *magnetic resonance imaging* (MRI). Several methods are used to quantitatively define radiographic criteria for hydrocephalus. The most common method used to define hydrocephalus is when one of the following two signs is present (Figure 2.2): (S. M. Greenberg, 2016)

a. The size of both temporal horns *(* TH) ≥ 2mm (in normal conditions without hydrocephalus, TH is generally not visible) accompanied by the absence of the Sylvian fissure & interhemispheric fissure and cerebral sulcus.
b. Both TH are ≥ 2 mm in size, and the FH:ID ratio is > 0.5 (where FH (*frontal horn*) is the widest measurement of the frontal horn, and ID (*internal diameter*) is the distance between the two internal tables at the level of FH measurement)

Other criteria that can be used to define hydrocephalus using CT scan and MRI imaging are as follows: (S. M. Greenberg, 2016)

a. Dilation (*ballooning*) of the frontal horns of the lateral ventricles (“ *Mickey Mouse* ”

sign) and/or dilation of the 3rd ventricle. The 3rd ventricle is generally slit-shaped in normal conditions without hydrocephalus.

b. Hypodensity of the periventricular area on CT scan, or hyperdensity of the periventricular area on T2WI MRI sequence indicates the presence of a transependymal CSF absorption process that is not found in physiological conditions.
c. The FH:ID ratio can stand alone as a suggestive criterion for hydrocephalus when the FH:ID >50%. The FH:ID ratio <40% is categorized as normal and the FH:ID ratio 40–50% as the borderline category.
d. Evans ratio/index >0.3 is suggestive of hydrocephalus where Evans ratio is the ratio of FH to the maximum biparietal diameter (BPD) measured in the same CT scan section.
e. Thinning of the corpus callosum and/or upward *bowing* of the corpus callosum on sagittal MRI. This is commonly seen in chronic hydrocephalus.

Hydrocephalus management

for hydrocephalus is with ventricular shunt, which involves diversion of the CSF from the ventricular system and subarachnoid space to an alternative anatomical location, most commonly diversion to the peritoneal area. CSF Diversion in hydrocephalus is the most frequent indication for neurosurgical intervention in children. CS S shunts can substantially reduce morbidity and mortality in cases of hydrocephalus, but the use of shunts in CSS diversion also provides a significant complication rate, especially related to mechanical failure of the shunt and shunt (Jamil & Kestle, 2017). CSS diversion can be classified into 2 large groups, namely temporary and permanent CSS diversion.

a. Temporary CSS Diversion

Temporary CSS diversion can be performed with an *extraventricular drainage* (EVD)

device, a catheter inserted percutaneously into the ventricular system and connected to an external transducer. EVD has the benefit of measuring intracranial pressure and at the same time for CSS drainage which is useful for preventing secondary brain injury. The use of EVD as a temporary CSS diversion method has been reported to be beneficial in the pediatric population with traumatic brain injury, previous shunt system failure and early-onset hydrocephalus (Ngo et al., 2009; Walker et al., 2013). Other indications for EVD placement as CSS diversion are spontaneous (non-traumatic) intracranial hemorrhage, obstructive hydrocephalus, infection and *intraventricular hemorrhage* (IVH) (Walker et al., 2013).

CSS diversion with EVD is temporary. The use of EVD for a long time, more than 5-10 days, has been reported to be associated with an increased risk of infection in the central nervous system (Ngo et al., 2009; Qalab et al., 2016; Walker et al., 2013). EVD devices are generally removed when there has been normalization of ICP after a dependency test on EVD. In certain cases where independence from EVD cannot be achieved, it is necessary to change the CSS diversion method to a permanent CSS diversion, such as CSS shunt implantation or in certain circumstances *endoscopic third ventriculostomy* (ETV) can be performed (Walker et al., 2013).

b. Permanent CSS Diversion

Permanent CSS diversion consists of *endoscopic third ventriculostomy* (ETV) and placement of a CSS shunt from the ventricular system to another distal body part. The initial decision in the management of hydrocephalus is generally related to the choice between performing ETV and CSS shunt placement. ETV is a method of CSS diversion by creating a bypass from the base of the third ventricle so that the CSS can exit into the prepontine cistern so that it can enter the CSS circulation in the subarachnoid space and be absorbed into the superior sagittal sinus. Patients who are considered ideal for ETV are older children who have obstruction in the

aqueduct of Sylvius causing enlargement of the lateral ventricles and the third ventricle but not the fourth ventricle (Garton, 2004; Kestle, 2003).

The mainstay of hydrocephalus management to date is the installation of a CSS shunt, with a mechanism to divert CSS from the ventricular system to other body cavities. CSS shunts began to be developed around 1950 to 1960 and were reported to significantly improve survival and neurological function in children with hydrocephalus (Bayston, 2019; Kestle, 2003).

