UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA
Denkleiers • Leading Minds • Dikgopolo tša Dihlalefi

Investigating the use of neurorehabilitation scales in paediatric neurosurgical patients at a tertiary academic hospital in Gauteng

by

Nicoleen Smit

Dissertation submitted in fulfilment of the requirements for the degree

Master of Science degree in Human Physiology

Department of Physiology

School of Medicine

Faculty of Health Sciences

University of Pretoria

Supervisor: Prof. L.C. Padayachy

Co-supervisors: Dr CW Grobbelaar, Dr V Padayachy

2023

Declaration

University of Pretoria

Faculty of Health Sciences

Department of Physiology

I, Nicoleen Smit,

Student number: 17001014

Subject of the work: Investigating the use of neurorehabilitation scales in paediatric neurosurgical patients at a tertiary academic hospital in Gauteng

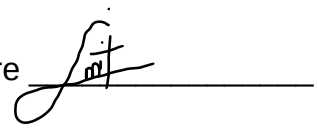
Declare that,

1. I understand what plagiarism entails and am aware of the University's policy in this regard.

2. I declare that this project (e.g., essay, report, project, assignment, dissertation, thesis etc.) is my own, original work. Where someone else's work was used (whether from a printed source, the internet or any other source) due acknowledgement was given and reference was made according to the departmental requirements.

3. I did not make use of another student's previous work and submitted it as my own.

4. I did not allow and will not allow anyone to copy my work with the intention of presenting it as his or her own work.

Signature 

Acknowledgements

I would like to express my sincere appreciation for:

My supervisor, Prof. Padayachy, thank you for your advice, and input, and for taking the time to take another student under your wing.

My co-supervisors, Dr. Padayachy, thank you for the time you made to help me with my project, for arranging keys when you were busy, and for your patience. I would also like to give special thanks to Dr. Grobbelaar, who always asked if I was all right and coping and who also assisted me with project editing until the last day. I could not have asked for a better co-supervisor.

Thank you to the office staff at the Neurosurgery department, especially Daphney Matlala, for always being friendly and helpful. Daphney, thank you for making the file retrieval much easier.

To our research assistant, MJ Bassa, who turned into a friend and helped me more than I could ever thank him for and who was also great emotional support. Thank you for the laughter, your help, and for listening to all my complaints. Daniella Bove, the best honours assistant anyone could ever ask for. Thank you so much for the time and effort that you have put into this study.

I would like to express my gratitude to my parents, who supported me emotionally and financially. Thank you for making me believe that I can achieve more and being my biggest supporter. Also, to my special friend, Zander, thank you for putting up with all my stress rants and mood swings and for just being there for me.

I truly appreciate all of you.

Abstract

Introduction: Children with central nervous system disorders frequently display altered synaptic processes, discordant brain activity, delayed development, and reduced neuroplasticity. A major hallmark of neuroplasticity is the ability of the brain to reorganize and heal after injury, and may be enhanced through neurorehabilitation. Early rehabilitation, particularly for conditions such as traumatic brain injury, brain tumours, spina bifida, and hydrocephalus, can dramatically improve patients' functional outcomes. This study sought to examine the criteria used for identifying paediatric neurosurgery patients' eligibility for neurorehabilitation, evaluate the clinical outcomes assessed by particular neurorehabilitation scales, and examine the time between surgery and rehabilitation, as well as the length of the overall inpatient stay.

Materials and Methods: This retrospective study was conducted at Steve Biko Academic Hospital (SBAH) and Tshwane Rehabilitation Hospital (TRH), using patient records. The study evaluated the length of hospital stay, neurorehabilitation eligibility criteria, and the specific scales used in neurorehabilitation.

Results and Discussion: A total of 51 patients were included in the study. The study revealed that, despite the absence of defined criteria, clinical judgment based on physical, cognitive, developmental, and social factors was the primary determinant for transferring patients to the rehabilitation facility. Interestingly, 21.5% of the study population demonstrated cognitive and physical improvement based on the documented Glasgow Outcome Scale, Glasgow Coma Scale, and Waterlow Scales. The data revealed that patients with brain tumours spent the longest time at the tertiary academic hospital (approximately 47 days), and had the longest overall length of stay (119 days) with the least number of transit-affecting factors. Patients with hydrocephalus had the longest hospitalisation stay at the neurorehabilitation facility (approximately 70 days). The study highlighted disparities in hospitalisation periods based on neurological conditions, with notable impacts on hydrocephalus patients. Neurorehabilitation scale usage exhibited inconsistencies, and a fraction of patients demonstrated improvement in functional outcomes. Furthermore, other reasons for requiring transfer to a rehabilitation facility such as nutritional and psychosocial support were also considered. Rehabilitation interventions, including occupational therapy, physiotherapy, and speech therapy, were tailored to specific needs.

Conclusion: The study's results highlight the complex nature of neurorehabilitation in children, marked by extended hospitalisation and resource-intensive care demands, underscoring the vital necessity for tailored support. Furthermore, these findings emphasize the ongoing imperative of enhancing rehabilitation strategies, particularly for patients with limited cognitive and physical progress, stressing the continued dedication to advancing rehabilitative approaches to benefit a broader range of patients and enhance their overall well-being. Therefore, the inclusion of the Bayley Scales of Infant and Toddler Development may serve to improve the comprehensiveness of the assessment, particularly for younger patients, highlighting a potential area for improvement in the rehabilitation protocol.

Keywords: paediatric neurorehabilitation, neuroplasticity, Bayley Scales of Infant and Toddler Development, Glasgow Outcome Scale Extended Pediatric, Waterlow, Glasgow Coma Scale

Table of Contents

List of figures

List of tables

List of abbreviations

ADHD:	Attention-deficient-hyperactivity disorder
ATP:	Adenosine triphosphate
BBB:	Blood brain barrier
BSID:	Bayley scale of infant and toddler development
BT	Brain tumour
CBT:	Congenital brain tumours
CNS:	Central nervous system
CSF:	Cerebrospinal fluid
EVD:	External ventricular drain
EVT:	Endoscopic third ventriculostomy
GCS:	Glasgow Coma Scale
GOS:	Glasgow outcome scale
GOS-E:	Glasgow outcome scale extended
GOS-E Peds:	Glasgow outcome scale extended pediatric
HCP	Hydrocephalus
ICP:	Intracranial pressure
IMH:	Intramural hematoma
IVH:	Intraventricular haemorrhage
LL:	Lower limb

NGT:	Nasogastric tube
NHRD:	National Health Research Database
NPH:	Normal-pressure hydrocephalus
PEG:	Percutaneous endoscopic gastrotomy
ROM:	Range of motion
SB	Spina bifida
SBAH:	Steve Biko Academic Hospital
SDG	Sustainable developmental goals
TBI:	Traumatic brain injury
TBM:	Tuberculous meningitis
TRH:	Tshwane Rehabilitation Hospital
UL	Upper limb
VPS:	Ventriculoperitoneal shunt
WS:	Waterlow Scale

Chapter 1: Literature review

1.1 INTRODUCTION

The anatomical and physiological integrity of neural networks are major factors that influence motor, sensory, cognitive, autonomic, emotional, and social functioning.[1] The cells and tissues that make up these neural networks have to develop sufficiently to allow for optimal brain function,[2] especially considering that brain development and brain function in children can be affected by environmental events.[3] At birth the central nervous system (CNS) is still developing and it continues to mature until the age of two years.[4] At this young age the proportion of cerebral blood flow is at its highest and the neurons are still immature and vulnerable. In addition, children who sustain a CNS injury could develop altered synaptic mechanisms and neural activity, delayed development, and a change in neuroplasticity. Due to the differences in the nervous system of children during the various stages of development, varying clinical manifestations after injury are experienced.[4] This can affect how children perceive the world and their life experiences during development. During this early development phase, synapse formation is critical for learning and memory processing, making children more responsive to rehabilitation after injury.[3] Modern neurorehabilitation aims to regain functionality, and continuous therapeutic exposure and rehabilitation have been found to improve functional outcomes, including locomotion, communication, cognition, learning and auditory and visual responses.[5, 6]

Figure 1.1 illustrates the various brain regions involved in the aforementioned functions. The corpus callosum, a white matter structure, contributes to higher-order cognitive thinking. The cerebrum comprises four lobes: the frontal lobe, parietal lobe, temporal lobe, and occipital lobe. These lobes govern motor and sensory functions, information retention, and mood regulation. The cerebellum governs voluntary movements, attention, language, pleasure response, and memory. The brainstem, which includes the midbrain, pons, and medulla oblongata, connects the cerebrum and cerebellum to the spinal cord, overseeing autonomic functions such as breathing, heart rate, and temperature regulation. Additionally, the hypothalamus, a crucial structure in the brain, regulates various bodily functions, including hormone release, body temperature, and hunger.[7]

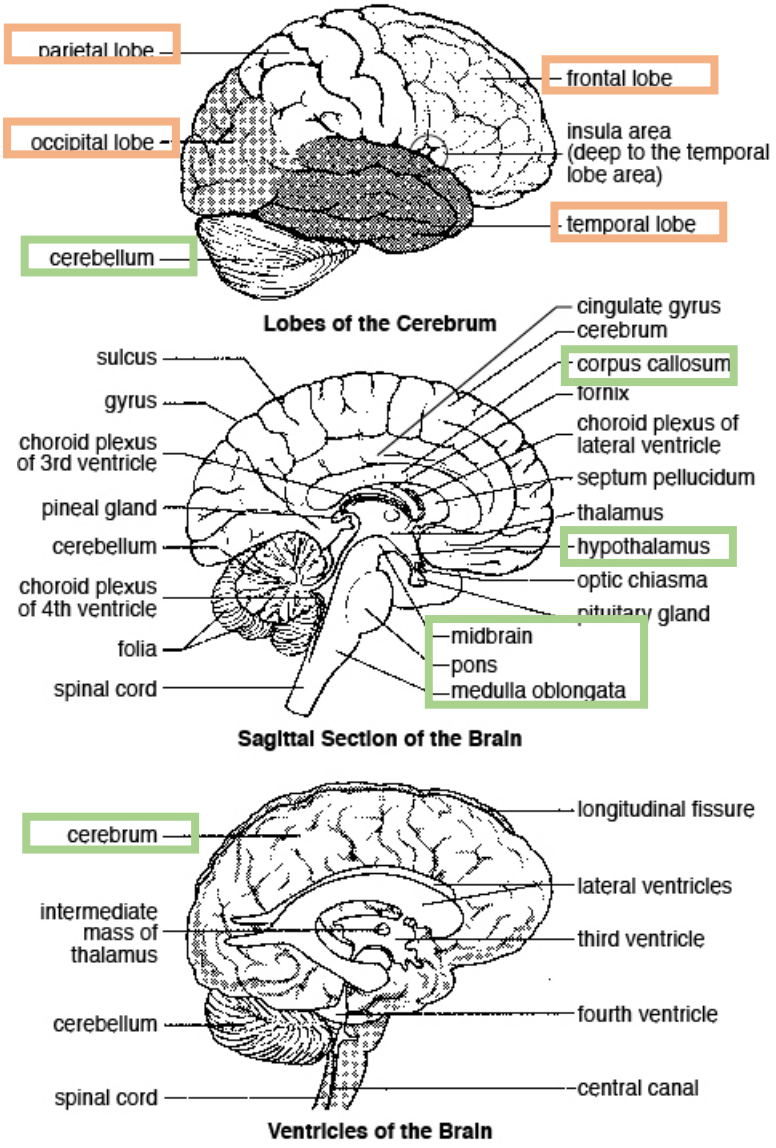


Figure 1.1: The different brain regions.[7]

1.2 COMMON CAUSES OF CHILDHOOD NEUROLOGICAL IMPAIRMENTS

1.2.1 Traumatic brain injury (TBI)

Traumatic brain injury (TBI) is the most common cause of acquired brain disability and death among children.[8] An estimated 185-230 out of every 100 000 children under the age of 15 years sustain TBIs, and of those, 25% of TBIs in children between the ages

of five and 15 years result in death.[9, 10] However, TBI cases are likely to be underreported, because individuals do not always seek or receive medical care.[11] The leading causes of TBI in children between the ages of 0-14 years is unintentional falls and being struck by an object. International data for TBI in children older than 14 years, indicate that motor vehicle accidents and falls are the most common causes.[12] Another common cause of TBI in children and adults involves injuries sustained in sports and other recreational activity.[12] Boys appear to sustain a higher rate of intentional injuries; however, injury severity for intentional and unintentional injuries is similar for boys and girls. There is also a difference in the type of injury sustained, with girls presenting with a higher percentage of subdural haematomas and boys having a higher percentage of extradural haematomas.[13]

The development of TBI can result from primary and secondary injuries.[11] Primary TBI is the direct impact to the brain that leads to an anatomical injury, whereas secondary TBI results from the primary impact and causes a molecular, chemical and inflammatory response that further damages the brain.[11] Primary TBI includes extra-parenchymal injury (outside of brain tissue), intra-parenchymal injury (within brain tissue) and vascular injury.[8] Table 1 summarizes the associated features of the different primary TBI types.

Table 1: The types of primary TBI symptoms

	Types	Definition
Extra-parenchymal injury	Epidural Haematoma	Blood builds up between the outer layer of the dura mater and the inside of the skull.[14]
	Subdural Haematoma	The build-up of blood between the arachnoid membrane and the dura mater.[8]
	Subarachnoid Haemorrhage	Microvascular ruptures in the subarachnoid space result in the build-up of blood between the arachnoid and pia mater.[8]
	Intraventricular Haemorrhage (IVH)	The blood within the ventricular system includes the lateral, third, and fourth ventricles. There are two types: Primary IVH: Bleeding directly into the ventricular system within the brain from an intraventricular source or a lesion contiguous to the ventricles. Secondary IVH: Bleeding extending from the parenchyma or subarachnoid space into the ventricular chambers. Once blood is inside the ventricles, it mixes with the cerebrospinal fluid (CSF) and circulates toward the subarachnoid space.[15]
Intra-parenchymal injury	Intracerebral Haemorrhage	It is a subtype of stroke in which blood starts to accumulate in the frontal and temporal white matter or in the basal ganglia and cerebellum due to disruption of the perforators.[8]
	Diffuse Axonal Injury	When the brain rapidly shifts directions inside the skull. This results in microscopic and gross damage to the axons in the brain at the junction of the grey and white matter. It usually affects the white matter tracts involved in the corpus callosum and brainstem[16]

Vascular injury	Vascular dissection	Structural failure of an arterial wall that results in an intramural bleed, which forms an intramural hematoma (IMH) that dissects the vessel wall. As the IMH expands, it causes the ipsilateral vessel wall to bulge into the vessel lumen toward the contralateral wall, which in smaller diameter vessels leads to obstruction of blood flow. [17]
	Carotid artery-cavernous sinus fistula	The internal carotid artery is torn from its points of dural attachment and ruptures, which results in the direct flow of blood into the cavernous sinus. The high blood flows from the artery and is pushed into a low-pressure cavernous vein. This causes problems with blood drainage from the eye socket and can cause the eye to bulge.[18]
	Dural arteriovenous fistula	Arteries arising from branches of the carotid or vertebral arteries drain directly into the Dural leaflets of the venous sinuses.[19] The Dural venous sinuses are large venous conduits within the dura mater layer of the meninges that are responsible for draining virtually all of the venous blood from the cerebral hemispheres.[20]
	Pseudo-aneurysm	A breach in the arterial wall where the blood leaks to outside layers of the wall and is being contained by the surrounding tissues.[21]

Secondary brain injury involves a cascade of released excitatory neurotransmitters such as glutamate and aspartate that increases intracellular calcium levels. This increase activates caspase enzymes and free radicals that degrade cells through necrosis. Degradation of neuronal cells induces an inflammatory response that increases the permeability of the blood brain barrier (BBB), leading to further cerebral oedema, increased intracranial pressure (ICP), worsening white matter injury, reduced cerebral blood flow, reduced adenosine triphosphate (ATP) generation, and further neuronal cell damage.[11, 22]

There are structural considerations that make children more susceptible to TBI. A child's head is proportionally larger and heavier in comparison to the rest of the body when compared to adults. The surface area of an infant's head is 19% of their total body surface area compared to that of an adult's head with an estimated 9% of the total body surface area.[10] The child's head is also highly vascularised, such that a small loss of blood volume can precipitate haemorrhagic shock in new-borns, infants and toddlers without any significant external bleeding.[8] Children still have underdeveloped myelin sheaths and lower brain density due to high water content.[8] The unmyelinated areas of the brain have the potential to absorb much more traumatic forces making the brain tissue more susceptible to TBI.[8] Head trauma can also induce cranio-cervical junction instability primarily because cranio-cervical stability depends on ligaments and soft tissue structures supporting the connection between the cervical vertebrae and cranium which, when not fully developed, may enhance the susceptibility to injury in traumatic incidents.[23] Weaker neck muscles in children also contribute to the elevated susceptibility to TBIs.[8]

Children who sustain TBIs can have temporary or long-term sensorimotor, cognitive, behavioural, and emotional difficulties which can influence everyday functioning.[9, 11] Communication disorders are also prevalent in these patients due to hearing, language comprehension and speech problems associated with TBIs, making the use of speech therapy necessary in most cases.[12] Li *et al.* found that children with TBI are more likely to develop new-onset psychiatric disorders such as personality changes, conduct and oppositional defiant disorders, attention-deficient-hyperactivity disorder (ADHD), mood disorders, anxiety disorders, and depressive disorders which may resolve within one year after the injury or persist onto adulthood if left untreated.[24]

1.2.2 Brain tumours

Brain tumours are one of the most common and fatal solid tumours in children.[25] They are also the most difficult neoplasms to treat due to its resistance to most conventional treatments.[25] One of the reasons for this, is that brain tumours are often located beneath the BBB which impedes chemotherapy drug accessibility.[25] The incidence of brain tumours range from 1.15 to 5.14 cases per 100 000 children worldwide and 33.4 to 47.2 per million in South Africa.[26] There is also a higher brain tumour prevalence across all brain tumour types among males.[27] The risk for brain tumours can vary from genetic factors to environmental factors. For example, the risk of astrocytomas and ependymomas in children increases with higher parental age at birth, and parental radiation exposure further compounds the risk of tumour development.[28, 29] However, more than 8% of childhood and adolescent tumours are due to germline predisposition syndromes such as Neurofibromatosis 1, tuberous sclerosis, L-Fraumeni syndrome, Gorlin syndrome or Turcot syndrome.[29] Signs and symptoms depend on a variety of factors, including tumour location, patient age, and tumour growth rate.[29] In general, brain tumours can lead to cognitive impairments, altered emotional functioning and epileptic seizures.[1]

Infants with brain tumours tend to have nonspecific symptoms and signs such as macrocephaly, which is the presence of an abnormally large head circumference relative to age and sex, irritability, vomiting, and delayed milestones.[29, 30] Older children may experience headaches, nausea, or vomiting due to increased ICP caused by the presence of the brain tumour in a limited cranial space. This pressure can obstruct the flow of CSF, causing hydrocephalus.[29] In some cases the diagnosis of brain tumours is sometimes delayed or even missed due to the fact that these symptoms can overlap with those of other diseases or conditions,.[31] The growth rate of brain tumours also correlates with the degree of cognitive dysfunction. Faster growing tumours are associated with accelerated cognitive decline.[1]

Supratentorial tumours are brain tumours that occur above the tentorium cerebelli, the layer of dura mater between the cerebellum and cerebral hemispheres. These are commonly seen in children younger than 3 years of age. Supratentorial tumours include low-and high-grade gliomas, pineal region tumours, germ cell tumours, and intraventricular tumours.[32] Posterior fossa tumours are common in children between

the ages of 4 and 10 years, and include medulloblastomas, astrocytomas, and ependymomas. Other brain tumours such as atypical rhabdoid teratoid tumours and brain stem gliomas are quite rare in children.[33] Congenital brain tumours (CBTs), including teratomas, are among the most common childhood brain tumours. These teratomas are found in various parts of the body such as sacrococcygeal, gonadal, mediastinal, retroperitoneal, cervicofacial, and intracranial areas. CBTs can be found in infants, toddlers, and children of all sexes with no significant distribution differences.[34] Choroid plexus papilloma is the third most common tumour in children and it is characteristically found in infants.[28]

Although the brain tumour itself may affect brain functioning, medical interventions such as surgery, radiotherapy or chemotherapy, may also negatively affect brain function and lead to long-term deficits.[1, 25] Survivors of paediatric brain tumours have displayed diminished psychological well-being, with children exhibiting increased symptoms of depression and lower levels of self-esteem.[35] However, rehabilitation following treatment for brain tumours has been found to provide more favourable outcomes in this area compared to patients with stroke or TBI.[36]

1.2.3 Spina bifida

Spina bifida is the most prevalent neural tube defect and occurs early after conception. Around 150 000 infants are born annually with this defect worldwide. Notwithstanding, the prevalence of spina bifida in Africa is high and the rates range from 0.77 to 6.1 per 1000 live births in South Africa specifically.[37-40] There is also a reported higher prevalence among females than males.[41] Spina bifida is a congenital disorder affecting the spinal column due to failure of the neural tube to close properly,[38, 42] resulting in malformation of the spinal cord, which can occur at various anatomical levels. These malformations lead to motor and sensory loss below the affected level, incontinence, and associated cognitive impairment. Cognitive impairment is mainly due to the presence of hydrocephalus in affected children.[43] Secondary impairments and complications may include deformities of the legs, feet, and back, endocrine dysfunction, pressure sores, and pain.[38]

There are two types of spina bifida, namely, open and closed defects.[37] These two types of spina bifida consist of different subtypes including: occulta, meningocele, and myelomeningocele.