2.1 Cerebrospinal Fluid (CSF) Shunt

The CSS shunt has three important components, namely the ventricular catheter, the valve, and the distal catheter. The ventricular or "proximal" catheter is a catheter located upstream of the valve, functioning to drain CSS from the ventricular system (usually the lateral ventricle) to the valve. The second component is the valve, functioning to regulate the flow of CSS in the shunt system using a pressure difference system or flow - *controlling mechanism* . An important mechanism in the valve component is the direction of CSS drainage which is only one direction, namely away from the ventricle. The third component is the distal catheter located at the end of the valve and connects the valve to an alternative anatomical location for CSS collection and reabsorption. Research related to the selection of anatomical locations for distal catheters has been widely conducted with the most commonly chosen locations being the peritoneal cavity, right atrium of the heart, and pleura (Badhiwala & Kulkari, 2017; Kestle, 2003).

The CSF shunt system is generally associated with a valve to regulate CSF drainage. The valve in the CSF shunt system plays a critical role in regulating CSF outflow . Disruption of the shunt valve can result in failure of the shunt system as a result of excessive CSF drainage and collapse of part of the ventricular system around the catheter. Modifications and innovations in

shunt valve design have focused on reducing complications from such drainage disruptions (Garton, 2004).

CSS Shunt Types

Types of CSS shunts are generally categorized based on the valve opening pressure *and* anatomical location of the proximal and distal catheters. Types of shunts based on the valve system can be classified into four major categories, namely:

a. **Differential pressure valves** (commonly referred to as "standard" valves). Shunts with this type of valve use a pressure gradient system across the valve to promote CSF drainage. Two common mechanisms found in this type of valve are (1) CSF pushing a thin gap in a silicone membrane to pass through the valve and (2) CSF pushing a small ball against a spring system to pass through the valve. The flow rate through these valves increases as ICP increases. These valves have a range of constant opening pressures , commonly known as *low pressure* , *medium pressure* , and *high pressure* . The higher the valve opening pressure, the higher the ICP required to open the valve and allow CSF drainage (Garton, 2004; S. M. Greenberg, 2016; Jamil & Kestle, 2017).

b. **Antisiphon valves.** This type of valve is an innovation to prevent excessive drainage of CSF which is mostly caused by the siphon effect through the shunt system. Movement of the patient from the supine position usually causes the distal part of the CSF shunt system to move to the lower level of the ventricle. This situation creates the potential for a siphon effect that increases the flow of CSF drainage through the shunt system, even in the presence of low ICP. Antisiphon valves use a differential pressure valve system with the addition of an antisiphon component, an additional device that uses a small amount of gravity to rotate the internal parts of the valve when the patient changes position from horizontal to vertical and then flows CSF through

different valve pressure components for each position (Garton, 2004; S. M. Greenberg, 2016; Jamil & Kestle, 2017).

c. ***Flow-regulated*** **valves .** CSF production in some cases of hydrocephalus is not affected by ICP, so one method to reduce excessive drainage in the differential pressure valve system is to flow CSF at a constant flow rate regardless of ICP. This mechanism is considered to be more similar to normal drainage physiology, where in certain circumstances that cause increased ICP (such as coughing and straining) will increase venous pressure, reduce pressure differences and reduce CSF drainage. The *flow-regulated valve* will change into a differential pressure valve system as a safety mechanism from excessive drainage in very high CSF pressure conditions (Garton, 2004; S. M. Greenberg, 2016; Jamil & Kestle, 2017).

d. ***Programmable*** **valves .** One of the challenges in performing CSS diversion with a shunt is determining the pressure that best meets the patient's needs. As the child grows, a higher valve height is considered preferable to avoid excess drainage. Transcutaneous *programmable shunt valves* , typically using magnets to rotate the valve's internal components to positions that increase or decrease the valve opening pressure, allow for the adjustment of different valve opening pressures (Garton, 2004; S. M. Greenberg, 2016; Jamil & Kestle, 2017).

Another classification of shunts can be grouped based on the location of the distal shunt catheter. Two types of shunts commonly used are (1) *ventriculoperiotenal shunt* (VPS) with the proximal catheter in the ventricular system and the distal catheter in the peritoneal cavity and (2) *ventriculoatrial shunt* (VAS) with the proximal catheter in the ventricular system and the distal catheter in the right atrium of the heart (Garton, 2004; Jamil & Kestle, 2017). Several types of CSS shunts based on the anatomical location of the distal catheter, namely:

a. **Peritoneum**

The peritoneal cavity is the most commonly used and preferred location for distal catheter diversion. This preference is based on the ease of access to the peritoneal cavity and the effectiveness of the peritoneum in absorbing CSF. Distal catheters placed in the peritoneal cavity can be inserted completely in full-term infants to allow for growth and thus avoid further procedures for shunt lengthening. Distal catheters placed in the peritoneal cavity do not need to be fixed to the abdominal wall (Jamil & Kestle, 2017; Tamburrini et al., 2018). The placement of distal catheters in the peritoneum has been reported to have many complications, such as abdominal pseudocysts, massive ascites, intra-abdominal pathological abnormalities and accumulation of high levels of non-absorbable protein in the CSF such as in malignancy and infection. The incidence of distal shunt catheter malfunction has been reported to be found in high CSF protein levels, generally exceeding 2 g/dL (Alraee et al., 2020; Garton, 2004).

b. Atrium

The location of the CSS diversion in the atrium is precisely in the right internal jugular vein (IJV) where its central position is parallel to the right atrium of the heart, as well as its large and relatively shallow size, and generally constant anatomical location, making the IJV the most suitable vein for the placement of a distal atrial catheter. The IJV's journey out of the base of the skull at the foramen lacerum and runs through the lateral side of the neck in *the neurovascular bundle* consisting of the IJV on the lateral side, the internal carotid artery on the medial side, and the vagus nerve on the posterior side. This makes the IJV constantly in a triangular area bounded by the clavicle inferiorly and two branches of the sternocleidomastoid muscle (trigonum Sedillot). The IJV unites with the subclavian vein to form the brachiocephalic vein in the inferior neck, behind the sternoclavicular articulation (Jamil & Kestle, 2017; Tamburrini et al., 2018). The location of CSS diversion in the atrium is not recommended in cases of CSS with high protein

levels because it can be at risk of causing thrombosis (Alraee et al., 2020).

c. Pleura

Access to the distal shunt catheter placement procedure in the pleural cavity is obtained by making an incision in the mid-axilla at the level of the 3rd and 4th intercostal spaces. Insert the proximal part of the shunt into the subcutaneous tissue leaving a 30 cm distal catheter to be inserted into the intrathoracic space. The catheter placement procedure in the pleural cavity can be performed using three different methods, namely thoracotomy, thoracoscopy, and minimally invasive procedures (Tamburrini et al., 2018). The selection of the pleura as the location for CSS diversion is generally the third choice if there are contraindications to the peritoneum and atrium (Hasegawa et al., 2020). The location of CSS diversion in the pleura should be avoided in cases of CSS with high protein levels because it can be at risk of causing pleural effusion which in severe cases can lead to respiratory failure (Aldana et al., 2008; Alraee et al., 2020).

d. Gall bladder

The gallbladder is a sterile organ that can function as a CSF fluid receptor and has a special function to carry out lysis played by bile fluid. This lysis function can help in breaking down CSF proteins, making the gallbladder a good choice for drainage. Some common obstacles found in choosing the gallbladder as a location for CSS diversion are (1) the formation of bile duct stones after CSS diversion and (2) increased intraventricular pressure during the digestion process of high-fat foods (Aldana et al., 2008; Alraee et al., 2020).

CSS shunt installation procedure

The procedure for inserting a CSS shunt generally uses a protocol published by *the Hydrocephalus Clinical Research Network* (HCRN) as part of an effort to reduce infectious complications in CSS shunts. The HCRN began this approach in 2007 and has been updated

several times based on routine evaluations. The initial protocol developed included 11 steps in the CSS shunt procedure, including hand washing procedures performed by the operator, use of double gloves, use of perioperative antibiotics, and patient positioning (Kestle et al., 2016). The HCRN issued its last updated recommendation in 2016. One of the updates made was to insert an *antibiotic-impregnated* (AIC) catheter. become a routine part of the HCRN protocol, whereas in the 2007 to 2011 versions of the protocol the AIC component was not part of the HCRN protocol and was only used by a few neurosurgeons (Kestle et al., 2016).

CSS shunt failure

Shunt placement as a management of CSS diversion is known to be prone to complications that result in shunt failure (Kanangi & Balasubramaniam, 2018). Failure of CSS shunts is generally categorized into (i) shunt malfunction consisting of obstruction, *overdrainage* , mechanical system failure or disruption of the distal catheter system and (ii) shunt infection (Vinchon et al., 2012).

CSS Shunt Infection

Infection of the CSS shunt can increase morbidity and mortality. The reported mortality rate reaches 30%. CSS shunt infections generally require long-term hospitalization and have an impact on increasing costs incurred (Kanangi & Balasubramaniam, 2018). The incidence of shunt infections has decreased in recent years but has not been completely eliminated.

Efforts to reduce the rate of CSS shunt infection were carried out by performing the installation procedure according to the HCRN protocol, with the latest protocol being revised in

2016. A study at several centers in 2011 was conducted to evaluate the outcomes of the HCRN protocol version 2007-2011 . This study showed that the implementation of the 11-step standardized protocol for this shunt installation procedure successfully reduced the shunt infection rate from 8.8% to 5.7% (Hanak et al., 2017).

One component of the HCRN protocol is the use of an *antibiotic-impregnated shunt catheter* . A meta-analysis study conducted by Konstantelias et al. in 2015 concluded that *antibiotic-impregnated catheters* reduce the rate of early postoperative infections, but it was also reported that infections occurring with these modified catheters tended to be associated with microorganisms with higher virulence, including methicillin-resistant *(Konstantelias et al., 2015).* HCRN published the results of prospective studies that contradicted those reported in previous studies where the use of *antibiotic-impregnated catheters* and standard catheters without *antibiotics* showed no significant difference in the incidence of CSF shunt infectious complications (Hanak et al., 2017; Kestle et al., 2016).

Definition of CSS shunt infection

There are various definitions of CSF shunt infection, where several definitions that are widely used in studies related to CSF shunt infection are (1) evidence of bacteriological culture in CSF, (2) signs and symptoms of infection and/or evidence of bacteriological culture in CSF, (3) a combination of bacteriological culture, pleocytosis in CSF and signs and symptoms of infection, (4) definition based on *the Centers for Disease Control and Prevention* (CDC) and (5) definition based on *the Hydrocephalus Clinical Research Network* (HCRN) (Zervos & Walters, 2019).