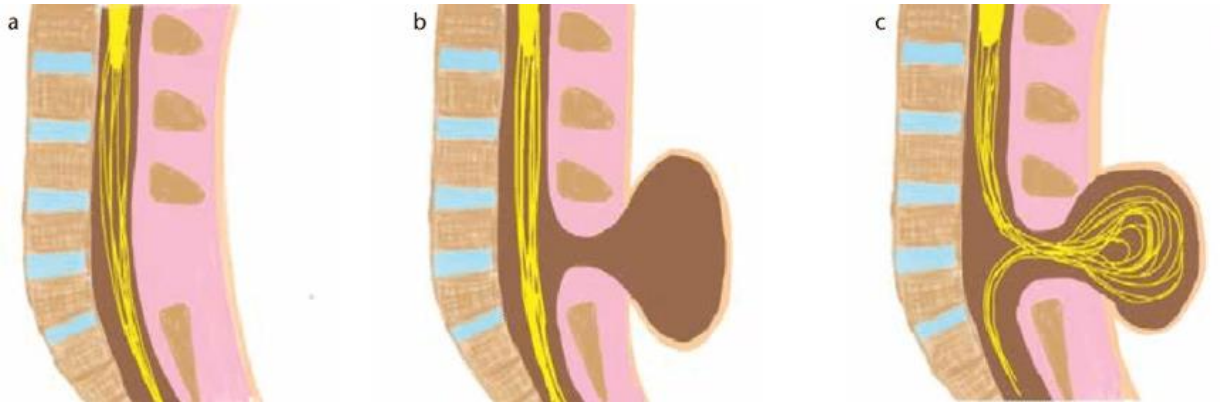


Figure 1.2: Illustration of Spina Bifida subtypes[44]
a: occulta, b: meningocele, c: myelomeningocele

Spina bifida occulta (figure 1.2a) is a mild and common form of spina bifida where there is incomplete closure of one or more vertebra in the spine. The defect is usually not visible from the outside, hence the name occulta referring to “hidden”. Patients with spina bifida occulta rarely present with symptoms.[45] Meningocele (figure 1.2b) occurs when a sac containing spinal fluid protrudes through the spine, and it may or may not be covered by a layer of skin.[46] Myelomeningocele (figure 1.2c) is the most severe form of this condition, where a portion of the spinal cord or nerves are exposed in a sac through an opening in the spine, which may or may not be covered by the meninges.[46]

Spina bifida may be a result of environmental or genetic factors.[46] In some cases, spina bifida can be caused by a folic acid deficiency as folic acid is required for closure of the neural tube during neurulation. Supplementing with folic acid or fortifying food with folic acid will act as a prevention measure.[47] Maternal hyperthermia and poorly regulated gestational diabetes mellitus may also increase the risk of neural tube defects such as spina bifida, as they would potentially disrupt the development of the neural tube.[44, 48]

Children with these impairments may engage less in scholastic and recreational activities, which may directly affect their behavioural and emotional wellbeing, social relationships, and mental and physical health.[38] ADHD symptoms, specifically the inattention type, which may also affect participation and attendance in school activities, have also been noted to occur in children with neural tube defects.[49] Rehabilitation has been postulated to improve control of voluntary movement and independent mobility in patients with neural tube defects; however, a rehabilitation program may be a lifelong process in these patients.[50]

1.2.4 Hydrocephalus

Hydrocephalus refers to a build-up of CSF in the cerebral ventricles, resulting in ventriculomegaly. An accumulation of CSF places pressure on brain tissue that may result in ischaemia, hypoxia, inflammation, and increased CSF pulsatility denoting impaired intracranial compliance.[51] Chronic ventriculomegaly may cause reduced gliosis, chronic inflammation, demyelination, axonal degeneration, periventricular oedema, metabolic impairments, and changes to BBB permeability.[51] Infants with hydrocephalus may exhibit signs and symptoms such as irritability, vomiting, poor feeding, and progressive macrocephaly. [51, 52] In children older than 2 years, one may observe symptoms indicative of intracranial hypertension, including headaches, vomiting, delayed developmental milestones, and papilloedema.[51] This can lead to various secondary cerebral complications, including brain damage. There are also functional concerns with regards to children with hydrocephalus including, impaired mobility and ambulation, impaired cognitive function, sensory deficits, endocrine dysfunction, seizures, depression, and chronic headaches.[53] In some cases, physical impairment requires extensive rehabilitation.[54]

Hydrocephalus can be intrinsic, which is hydrocephalus that is present from birth, or extrinsic hydrocephalus, which develops over time.[54] There are four types of hydrocephalus: obstructive or non-communicating hydrocephalus where there is an obstruction in the flow of the CSF; reduced absorption of CSF into the venous system is known as communicating hydrocephalus; excessive CSF production is known as hypersecretory hydrocephalus; and normal-pressure hydrocephalus (NPH) is when there is abnormal CSF mobilisation but it results in normal or only a marginal increase in ICP. NPH is also a form of communicating hydrocephalus.[51, 55]

This condition can be very difficult to treat, but if the correct procedures and appropriate rehabilitation strategy has been implemented, most children can achieve a fairly good cognitive outcome.[52] The two main treatments for hydrocephalus are CSF diversion surgery such as insertion of a ventriculoperitoneal shunt (VPS) and endoscopic third ventriculostomy (ETV).[52] VPS insertion involves the placement of a catheter into the ventricles of the brain and directing the distal part of the catheter beneath the skin to the abdominal wall and directly into the peritoneal space, to shunt CSF from the ventricles to the peritoneum. A hydrocephalus patient can become shunt independent, but that does not mean that the hydrocephalus has been successfully treated, thus frequent follow-up assessments are necessary as there is still a possibility for delayed deterioration.[52] ETV is a surgical procedure where an opening is made in the floor of the third ventricle using an endoscope, allowing CSF to drain into the subarachnoid space around the brain, thereby bypassing any obstructions to CSF flow. Complications after EVT may include failure (due to persistent obstruction), infection, CSF leakage, intraventricular haemorrhage, and damage to the tuber cinereum, particularly in patients who develop diabetes insipidus.[53]

Hydrocephalus is a common condition especially in low- and middle-income countries due to high birth rates and neonatal infections, particularly in the African continent.[56, 57] In sub-Saharan Africa alone, infant hydrocephalus cases are more than 200 000 per year.[51] Males also have a higher prevalence of hydrocephalus than females.[58] Patients with myelomeningocele will also at one point develop and be treated for hydrocephalus.[52] Children with Tuberculous meningitis (TBM), which is the most severe form of extra-pulmonary tuberculosis, can also cause hydrocephalus which will further worsen symptoms and neurological outcome.[59] Extra-parenchymal injury can potentially lead to the development of acquired hydrocephalus later on.[51]

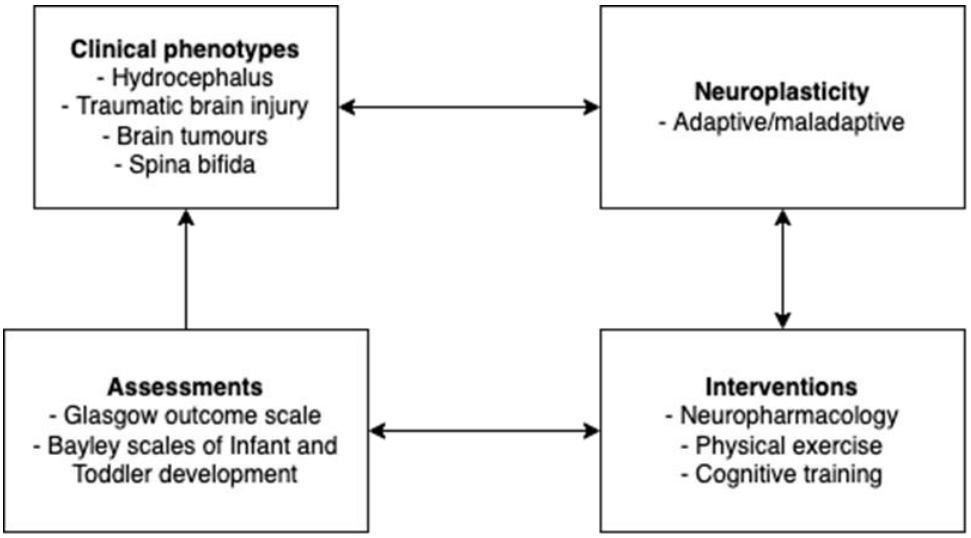


Figure 1.3: Flow diagram representing a conceptual overview of the relationships between clinical phenotypes, neuroplasticity, interventions, and assessments.[5]

1.3 NEUROREHABILITATION

Neuroplasticity is a term used to describe the rate at which an individual can learn and adapt to changing environments and how the CNS can continuously remodel and repair itself.[60] This reorganization of brain structures and connections could be attributed to genetic or environmental factors that require a neural response.[5] When this neural response results in a gain of functionality, it is seen as adaptive neuroplasticity. However, if it results in a loss of function or worsens the current injury, it is considered a maladaptive neural response.[5] These negative consequences can have a delayed onset, as the brain progressively changes over time, resulting in a maladaptive response only months or years after the initial trauma or incident. Cramer *et el.* found that adaptive and maladaptive neuroplasticity responses may occur simultaneously during recovery. Maladaptive neuroplasticity can encompass various outcomes, including the onset of new epilepsy, which is a common consequence following cerebral trauma. Additionally, it can lead to chronic pain and allodynia in cases of CNS injuries, particularly those affecting the dorsal spinal cord or thalamus. Furthermore, maladaptive neuroplasticity may manifest as dystonia and autonomic dysreflexia in individuals who have experienced spinal cord injuries.[5] The impact on neuroplasticity and functionality is also highly dependent on age. A developing brain

is more likely to reorganize itself and shift function from a non-functional brain area to a functioning one; this phenomenon is known as cross-modal plasticity.[5]

Neurorehabilitation promotes neuroplasticity, and if it is implemented early enough, it can make a significant contribution to functionality.[61] Neurorehabilitation is an approach to improve an individual's current nervous system capabilities that are affected in day-to-day functioning due to injury or disease. Rehabilitation techniques are rooted in theoretical constructs of CNS functioning and should therefore apply to various diagnoses. Patients may have different physical or neurological conditions, and neurorehabilitation will help to reduce limitations still experienced after surgery to improve overall quality of life.[62] A trans-disciplinary team is necessary to make neurorehabilitation successful. Such a team will include a nurse, physical and occupational therapist, speech/language pathologist, dietician, physician, and psychologist.[63, 64]

Nursing is a critical part of the multi-professional team during rehabilitation. Not only do nurses support patients with their basic needs, but nurses also help patients to become more self-aware and implement interventions so that patients, especially those with disabilities, can function more independently.[65] Nursing helps to take care of and support basic body functions as well as feeding, early mobilization, and bladder and bowel management. Nurses perform frequent check-ins with the patients to see if the patient is managing well or if there are any signs or symptoms of illness.[65]

Physiotherapy is another integral part of neurorehabilitation. This therapy aims to improve patient's lifestyle through interventions such as exercise, movement, manual therapy, education and advice.[66] Physiotherapy treatment can be categorised into eight different categories according to United Kingdom practices as depicted in figure 1.4. These categories might differ slightly when compared to South African practices.