The CDC defines CSF shunt infection as ventriculitis or meningitis inclusive and takes into account CSF bacteriological culture results, signs and symptoms of infection, vital signs, and

patient age (Zervos & Walters, 2019).

The HCRN defines CSF shunt infection with the following criteria: (1) presence of organisms on culture or Gram stain of CSF, wound *swab* , or fluid taken from the pseudocyst, (2) presence of shunt erosion (defined as damage to the surgical wound tissue with exposure of the shunt hardware), (3) formation of an abdominal pseudocyst in a ventriculoperitoneal shunt (can occur without positive culture results), or (4) positive blood culture results in a patient with a ventriculoatrial shunt (Kestle et al., 2016).

Infections in permanent CSS shunts are grouped into early and late infections based on the time of onset of infection. Early shunt infections are infections that occur within the first 6 months after shunt placement, while late shunt infections are defined as infections that occur more than 6 months after shunt placement (Erps et al., 2018; Konstantelias et al., 2015).

Pathogenesis of CSF shunt infection

CSS shunt is an exogenous antigen that can be recognized as a foreign object by the body's natural immune system. The development of technological advances and biocompatible materials has led to a decrease in the incidence of CSS shunt rejection. The direct response of the body as a host to the CSS shunt is the formation of a coating *protein* . on the shunt which aims to provide protection against infection by a mechanism of limiting bacterial attachment to the shunt wall. This limitation still allows bacteria to form micro colonization at the location of part of the shunt wall that is in contact with bacteria. The bacteria will then secrete mucopolysaccharides that form capsule mucus (glycocalyx) around the micro colonization. This mucus is a bacterial defense mechanism to prevent antibiotics from entering the inside of the capsule, allowing bacteria to continue to multiply. Another defense mechanism that bacteria have in this micro colonization is the release of bacteria in groups which can then colonize the distal part of the shunt to increase the

focus of infection. The ability of leukocytes to adhere to the shunt wall is worse when compared to bacteria which is thought to be caused by the irregular shape of the shunt wall due to holes and cracks on its surface. The shape of the shunt wall provides an advantage for bacteria to adhere (Bayston, 2019; Gutierrez-Murgas & Snowden, 2014; Kanangi & Balasubramaniam, 2018).

Late shunt infection is considered a distinct disease entity from early infection. Late shunt infection is thought to be related to the presence of the CSF shunt as a foreign body that allows bacterial colonization and not to the shunt placement procedure. The proportion of Gram-negative bacterial infections as causative pathogens in the late infection group was increased compared to early shunt infection, suggesting that these infections are related to a different retrograde infection mechanism from the distal end of the shunt (Erps et al., 2018; Vinchon et al., 2002).

Epidemiology of CSS shunt infection

The incidence of CSS shunt infection collected from various service centers provides highly variable figures, ranging from 0.33% to 60% with the highest incidence reported in several recent studies being between 1% and 6%. (Erps et al., 2018; Hanak et al., 2017; Kanangi & Balasubramaniam, 2018; Zervos & Walters, 2019). Erps, et al. in 2018 reported the results of a retrospective study of 1,570 patients over 20 years with findings of an average annual infection rate for early shunt infection of 3.65% and late shunt infection of 0.55% where in the early infection group, the median time interval between shunt installation and infection was 19 days (1-164 days), while in the late infection group it was 305 days (196-2181 days) (Erps et al., 2018).

A retrospective observational study of 1,173 patients with hydrocephalus who underwent CSS shunt placement over a 20-year period in 2006 by Vinchon and Dhellemmes reported 13.6% of patients experienced shunt infection with approximately 90% occurring in the first year after shunt placement (Vinchon & Dhellemmes, 2006). Another retrospective observational study with

a smaller sample in 2017 reported 51% of the sample experienced shunt failure with 12.2% of these being shunt infection (Tervonen et al., 2017). CSS shunt infection was reported to be responsible for 45% to 69% of shunt failure events in the first month after CSS shunt placement. This figure was reported to decrease to 6% after 2 years after shunt placement. This phenomenon is thought to be related to the involvement of normal flora contamination in the shunt installation procedure (Hanak et al., 2017; Zervos & Walters, 2019).

This varying incidence rate is thought to be due to differences in health service facilities, the abilities and skills of surgeons performing CSS shunt installation procedures and the type of CSS shunt used (Kanangi & Balasubramaniam, 2018).

Risk factors for CSS shunt infection

Several previous studies have been conducted to identify risk factors to predict shunt infection events more accurately and develop prevention strategies. Several risk factors suspected to play a role are (1) history of prematurity, (2) history of low birth weight, (3) age and nutritional status at the time of shunt installation, (4) abnormal levels of leukocytes, protein and glucose in CSF before the shunt installation procedure, (5) infection as the etiology of hydrocephalus, (6) use of single intraoperative gloves, (7) duration of surgical procedure, (8) experience of the surgeon, and (9) presence of postoperative CSF leakage (Erps et al., 2018; Hasanain et al., 2019; McGirt et al., 2003; Simon et al., 2014).

a. History of premature birth

A retrospective study of 442 patients with VP shunt placement within 6 years reported that a history of preterm birth was significantly associated with an almost 5-fold increased risk of shunt infection (McGirt et al., 2003). The relationship between preterm birth and the incidence of shunt infection is thought to be related to the underdevelopment of the immune system in premature

infants, the immaturity of the integumentary system which also functions as a mechanical immune system, and the high density of bacteria on the skin of premature infants (Kulkarni et al., 2001). Infants born with a gestational age of less than 32 weeks are susceptible to hypogammaglobulinemia due to the lack of maternal transplacental immunoglobulin G (IgG) transport which generally occurs after 32 weeks of gestation. This hypogammaglobulinemia can result in susceptibility to infection (Capasso et al., 2015).

b. History of low birth weight (LBW)

Low birth weight is suspected to play a role in the occurrence of ventricular fibrillation . A retrospective study by Bruinsma et al in 2000 reported that low birth weight infants have a greater risk of shunt infection, where this study recorded an infection incidence rate of 47.5% in the group with a birth weight of 2,000 grams or less (Bruinsma et al., 2000). A more recent retrospective study by Spader, et al. in 2015 reported that the group of newborns with ventricular access device infection had a lower birth weight compared to the group of patients without infection (Spader et al., 2015).

Low birth weight is associated with *intrauterine growth restriction* (IUGR) and prematurity. The relationship between low birth weight resulting from IUGR and the incidence of infection is thought to be related to impaired immune response by various mechanisms, including: (1) depression of T cells due to thymus dysfunction, for example, thymolymphatic atrophy, (2) increased CD8 from high systemic cortisol levels in response to stress, (3) lower immunoglobulin G levels due to impaired transplacental passage due to shrinkage of the placenta, and (4) lower complement levels due to poor liver function (Hviid & Melbye, 2007; Zohdi et al., 2012).

c. Age at time of shunt insertion

Age at the time of shunt insertion is one of the factors that influence the incidence of shunt

infection. Several authors reported that age plays a role in increasing the risk of shunt infection using the following limits: which vary. Vinchon and Dhellemmes in 2006 reported that CSS shunt placement at age less than 4 months had significantly higher shunt infection (OR 9.7%, *p* 0.008) (Vinchon & Dhellemmes, 2006).

A 1984 study of 1,141 CSF shunt procedures reported that patients aged 1 to 6 months at the time of shunt placement had a significantly higher risk of developing shunt infection or colonization compared to patients older than 6 months (Pople et al., 1992; Renier et al., 2009). McGirt et al. in 2003 also reported the results of a retrospective study of patients with VP shunt placement where each 1-year decrease in the age of the patient undergoing the shunt procedure was significantly associated with a 4% increase in the risk of infection (McGirt et al., 2003).

The relationship between age at the time of shunt installation and the risk of shunt infection is associated with the development of immunity in infants and children. Immunoglobulin in newborns is dominated by immunoglobulin G (IgG) obtained from maternal IgG that crosses the placenta. Maternal IgG concentrations will decrease rapidly due to physiological catabolism in the first year of life. Maternal IgG has limited specificity because it is highly dependent on the history of antigen exposure in the mother. Antibody production in infants begins around the 3rd month of life and at the age of 4-6 years IgG levels will be equivalent to adult IgG levels (Capasso et al., 2015; Pople et al., 1992). Newborns are susceptible to Gram-negative pathogen infections, this is related to the absence of maternal IgM transport across the placenta where IgM is the main antibody against Gram-negative pathogens (Renier et al., 2009).

d. Nutritional status at the time of shunt insertion

A prospective study of 124 hydrocephalus patients undergoing shunt surgery from 2001 to 2003 reported that patients with malnutrition at the time of CSF shunt placement had a significantly

higher risk of shunt infection compared to patients with normal nutritional status (Jain et al., 2007). The increased predisposition of malnourished patients to infection is generally caused by impaired immune function. In severe malnutrition, there is a disruption of *skin barrier function* which can be caused by thinning of the dermis accompanied by decreased hydration of the stratum corneum and decreased proliferation of epidermal cells and decreased collagen levels. Disruption of *the skin barrier* can allow pathogen contamination (Grover & Ee, 2009; Ibrahim et al., 2017; Leite et al., 2011; Sugiyama et al., 2011).

Malnutrition can also result in impaired wound healing due to impaired wound contraction, increased inflammatory cell count, poor collagen deposition, extracellular matrix edema, and impaired neovascularization (Ibrahim et al., 2017). Malnutrition has an impact on decreasing innate *and* adaptive immune responses. Malnutrition can affect the function of complement and innate immune cells, including monocytes/macrophages, neutrophils, NK cells, dendritic cells, and T and B cells in their response to pathogens. This makes patients with malnutrition susceptible to infection (Ibrahim et al., 2017; Katona & Katona-Apte, 2008).

e. CSS analysis at the time of shunt installation

Leukocyte, protein, and glucose examination in CSF analysis immediately before and/or during shunt installation can provide prediction of shunt infection after CSF shunt installation procedure. A study conducted by Ambekar, et al. in 2013 reported that increased protein levels in CSF > 200mg/dl were associated with an increased risk of shunt failure (Ambekar et al., 2013).