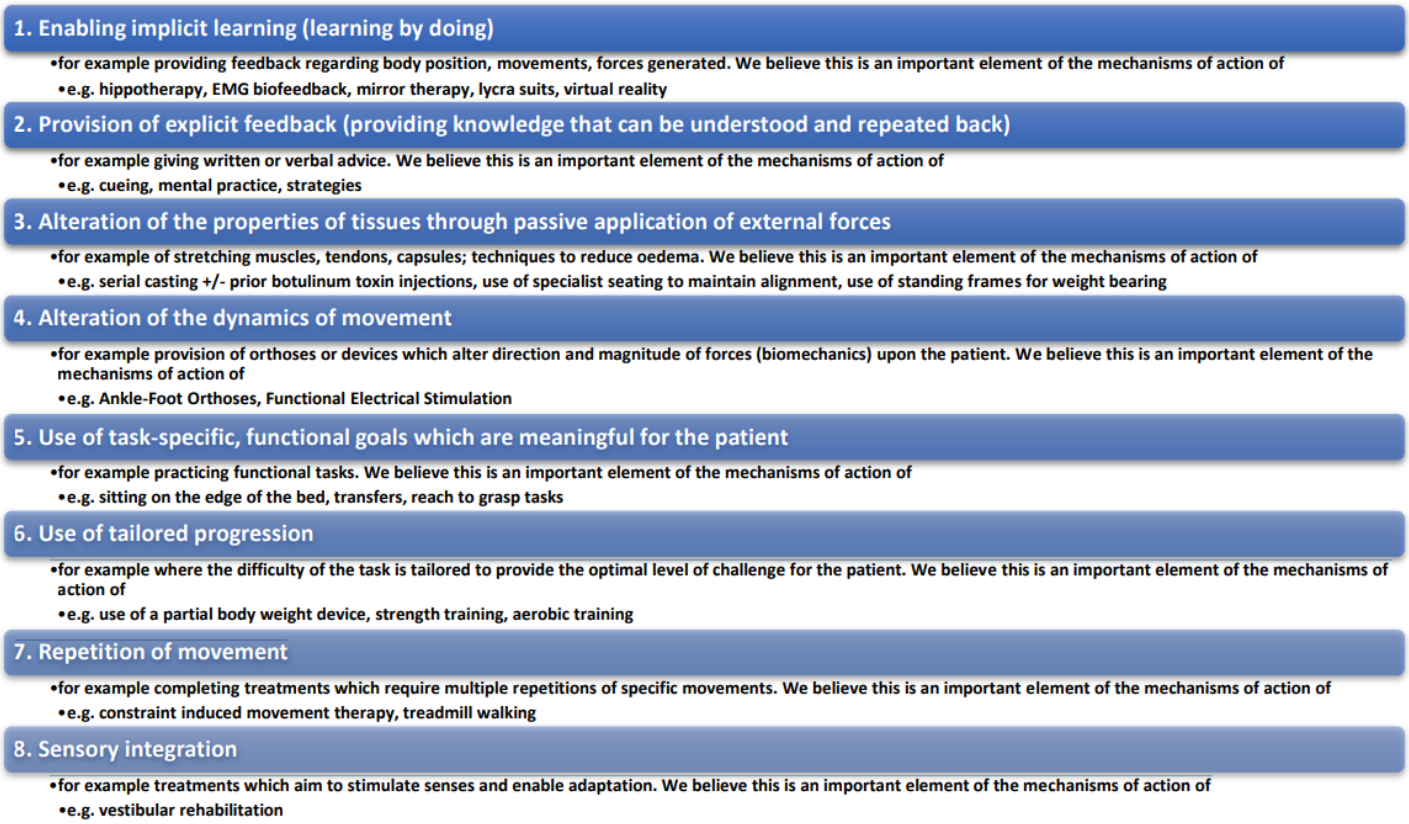


Figure 1.4: Summary outlining identified intervention categories, and examples.[66]

Occupational therapy assists and encourages children with neurological disability to engage and participate in day-to-day activities in order to lead more sociable and independent lives.[67] The most commonly used occupational therapy treatment interventions are caregiver education, sensory stimulation techniques, and daily activity management activities such as mobility, postural control and motor learning.[68] Daily activity interventions may include play-based activities, play engagement, and instructions on how to use specific skills like appropriate social cues.[69]

Speech therapists can assist children directly or indirectly to help focus and improve different language elements, attention, listening, and conditions like dysphagia. Direct interventions can be performed individually or in a group setting.[70] A group setting creates opportunities for the child to interact and learn from their peers. Indirect

interventions focus more on parent-child interactions. The speech therapist provides educational programmes and advice to the caregivers to improve the communicative environment.[70] Children with more complex or severe language impairments will benefit more from direct interventions.[71] Speech therapy interventions may include play interventions, speech sounds, vocabulary, sentence structures, and reinforcement, which involves some form of reward such as the provision of stickers or praise.[70]

Neurological impairments can change the nutritional intake of the patient, which can lead to malnutrition. Also, neurological impairments could cause dysphagia, further increasing the risk of malnutrition.[72, 73] Optimal nutrition will help the body to heal better, support cognitive function, advance rehabilitation progress, and reduce morbidity and mortality.[3, 73, 74] Thus, a nutritional assessment is first conducted to identify the presence of any nutritional problems, thereafter a nutritional intervention plan is created and implemented by the dietician.[73] Patients with dysphagia may require enteral nutrition, percutaneous endoscopic gastrotomy (PEG) feeding or nasogastric tube (NGT) feeding.[75] The neurorehabilitation team needs to be cautious and aware that during rehabilitation activities dislodgement of an insitu PEG or NGT is possible. The presence of feeding devices is also most likely to cause agitation in patients.[75] Importantly, children have psychosocial milestones that need to be achieved.

Psychologists are also part of the multi-disciplinary team and often work with speech therapists to facilitate cognitive and speech strategies together. Neurorehabilitation psychologists assist with optimizing child-appropriate participation, social skill development, and learning during the six stages of growth leading up to adolescence. This support ensures that the child can progress optimally to the next stage of development.[76] Neuropsychological evaluation during these developmental stages is important to ensure that the correct strategies are implemented.[77] In addition, social workers form part of the neurorehabilitation team, especially with TBI cases, to assess individual, family, and environmental contextual factors, as well as to provide familial support and placement in special schools or care facilities where needed.[78]

Neurological rehabilitation aims to restore function and independence while improving overall health and quality of life – physically, emotionally, and socially. The goal of

neurorehabilitation is to help patients improve their condition to the point where the patient can return home without, or in some cases, with very few functional limitations.[79] However, this is not always possible. In these cases a patient can be discharged to the care of the family with the help of the social worker under the guidance of members of the multi-disciplinary team.[79] If the patient is still unable to recover sufficiently to be discharged from the rehabilitation centre and the family cannot provide adequate care at home, a nursing home or long-term care facility could provide a better long-term solution.[80]

A study by Königs *et al*. found that more intensive neurorehabilitation in patients with severe TBI promote functionality and recovery when it is implemented early enough.[81] Patients with primary brain tumours who undergo neurorehabilitation after a surgical intervention make great functional improvements.[82] Similarly, cognitive scores also improve with neurorehabilitation across tumour types. However, patients with recurring tumours make smaller functional gains with rehabilitation.[82] Neurorehabilitation may improve urinary/bladder control and cognitive function in spina bifida patients over a three month period; however, future research is required to establish the long term benefits.[83] Hydrocephalus is dependent on the shunt success, as a shunt failure will have a big impact on the duration of neurorehabilitation and improvements in function.[84] Patients with hydrocephalus, who undergo shunt insertion without complications and achieve full recovery, can experience significant cognitive and functional improvements through neurorehabilitation.[85]

There is a high incidence of complications within the first 30 days of paediatric neurosurgery,[86] and can induce further neurological decline which could lengthen the rehabilitation period and overall hospitalisation time. Common neurosurgical complications may include brain oedema, CSF leakage or dural tears, skull fractures, seizures, cerebral ischaemia, elevated ICP, cranial nerve palsies, or postoperative haemorrhage.[86, 87] The anaesthesia provided could also cause cardiovascular complications, hypothermia, hypoxemia, respiratory complications, or allergies.[86] Post-surgical neuroinflammation may also result in further neural dysfunction and impaired neurogenesis.[88]

1.4 PATIENT TRANSFER FROM SBAH NEUROSURGERY WARDS TO TRH

In-ward multi-disciplinary assessments are done at Steve Biko Academic Hospital (SBAH) on each paediatric neurosurgical patient by the physiotherapist, occupational therapist, and speech therapist. This team is in constant communication with the attending neurosurgeon and will assess whether the patient is unable to care for themself or by untrained individuals. A period of rehabilitation at a specialized neurorehabilitation centre, Tshwane Rehabilitation Hospital (TRH) in this case, is recommended, which may improve outcomes. The patient receives a formal neurodevelopmental assessment on admission at THR and continuous in-hospital assessments throughout the rehabilitation program. Neurodevelopmental assessments are done at discharge from TRH. Figure 1.5 below encapsulates the patient transfer process from SBAH (acute care) to TRH (rehabilitation care).

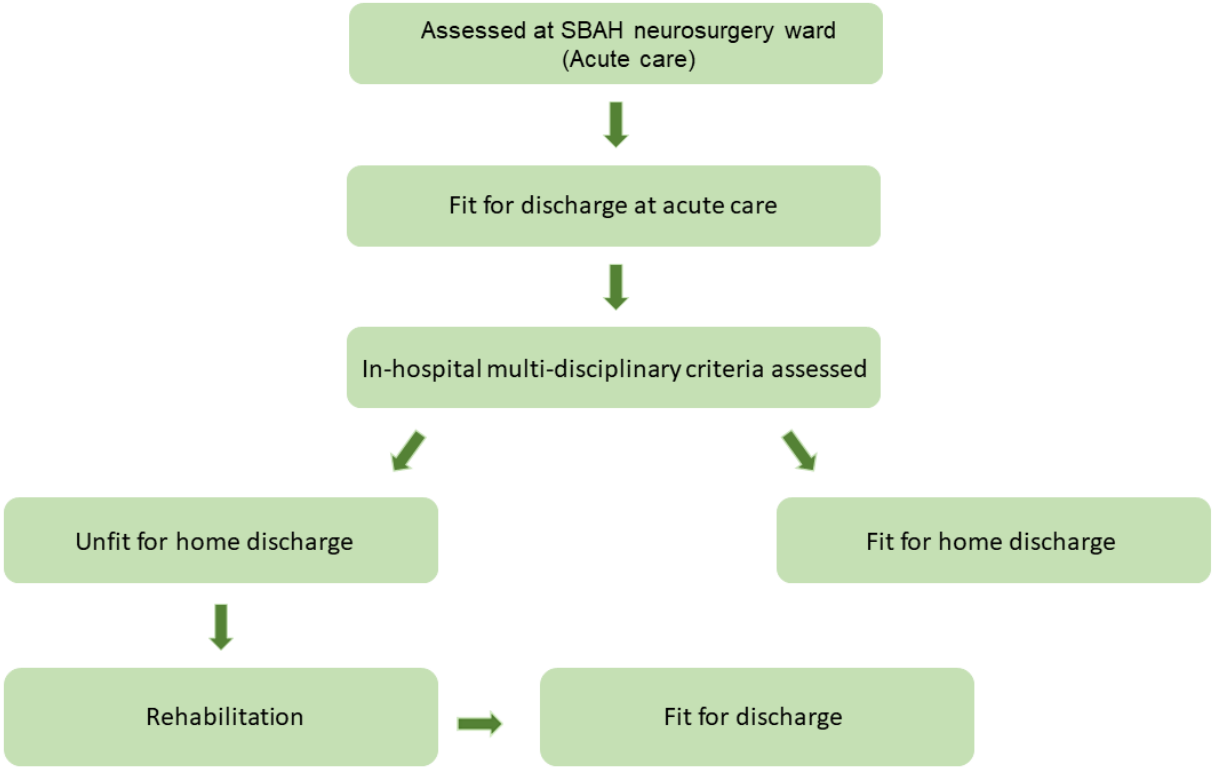


Figure 1.5: Flow diagram representing the patient transfer procedure.

1.5 SCALES OF NEUROREHABILITATION

Neurorehabilitation scales are used to evaluate the level of impairment in patients and to measure any functional improvement with rehabilitation. Most of these scales are condition-specific in order to achieve the best possible measure.[89]

1.4.1 Bayley Scales of Infant and Toddler Development (BSID)

The Bayley Scales of Infant and Toddler Development (BSID) is a common tool that is routinely used in clinical settings to identify developmental impairment and management plans for children.[90, 91] The first BSID was published in 1969, and it only assessed motor and mental domains in 3 to 28-month-old children at that time. The second edition, published in 1993, added a behaviour rating domain for the 1-42-month age group. In 2006, the third edition was published and assessed five domains, including cognition, motor, language, socio-emotional, and adaptive behaviour as seen in Table 2. The BSID 4 was published in 2019, which is currently used and has remained unchanged from the third edition.[91]

There is still, however, a significant difference between the third and fourth editions of the Bayley scales. In BSID III, the scoring is dichotomous (1, 0), whereas the scoring in BSID 4 is polytomous (2, 1, 0). The BSID 4 is more time efficient as it takes 30% less time to complete. The BSID III's scoring is software-based, and the BSID 4's scores require web-based administration. Although both editions have the same five domains, the fourth edition features fewer items in each section.[92]

Depending on the risk factors, assessments are conducted at 12, 18, 24, or 30 months of age; however, the assessment can be done at different time points with a 6-month gap between assessments. All assessments are performed by experienced clinicians trained in BSID test practices that may include developmental paediatricians, neuropsychologists, child psychologists or a qualified paediatric nurse practitioner trained in BSID 4 assessment.[91]

The five domains of the BSID assist the multi-disciplinary neurorehabilitation team to confirm which areas of development require more or less attention during rehabilitation.[93] Each domain is scored separately, and an overall score is calculated. If the scores are within the bottom 10th percentile it means that there is a developmental delay, 16th percentile infers mild impairment, and 50th percentile

signifies average functioning.[94] In essence this validated and reliable scale is a suitable tool to assess neurodevelopment in patients, as well as assess neural delay at an early age so that any interventions can be incorporated as soon as possible.[91, 95-97]

Table 2: The BSID 5 Domains (Made with Microsoft Word)[93]

Domain	**BSID 4**
Cognitive scale	81 items
Language scale	42 receptive items 37 expressive items
Motor scale Motor scale	46 fine motor items 58 gross motor items
Social-Emotional scale	Derived from Greenspan Chart
Adaptive behaviour scale	Utilizes the Vineland behaviour assessment system.

1.4.2 Glasgow Outcome Scale (GOS)

The Glasgow Outcome Scale (GOS), introduced in 1975, stands as one of the earliest developmental measurement scales. Unlike some other scales, GOS does not concentrate on a specific mental or physical outcome; rather, it evaluates overall brain functioning. This assessment tool serves the purpose of comparing functional outcomes following a head injury and assessing the effectiveness of interventions employed in head injury management. GOS, through its evaluation, aims to determine a patient's degree of dependence and independence.[98-100] There are five levels of outcome assessment as depicted in table 3 below: a score of 1 represents death, 2 signifies a vegetative state with minimal responsiveness, 3 indicates severe disability requiring daily support due to dependence on others, 4 suggests moderate disability but the ability to function independently, and 5 corresponds to a good recovery,

allowing the patient to resume a normal life.[99, 100] The GOS is the most commonly used tool globally to assess functional outcomes in TBI.

Table 3: The GOS assesses five possible outcomes. [99]

Outcomes	**Description**
Unfavourable	
Death	Score - 1
Vegetative state	Score - 2 Patient has normal respiratory function and sleep-wake states. Patient may look at moving objects, bright lights, or loud sounds and withdraw from a painful limb stimulus.
Severe disability	Score - 3 Patients are dependent on others to assist with daily tasks.
Favourable	
Moderate disability	Score - 4 Can act independently at home and can make use of public transport; however, there are significant mental or physical neurological impairments.
Good recovery	Score - 5 Patient can maintain an independent existence and can resume previous employment.

The Glasgow Outcome Scale Extended (GOS-E) version has also been modified to the Glasgow Outcome Scale Extended Pediatric (GOS-E Peds) for children that are two years old or younger. The paediatric GOS's verbal and motor divisions have specifically been altered to cater for children or neonates with the inability to talk to ensure accurate total scoring and to measure functional outcome.[101, 102] The GOS-E Peds scale has also been validated to assess clinical outcomes from infancy to early

childhood. The GOS-E Peds is an 8-point scale ranging from 8 representing death to 1 indicating upper good recovery in a social and functional aspect, and answers should be in accordance with what is age-appropriate at the time of the assessment (Appendix A). [102, 103]

1.4.3 Glasgow Coma Scale (GCS)

The Glasgow Coma Scale (GCS) was developed in 1974 by Teasdale and Jennett and is a tool used to measure the level of consciousness (figure 1.6).[104] Originally, it was a 14-point scale but was revised three years later into a 15-point scale. The GCS examines three independent areas: eye opening, verbal response, and motor responsiveness. Each area is scored separately by a numerical value, and each value is then combined to form a total overall score. If the patient scores 3 out of 15, then it is associated with a deep coma, and 15 out of 15 indicates that the patient is fully awake, alert, and orientated.[104]

Glasgow Coma Scale

BEHAVIOR	RESPONSE	SCORE
Eye opening response	Spontaneously	4
	To speech	3
	To pain	2
	No response	1
Best verbal response	Oriented to time, place, and person	5
	Confused	4
	Inappropriate words	3
	Incomprehensible sounds	2
	No response	1
Best motor response	Obeys commands	6
	Moves to localized pain	5
	Flexion withdrawal from pain	4
	Abnormal flexion (decorticate)	3
	Abnormal extension (decerebrate)	2
	No response	1
Total score:	*Best response*	15
	Comatose client	8 or less
	Totally unresponsive	3

Figure 1.6: The layout of the GCS scoring system.[104]

The eye opening and motor response may require painful stimuli in various locations as depicted in figure 1.7 below.