A 2007 cohort study reported that CSF glucose levels <24 mg/dl, protein levels >170 mg/dl, erythrocyte counts >10/mm3, and leukocyte counts >6/mm3 had a sensitivity level of around 80% as predictors of shunt infection (Lenfestey et al., 2007). A retrospective observational study in 2018 reported something similar where increased protein levels and *polymorphonuclear*

leukocytes (PMN) in CSF that were more than normal and CSF glucose levels that were less than normal were associated with shunt infection which had an impact on *exposure* of the CSF shunt (Arifin et al., 2019).

Clinical manifestations of CSF shunt infection

CSF shunt infection presents with two general clinical manifestations, namely specific and non-specific signs of infection, and signs and symptoms of shunt malfunction.

Shunt malfunction can mimic, occur concurrently with, or be a result of infection. The reported incidence of shunt malfunction as a result of asymptomatic infection ranges from 2% to 25%, with the largest study reporting an infection rate of 9%. Shunt malfunction can gradually lead to headache, nausea, altered mental status, and/or lethargy, which are the presenting symptoms in 65% of CSF shunt infections (Zervos & Walters, 2019).

Clinical manifestations of CSF shunt infection depend on the location of the infection, the age of the infected patient, and the type of organism causing the infection (Quinones-Hinojosa, 2012). Different clinical manifestations in each patient result in a clinical finding that cannot be used alone without being accompanied by other modalities to diagnose CSF shunt infection (Zervos & Walters, 2019).

A systematic review study by Zervos and Walters in 2019 reported that fever was only found in 16% to 42% of all reports of CSF shunt infections. Other common clinical manifestations found in patients with CSF shunt infections are abdominal pain in the ventriculoperitoneal shunt, signs and symptoms of ventriculitis and meningitis, meningismus, and rubor. (Zervos & Walters, 2019). The use of a combination of signs and symptoms found is the most effective way to assess the clinical findings of CSF shunt infections. A study of 647 shunt operations and 55 shunt infections, the specificity value for the occurrence of infection in findings of CSF leak, CSF

purulence, skin erosion, meningismus, erythema, or abdominal pain was more than 99% while the sensitivity value was less than 25% (Piatt Jr. & Garton, 2008).

Diagnosis of CSS shunt infection

Several studies have shown heterogeneity in the modalities used in establishing the diagnosis of CSS shunt infection. Clinical manifestations, history of the disease and bacteriological culture examination are the modalities commonly used in establishing the diagnosis of CSS shunt infection.

A meta-analysis study by Konstantelias et al. in 2015 reported that of the 36 studies examined, only 13 studies used a combination of signs and symptoms of infection, laboratory tests that indicated an infection and bacteriological culture of the CSF while the remaining 23 studies only used bacteriological culture of the CSF as a confirmation of the diagnosis of CSF shunt infection (Konstantelias et al., 2015). This shows that there is still no global recommendation that is used uniformly to determine the diagnosis of CSF shunt infection.

Variations in definitions and diagnostic modalities stem from the low sensitivity and specificity of the signs and symptoms and commonly used tests. *Tapping* of the shunt alone has half the sensitivity of bacteriological culture of the shunt hardware. Findings of CSF eosinophilia, lactic acid, serum anti- *Staphylococcus epidermidis titers* , procalcitonin, and C-reactive protein (CRP) are nonspecific and their usefulness in establishing the diagnosis of CSF shunt infection has not been proven (Zervos & Walters, 2019).

a. CSS Analysis

CSF shunt infection can show normal results on CSF analysis examination so it is important to combine findings from signs and symptoms of infection with CSF analysis results to increase the sensitivity and specificity of establishing the diagnosis of shunt infection. The finding of

pleocytosis in CSF when combined with clinical manifestations of fever has a sensitivity of 82%, a specificity of 99% and a positive predictive value of 93% (Zervos & Walters, 2019).

The presence of changes in the number and differences of cells in the CSF also depends on the pathogenesis of the colonizing organism, for example more severe infections (usually caused by gram-negative organisms) tend to trigger higher leukocyte counts and percentages of polymorphonuclear leukocytes (PMNs) compared to organisms with lower virulence (Fulkerson et al., 2011).

CSF analysis parameters can be meaningful and used as a modality to decide to start empirical antibiotics while waiting for culture results when combined with signs and symptoms of infection. A study of 116 patients reported that the finding of fever accompanied by CSF neutrophils of more than 10% had a specificity value of 99% for diagnosing shunt infection (Mcclinton et al., 2001).

b. Bacteriological Culture

Bacteriological culture examination is the most important component in the diagnosis of shunt infection . CSF shunt or lumboperitoneal shunt *tapping examination* should be considered after all alternative sources of infection have been excluded and at least one of the following criteria is met: (1) fever associated with symptoms or signs of shunt obstruction, (2) unexplained fever shortly after shunt placement without other explanation, (3) meningismus, (4) erythema of the incision, (5) purulent discharge from the incision, (6) erosion of the shunt device through the incision or skin, (7) presence of an abdominal pseudocyst, and/or (8) peritonitis (Steinbok et al., 2010; Zervos & Walters, 2019).