Noxious stimuli technique	Method of applying the noxious stimuli
Trapezius grip/pinch	Grasping approximately two inches of the trapezius muscle, located by palpating the area superior to the clavicle and medially to the shoulder, between the thumb and index finger and simultaneously twist and squeeze the muscle firmly
Pressure to the side of a finger	Using a pen or pencil apply pressure to the side of the nail bed
Pressure to the nail bed	Applying pressure to the lunula (the crescent-shaped whitish area of the bed of a fingernail or toenail) with a blunt instrument such as a pencil or pen
Fingertip pressure	Using a pen or pencil apply pressure across the tip of the finger nail
Sternal rub	Rubbing the knuckles of a closed fist firmly and vigorously on the person's sternum
Supraorbital pressure	Locate the notch on the supraorbital margin and apply straight upward pressure with the tip of the thumb ensuring that no pressure is applied to the eyeball
Retromandibular or styloid process stimulation	Inserting a fingertip as high as possible into the depression between the back of the mandible and the mastoid process (just in front of the earlobe) an apply pressure
Ear lobe stimulation/ pressure	Using thumb and index finger apply pressure to the earlobe

Figure 1.7: The various locations used to apply painful stimuli to elicit a response.[104]

This tool is valid and reliable, however there has been some controversy about the GCS on inter-rater bias and the moral and ethical implications when applying pain stimuli to patients.[104, 105]

1.4.4 Waterlow Scale (WS)

The Waterlow Scale (WS) (figure 1.8) is often used in clinical practice to assess the risk of developing pressure sores and it is also a promising tool for risk stratification of surgical patients.[106] It looks at a wide variety of risk factors which also enables a multi-

disciplinary team to use this scale on a wide variety of patients and to enable nurses to take preventative measures.[107, 108] Paediatric nurses can also use this assessment for paediatric risk assessment.[109] WS has been seen as unreliable and has questionable validity and thus should be used in conjunction with other assessment tools.[107, 110]

Weight/size relationship:

0. Standard
1. Above standards
2. Obese
3. Below standards

Skin type and visual aspect of risk areas:

0. Healthy
1. Frail
1. Dry
2. Edematous
1. Cold and humid
2. Alterations in color
3. Wounded

Sex/Age:

1. Male
2. female
1. 14–49 years
2. 50–64 years
3. 65–74 years
4. 75–80 years
5. Over 81 years

Special risks:

Tissue malnutrition:

8. Terminal/cachexia
5. Cardiac insufficiency
6. Peripheral vascular insufficiency
2. Anemia
1. Smoker

Continence:

0. Complete, urine catheter
1. Occasional incontinence
2. Urine catheter/fecal incontinence
3. Double incontinence

Mobility:

0. Complete
1. Restless
2. Apathy
3. Restricted
4. Inert
5. On chair

Appetite:

0. Normal
1. Scarce/feeding tube
2. Liquid intravenous
3. Anorexia/Absolute diet

Neurological deficit:

5. Diabetes, paraplegic, ACV

Surgery:

5. Orthopedic surgery below waist
5. Over 2 hours in surgery

Medication:

4. Steroids, cytotoxics, anti-inflammatory drugs in elevated dosage

Scoring: Over 10 points: at risk. Over 16 points: high risk. Over 20 points: very high risk.
Source: Waterlow.[50]

Figure 1.8: WS assessment criteria[108]

1.5 PROBLEM STATEMENT

The duration of hospitalisation is determined by various clinical and social factors, including physical and cognitive disability. Successful neurorehabilitation aimed at reducing limitations and disability, is expected to enhance overall patient health and reduce the likelihood of future readmissions. Delays in neurorehabilitation could exacerbate neurological impairments and potentially result in long-term institutionalization among paediatric patients with neurological conditions.

The study sought to investigate the transit time between surgery and rehabilitation as well as the hospitalisation duration of paediatric patients at the Steve Biko Academic

Hospital (SBAH) neurosurgery department and Tshwane Rehabilitation Hospital (TRH) to evaluate whether all measures were taken and simplified. It also aimed to investigate the criteria used to determine which children were eligible for neurorehabilitation treatment, as well as the outcomes of children who underwent neurorehabilitation using the Bayley Scales of Infant and Toddler Development and the Glasgow Outcome Scale Extended Pediatric.

1.6 AIM

This project aimed to assess the transit care time, hospitalisation duration, and clinical outcomes as measured by BSID- and- GOS-E Peds for children undergoing neurorehabilitation.

1.7 OBJECTIVES

- To investigate the criteria used to determine the eligibility of children for further rehabilitation and transfer to TRH, including the transit care time and hospitalisation period.
- To investigate whether the following neurorehabilitation scale scores correlated with eligibility and outcome using hospital and rehabilitation records:
    - Bayley Scales of Infant and Toddler Development
    - Glasgow Outcome Scale Extended Pediatric
- To provide an assessment of the frequency of use of the neurorehabilitation scales at different time points at the rehabilitation hospital. These time points are:
    - On admission
    - Continuous in-hospital assessment throughout the rehabilitation program
    - Upon discharge

Chapter 2: Materials and Methods

2.1 STUDY DESIGN

A retrospective study design was implemented to evaluate the transit time, hospitalisation duration, criteria used to determine eligibility for neurorehabilitation, as well as the neurorehabilitation scales used during the rehabilitation of paediatric patients with neurological injuries during January 2019–November 2022 at the SBAH neurosurgery unit and TRH.

2.2 SAMPLE SIZE AND DATA COLLECTION

Out of the 81 paediatric patients included in the patient list, this retrospective study included 51 paediatric patients who met the following inclusion criteria:

- Both male and female children between the ages of 0-18 years.
- Children admitted to the SBAH neurosurgery department between January 2019 and November 2022.
- Children diagnosed with traumatic brain injury, brain tumours, spina bifida, and hydrocephalus.
- Children transferred from SBAH to TRH for neurorehabilitation between January 2019 and November 2022.

Of the 30 paediatric patients excluded from the study, 15 patients had a different diagnosis from those in the inclusion criteria, six patients were transferred from another hospital to TRH for neurorehabilitation, three of the 30 patients admitted to TRH did not fall between the period January 2019 and November 2022, and six patients' files were missing from SBAH and TRH.

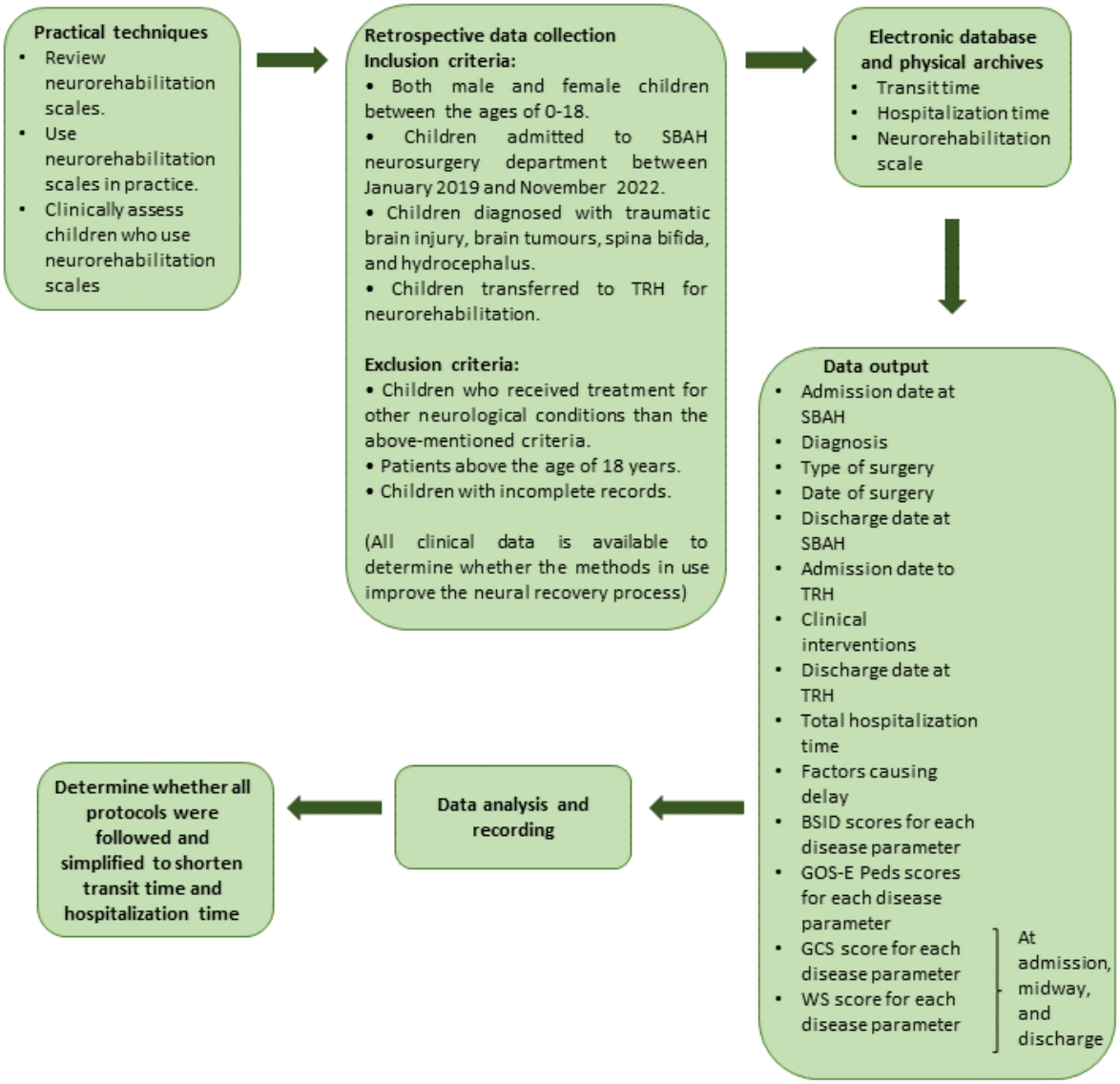


Figure 2.1: Flow diagram representing the project procedure (Made with Microsoft PowerPoint)

After University of Pretoria Faculty of Health Sciences Research Ethics Committee (Ethics number: 558/2022) and hospital management approval via the National Health Research Database (NHRD) (Approval number GP_202212_009), a patient list was provided by Dr. V Padayachy, senior medical officer at TRH, of all eligible patients transferred from SBAH for further rehabilitation. The following information was obtained from the TRH files and inserted on a data extraction form: sex, date of birth, admission date at TRH, diagnosis, in-hospital rehabilitation provided, GOS scores, GCS scores, BSID scores, and Waterlow scores – on admission, throughout rehabilitation, and at discharge – discharge date at TRH, total hospitalisation time at TRH, total overall hospitalisation time, and factors that affected transit time at TRH.

Following the provision of the patient list, patient files were requested from the records department at SBAH. The following data was collected from each patient's file at SBAH and captured on a data extraction form: biological sex, date of birth, age of admission at SBAH, admission date at SBAH, diagnosis, type of surgery performed, date of surgery, discharge date at SBAH, total hospitalisation time at SBAH, admission date at TRH, in-hospital rehabilitation provided at SBAH, and factors that affected transit time at SBAH.

Once the data collection was completed, the data from both hospitals were combined into one Excel spreadsheet, recording the patients' sex, age of admission at SBAH, diagnosis, type of surgery, total hospitalisation time at TRH, total hospitalisation time at SBAH, total hospitalisation time overall, inpatient occupational therapy, inpatient speech therapy, inpatient physiotherapy, inpatient psychological therapy, inpatient nutritional therapy, BSID score, GOS-E Peds score, GCS scores, WATERLOW scores, and factors affecting transit time. The combined spreadsheet was then further divided into four separate patient sheets containing brain tumours, hydrocephalus, spina bifida, and/or traumatic brain injury. Patients with two neurological conditions were represented in chapter 3 through graphs and tables.