Bacteriological culture examination is useful to prove the presence of pathogens responsible for shunt infections which can be used to confirm the diagnosis of shunt infection.

Bacteriological culture also provides benefits in predicting the source of infection that occurs (Hanak et al., 2017; Vinchon & Dhellemmes, 2006).

Several studies report that as many as 60% to 79% of shunt infections are caused by contamination of normal flora on the CSS shunt device during the shunt installation procedure, this is concluded from the discovery of bacteria with the genus *Staphylococcus* and *Streptococcus.* (Hanak et al., 2017; Vinchon & Dhellemmes, 2006). Some researchers recommend that anaerobic bacteriological culture examination should be performed for 10 days to allow detection of coagulase-negative *Staphylococcus* , *Propionibacterium sp.* and *Bacillus sp* . One of the bacteria that is also widely reported to be the cause of shunt infections is *Propionibacterium acnes* which is a gram-positive anaerobic rod commensal bacterium in sebaceous glands and hair follicles. It is generally reported that positive bacteriological cultures are more likely to be the result of contamination than actual infection (Steinbok et al., 1996; Westergren et al., 1997; Zervos & Walters, 2019).

c. Blood Laboratory Examination

Laboratory blood tests are useful in providing information related to systemic signs of infection. Interleukin-6 is produced by macrophages to modulate the production of *C-reactive protein* (CRP) by hepatocytes and adipocytes approximately 6 hours after the onset of infection. The CRP produced will attach to phosphorylcholine in microorganisms to help facilitate the complement system to further activate the body's immune system. CRP is reported to have a sensitivity value for shunt infections that varies depending on the study design and the laboratory's cutoff value, with a sensitivity of 75% to 97% and a specificity of 73% to 80% (Lolak & Bunyaratavej, 2013; Von Der Brelie et al., 2012; Zervos & Walters, 2019).

Blood culture examination is an important part of the diagnosis if there are signs and

symptoms that indicate sepsis, especially in patients with venticuloatrial shunts. Installation of VA shunts has a risk of *shunt nephritis* caused by chronic low-grade infection that results in the deposition of immune complexes on the glomerular basement membrane (Zervos & Walters, 2019).

d. Supporting Imaging Examination

Imaging modalities for the head, either with *Magnetic Resonance Imaging* (MRI) or *Computed Tomography Scanning* (CT Scan), can be used to detect intracranial pathology, evaluate the location of the shunt catheter, and assess changes in ventricular size. Both of these modalities are considered more effective than *two-deoxy-2-[fluor- 18] -fluoro-D glucose examination* integrated with *positron emission tomography* (PET) which is proposed as a method to detect inflammation along the shunt system. The disadvantages of PET modality are the cost and limited availability for highly sensitive but nonspecific testing. *Ultrasound* (USG) modality can also be used to detect a shunt infection if there is a larger accumulation of CSF, pseudocysts with internal septa, thickening of the ventricular wall and internal echogenicity (Bolster et al., 2016; Zervos & Walters, 2019).

CSS shunt infection management

Several previous studies have tested two commonly used approaches to the management of shunt infections, namely (1) shunt removal or shunt replacement combined with antibiotic administration and (2) single treatment with antibiotic administration. Single treatment with antibiotic administration without shunt removal or replacement has been reported to have a very low success rate (James & Bradley, 2008; Kulkarni et al., 2001; Odio et al., 1984; Walters et al., 1984).

The best approach to managing shunt infection is to remove all components of the shunt,

place a temporary external drainage device, administer systemic antibiotics, and delay reinsertion of the permanent shunt. This comprehensive approach has been reported to have a success rate of 85% (Dawod et al., 2016; Schreffler et al., 2002; Turgut et al., 2005).

Systemic Antibiotics

Initial management when a shunt infection is suspected can be done by administering systemic empirical antibiotics that can include coagulase-negative *Staphylococcus* , *S. aureus, P. acnes* and gram-negative organisms (including *P. aeruginosa*). Commonly given empirical antibiotics are vancomycin combined with the β-lactam anti-pseudomonas group (cefepime, cefazidime, or meropenem) (Dawod et al., 2016). The selection of empirical antibiotics used needs to be adjusted to the distribution map of germs and microbiological resistance patterns found at the local health service center. Microbiological cultures are performed before administering empirical antibiotics so as not to bias the growth of bacterial cultures where empirical antibiotics must be immediately replaced with antibiotics that are in accordance with the results of culture and sensitivity examinations.

Intraventricular Antibiotics

Intraventricular antibiotic administration has been reported to increase the effectiveness of CSF shunt infection therapy. The intraventricular route provides great benefits in situations where (1) intravenous antibiotic administration cannot sterilize the CSF, (2) there are bacteria that are resistant to several antibiotics (especially coagulase-negative *Staphylococcus*) that are only sensitive to antibiotics with poor CSF penetration, and (3) the CSF shunt cannot be removed (Dawod et al., 2016; Mader et al., 2018; Ragel et al., 2006).

The CSF is protected from systemic circulation by the blood-brain barrier and the blood-CSF barrier so that drug compounds that will enter the CSF must pass through the BBB by passive

diffusion. Lipophilic drugs such as quinolones and rifampicin are more easily able to pass through the blood-brain barrier *(* BBB) and the blood-CSF barrier compared to hydrophilic drugs such as beta-lactams and vancomycin. Drug *(Nau et al., 2010; Ragel et al., 2006).*

Penetration of antibiotics into CSF depends on the degree of meningeal inflammation, which is more common in meningitis than in ventriculitis. Meningeal inflammation causes the opening of *tight junctions* that form the BBB and decreased CSF production which causes decreased *clearance* of substances from CSF. This results in increased penetration accompanied by decreased *clearance of* antibiotics from CSF in meningitis that is not present in ventriculitis (Mader et al., 2018; Nau et al., 2010).

Shunt release

Intravenous and/or intraventricular antibiotics alone without removal of the infected shunt have been associated with low success rates (approximately 35%) and high mortality. These findings are thought to be due to the ability of microorganisms to hide within *biofilms* that act to protect them from antibiotics and the *host immune response* . Shunt removal followed by immediate replacement of the shunt and combined with intravenous antibiotics have been associated with success rates of 65–75%, but this approach has been reported to have a high recurrent infection rate (Dawod et al., 2016; Schreffler et al., 2002; Turgut et al., 2005).

Rehabilitation in Hydrocephalus Management

Hydrocephalus in infants and children results from the excessive accumulation of cerebrospinal fluid within the ventricles and/or subarachnoid space, leading to a range of complications necessitating rehabilitation. During this critical period, high-pressure hydrocephalus is frequently observed and can significantly impact physical development, particularly in relation to the motor system, milestone attainment, balance, coordination, and overall mobility. Additionally, associated

conditions such as cognitive impairment, epilepsy, sensory deficits, and endocrine dysfunction further exacerbate the clinical burden. If motor dysfunction is not appropriately managed alongside these comorbidities, affected individuals may experience substantial challenges in school and social integration, ultimately leading to a profound decline in the quality of life for both the patient and their family.(Karadag-Saygi & Kenis-Coskun, 2018)

The cognitive impairment profile in pediatric hydrocephalus encompasses a broad range of dysfunctions, making neuropsychological assessment a complex and demanding process. Commonly reported cognitive deficits in children with hydrocephalus include impairments in attention, executive functioning, memory, visuospatial abilities, and language, often accompanied by behavioral disturbances.(Zielińska et al., 2017)

To effectively address the cognitive and functional needs of individuals with hydrocephalus throughout their lives, the implementation of clinical pathways and specialized clinics that integrate neuropsychological care is essential. The involvement of neuropsychologists with expertise in brain-behavior relationships, neurodevelopment, and cognitive assessment is crucial in this process. To ensure appropriate management and continuity of care for individuals with congenital hydrocephalus, care models should: (1) incorporate routine neuropsychological evaluations for adolescents and young adults to assess their readiness for adult roles and responsibilities, (2) establish a structured approach to facilitate access to necessary services and support, such as developmental disability funding and vocational rehabilitation, while also assisting in planning for adult decision-making processes, including supported decision-making and guardianship, and (3) promote coordinated, multidisciplinary care. Furthermore, for individuals with adult-onset hydrocephalus or recently diagnosed unrecognized congenital

hydrocephalus (UCH), specialized multidisciplinary clinics—comprising professionals from neuropsychology, neurology, neurosurgery, rehabilitation, and vocational services—are essential to address their specific needs. Given the importance of these integrated care models, further research is necessary to evaluate their effectiveness and facilitate their broader implementation in clinical practice.(Dasher et al., 2024)

Physiotherapy interventions were implemented to promote head and trunk control, enhance sensory awareness, and improve overall coordination and balance. A range of therapeutic approaches, including neurodevelopmental techniques, sensory stimulation, hippotherapy, and sensory integration therapy, were employed to target specific developmental milestones and functional capacities. The patient's progress was evaluated using standardized outcome measures such as the Gross Motor Function Measure, Infant Neurological International Battery, Hammersmith Infant Neurological Examination, and New Ballard Score, assessed both before and after the intervention. Following four months of physiotherapy rehabilitation, significant improvements were observed across all assessment metrics, with notable advancements in gross motor function, neurological examination scores, and developmental milestones. These results highlight the efficacy of physiotherapy rehabilitation in mitigating developmental delays associated with non-communicating hydrocephalus. This case emphasizes the critical importance of early physiotherapy intervention in optimizing functional outcomes and enhancing the quality of life for affected children.(Vikhe et al., 2024)

Consclusions

Early and targeted physiotherapy intervention plays a crucial role in managing developmental delays and neurological impairments associated with hydrocephalus. This case highlights the

effectiveness of physiotherapy in improving motor function, sensory awareness, coordination, and overall developmental milestones. The significant progress observed across standardized outcome measures reinforces the importance of integrating physiotherapy into the multidisciplinary management of hydrocephalus. Future research and clinical applications should focus on optimizing rehabilitation strategies to further enhance functional outcomes and quality of life for affected children.

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