Supervisor, Prof. Padayachy; co-supervisors, Dr. V Padayachy and Dr. CW Grobbelaar; and neurosurgery senior registrar, Dr. S Mabaso, provided guidance during data collection to ensure all relevant data was obtained.

2.3 ETHICAL CONSENT

The protocol was submitted to and evaluated by the University of Pretoria Faculty of Health Sciences Research Ethics Committee (Ethics number: 558/2022). Approval was obtained from the National Health Research Database (NHRD) (Approval number GP_202212_009) prior to data collection. A code of conduct was followed when conducting research at SBAH and TRH.

Information about patients was kept strictly confidential and anonymous in accordance with all legal requirements to protect patient privacy. All patient data were anonymized. Physical files of patients were not removed from hospital premises. Data collected was saved on a secure cloud, password protected and only accessed by the research team.

The results of this research were not shared on social networks or by any person not featured in the study. The project in physiology is retrospective and made use of existing datasets that formed part of clinical data obtained from past rehabilitated paediatric patients. No direct participant contact was involved at any stage of the research.

2.4 STATISTICS

The study employed several statistical methods and data presentation techniques to analyse its findings. Descriptive statistics played a fundamental role, as it was used to summarize and provide an overview of the data, including demographic and clinical characteristics of the patients, such as sex distribution and mean age for different patient groups. The data was effectively presented using tables and figures, which aided in visualising key information, such as the prevalence of various neurological impairments and the increase in patient transfers from SBAH to TRH. Percentage analysis was a prominent feature, facilitating comparisons and the assessment of factors influencing hospitalization time, surgical procedures, and documented improvements in patients' conditions based on Glasgow Coma Scale (GCS) and Waterlow Scale (WS) scores. Longitudinal analysis was conducted to track changes in GCS and WS scores over time, enabling the evaluation of patients' progress during their rehabilitation stay. These statistical methods collectively contributed to a comprehensive understanding of the study's results and the factors influencing patient outcomes.

Chapter 3: Results

To provide a thorough comprehension of the results, the important findings of this retrospective study are addressed in this part, along with pertinent tables and figures. The analyses cover demographic and clinical information, neurorehabilitation scale results, and therapeutic approaches. In addition to the objectives described, the study contains other relevant data that may be utilised in future research.

3.1 DEMOGRAPHIC AND CLINICAL CHARACTERISTICS

3.1.1 Sex and age distribution

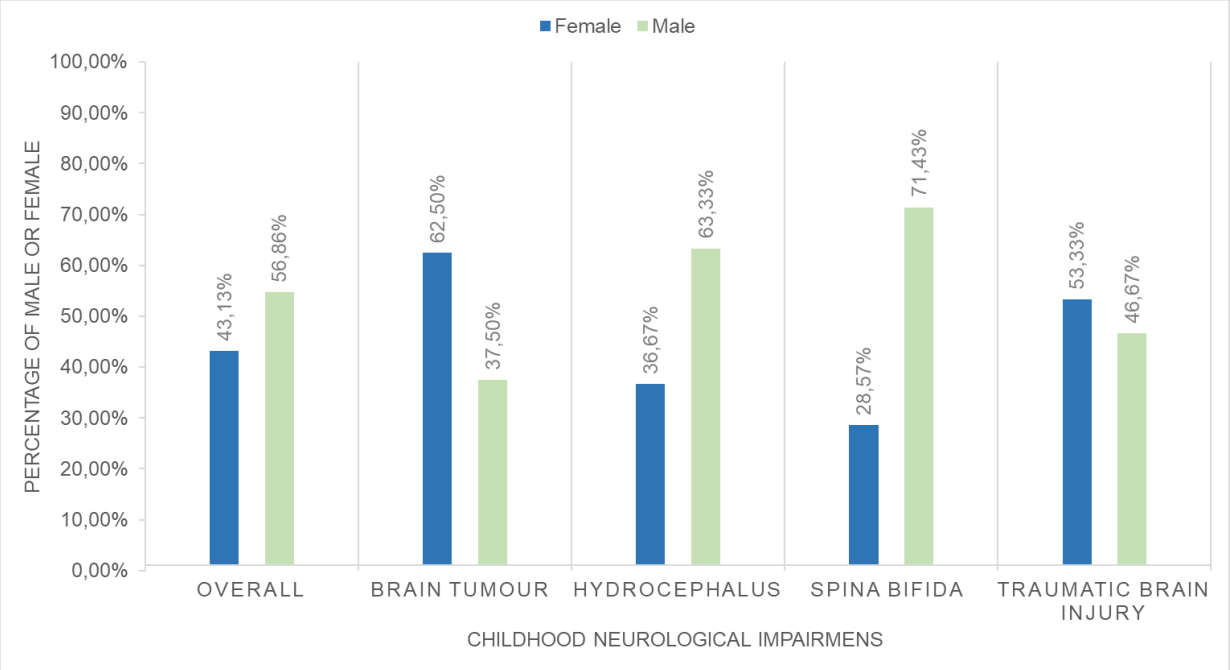


Figure 3.1: Sex distribution overall and across childhood neurological impairments.

As seen in Figure 3.1, a total of 51 patients were enrolled in the study, including 29 males (56.86%) and 22 females (43.13%) who underwent rehabilitation at TRH. In patients with brain tumours, 62.5% (n = 5) were female and 37.5% (n = 3) were male. Hydrocephalus was observed in 63.33% (n = 19) of males and 36.67% (n = 11) of females. Spina bifida predominantly affected males (71.43%; n = 5) with only 28.57% (n = 2) in females. In patients with traumatic brain injury, 46.67% (n = 7) were male and 53.33% (n = 8) were female.

The overall mean age of the study cohort was 25 months. The mean age and sample variance of patients with brain tumours, hydrocephalus, spina bifida, and TBI was 37

months and s2 – 9.11, 17 months and s2 – 3.23, 3 months and s2 – 0.02, and 48 months and s2 – 11.52, respectively (Appendix B).

3.1.2 Impairment prevalence

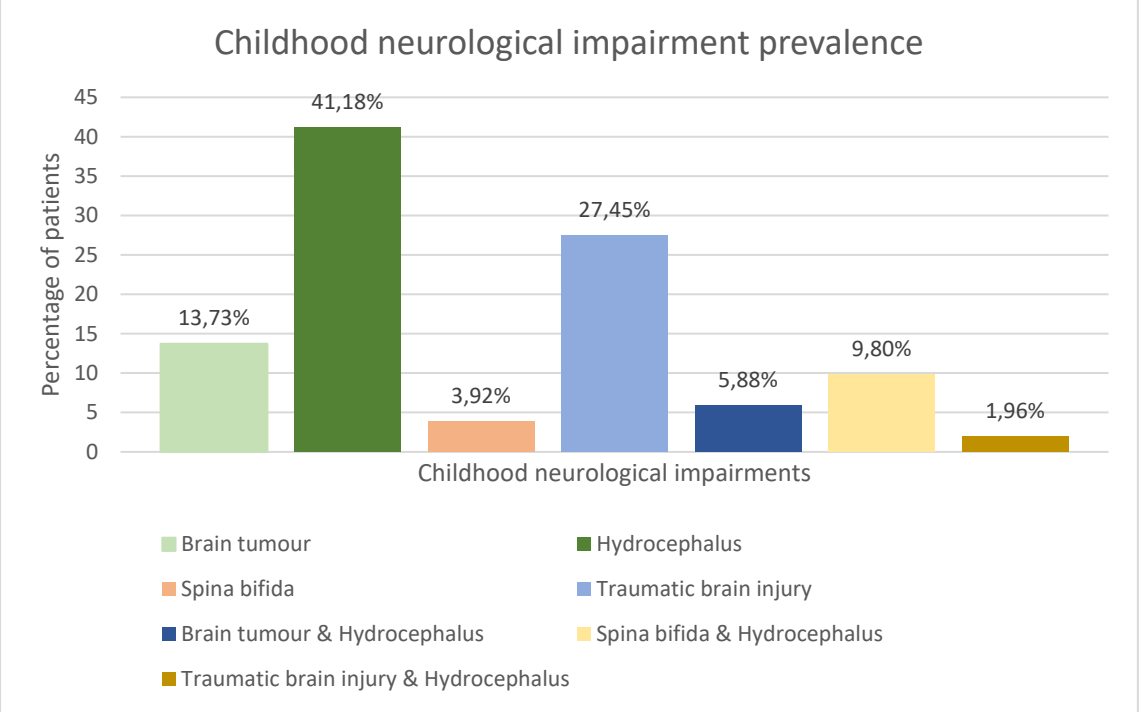


Figure 3.2: Representation of childhood neurological impairment prevalence.

Figure 3.2 highlights the prevalence of each neurological impairment, as well as the prevalence of patients who had more than one neurological condition. The majority of patients in this study population were diagnosed with hydrocephalus without other lesions (41.18%; n = 21). Following hydrocephalus, the next most common conditions were traumatic brain injury (TBI) at 27.45% (n = 14), brain tumours at 13.73% (n = 7), and spina bifida at 3.92% (n = 2). Patients who had a combination of neurological conditions were mostly diagnosed with spina bifida and hydrocephalus at 9.80% (n = 5). Patients who had brain tumours and hydrocephalus were 5.88% (n = 3) of the population, and only 1.96% (n = 1) had a traumatic brain injury and hydrocephalus.

3.1.3 Annual patient admission

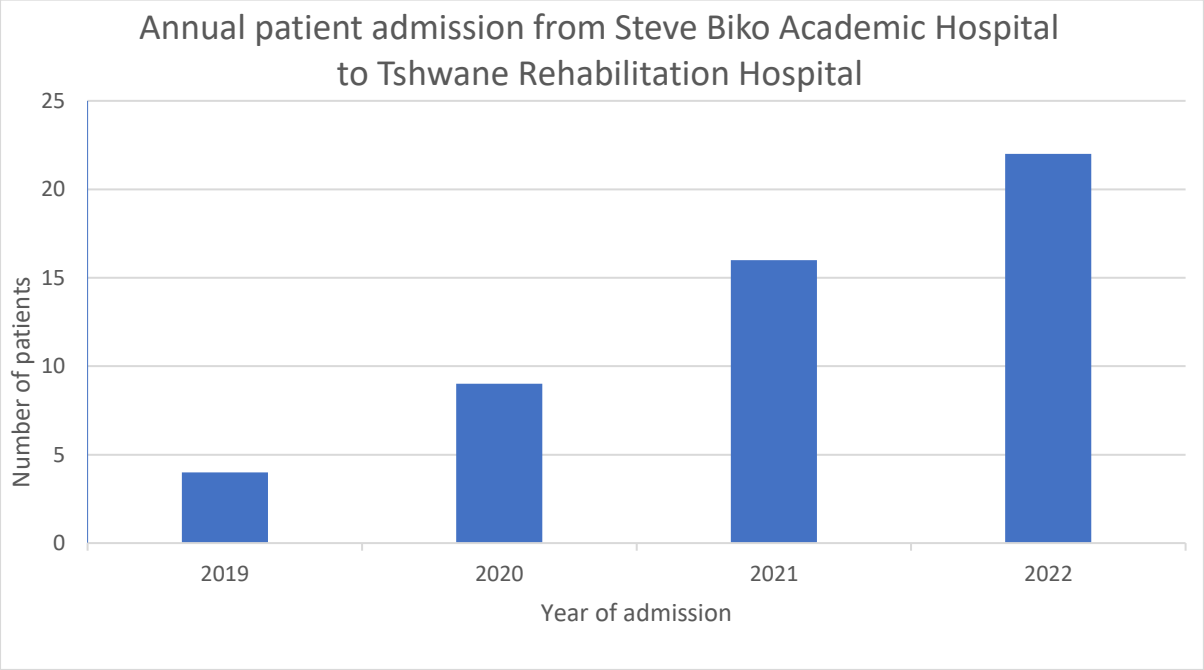


Figure 3.3: Annual patient admission from SBAH transferred to TRH.

The patients included in the study and admitted to TRH exhibited a substantial annual increase, with a growth rate of 125% from 2019 to 2020, followed by approximately 77.78% from 2020 to 2021, and a more moderate increase of around 37.5% from 2021 to 2022 as depicted in Figure 3.3.

3.1.4 Surgical procedures

Most patients with TBI did not require surgery. However, the majority of patients with hydrocephalus had ventriculoperitoneal (VP) shunt (31.37%; n = 16)- and- external ventricular drain (EVD) insertion (3.92%; n = 2), or both (17.65%; n = 9) as depicted in Table 4 below.

Table 4: Types of surgeries conducted.

Type of surgery	**n (%)**
Burr holes	1 (1.96)
Craniotomy	4 (7.84)
Cystoperitoneal shunt insertion and VP shunt insertion	1 (1.96)
EVD and VP shunt insertion	9 (17.65)

Type of surgery	n (%)
Laminoplasty	1 (1.96)
EVD Insertion	2 (3.92)
MMC closure	1 (1.96)
No surgery required	8 (15.69)
Left femur open reduction and internal fixation	1 (1.96)
Tracheostomy	1 (1.96)
Suturing of tongue laceration by Maxillo-facial	1 (1.96)
VP shunt insertion	16 (31.37)
No surgical procedure required	5 (9.80)
Grand Total	51

3.1.5 Criteria for transfer eligibility

The criteria for assessing eligibility for transfer to the rehabilitation hospital were determined through individualised evaluation and multidisciplinary team assessment. The absence of specific details regarding these criteria prohibits a comprehensive understanding thereof. It is acknowledged that the requirement for rehabilitation extends beyond functional disability and includes the necessity for nutritional support, psychosocial rehabilitation, caregiver education, specialised speech and language therapy, occupational and physical therapy, behavioural interventions, educational support, the need for adaptive equipment and assistive devices, and possible community integration strategies.

3.1.6 Transit care time and hospitalization period

An objective of this study was to examine the duration of hospital stays for each patient at SBAH and TRH, as well as the overall hospitalisation time. Brain tumour patients had the longest stay at SBAH, averaging around 47 days. Hydrocephalus patients, on the other hand, had the longest stay at TRH, averaging approximately 70 days. The combined total duration of hospitalisation for brain tumour patients was also notably extended, averaging about 119 days, which is the overall longest hospitalisation period. In contrast, patients with spina bifida had the shortest stay at SBAH,

approximately 26 days. Patients with traumatic brain injury (TBI) spent the shortest amount of time at TRH, averaging around 28 days, and this group also had the shortest overall hospitalisation period, averaging approximately 53 days.

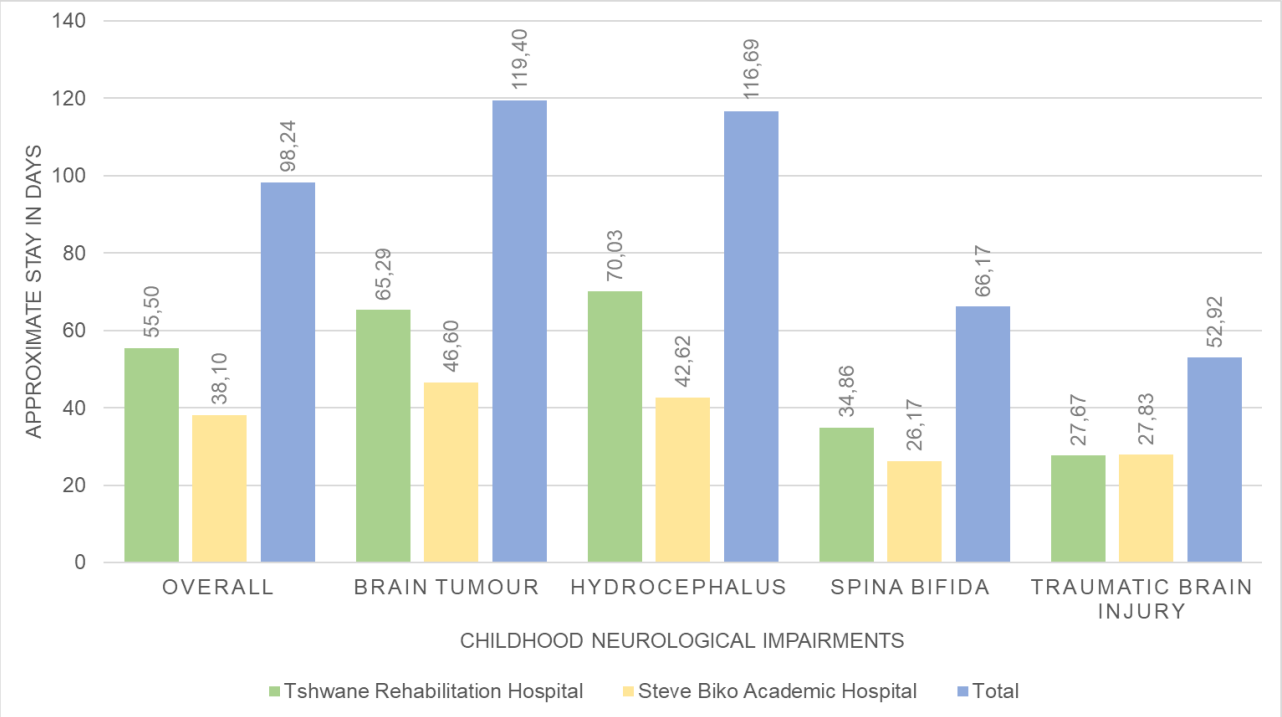


Figure 3.4: Figure 3.4: Mean hospitalisation time comparison: TRH, SBAH, combined total.

Table 5 highlights the factors affecting transit time and includes a description of the overall number of patients, and the number of patients diagnosed with each neurological impairment. The overall number is the true number of patients. If the patient was diagnosed with more than one impairment, the patient is still accounted for as one individual in the overall column. Herein, hydrocephalus patients faced more issues affecting hospitalisation time, notably shunt complications, and gastrointestinal and feeding problems, while brain tumour patients had fewer contributing factors.

Table 5: Factors affecting transit time

Factors		**Overall**	**BT**	**HCP**	**SB**	**TBI**
Shunt Issues and Complications	• Blocked VP shunt	2		2	1	
	• Shunt malfunction	2		2		
	• Septic shunt	3		3		
	• Shunt revision	1		1		

Factors		Overall	BT	HCP	SB	TBI
Respiratory and Ventilation Issues:	• Required respiratory ventilator	1		1	1	
	• Intubation and ventilation required due to neurological deterioration	1				1
	• Lung contusions	1				1
Gastrointestinal and Feeding Issues:	• Nausea	2		2	1	
	• Vomiting	4		3		1
	• Constipation	1		1		
	• PEG tube opened during physio	1				1
	• Diarrhea	1		1		
Neurological Conditions:	• Strokes of unknown origin	1		1		
	• Seizures	2	1			1
COVID-19 Infection	• Patient got COVID-19	1		1		
Weight Issues:	• Underweight	1			1	

Factors		Overall	BT	HCP	SB	TBI
Other complications:	• Full anterior fontanel Posterior open	1		1		
	• Dermatitis	1		1		
	• Edema	1		1		
	• Abdominal tenderness	1		1		
	• Pressure sores	1				1
	• Flu	2		1		1
	• Bit tongue	1				1
	• Temporary discharge at TRH	2		1		1
Social and Family Issues:	• Mother is a minor (patient's social issues)	1			1	

3.2 NEUROREHABILITATION SCALE SCORES

An objective of this study was to assess the use of neurorehabilitation scales such as the Bayley Scale of Infant and Toddler Development (BSID) and of the Glasgow Outcome Scale Extended Pediatric (GOS-E Peds) in informing eligibility for rehabilitation, as well as the outcome of the rehabilitation provided. The results show that the BSID scale was not used at TRH. However, the scales that were implemented at TRH included the Glasgow Outcome Scale Extended Pediatric (GOS-E Peds), the Glasgow Coma Scale (GCS), and the Waterlow Scale (WS). These scales were used inconsistently with their use implemented on admission at TRH, tapering off during the hospitalisation period and only being used again at discharge.

Regarding Table 6, the overall number represents the actual count of individual patients. If a patient was diagnosed with multiple impairments, they are still counted as a single individual in the overall column. In this case, the GOS-E Ped was implemented in 25 out of the 51 patients to assess eligibility for neurorehabilitation and

the degree of neurological impairment. Of these 25 children, 21 patients had a GOS-E Ped score of 5/5 when discharged from SBAH, signifying a good recovery. The GOS-E Ped assesses disability and functional outcomes in paediatric patients. However, this score does not take into consideration other rehabilitation requirements which may include nutritional support, psychosocial rehabilitation, caregiver education, specialised speech and language therapy, occupational and physical therapy, behavioural interventions, educational support, the need for adaptive equipment and assistive devices, as well as the need for community integration strategies.

As seen in Table 6, the GCS of 47 out of 51 patients was assessed on admission to TRH, including all brain tumour and hydrocephalus patients. However, after the admission assessment, the number of assessments during hospitalisation and at discharge decreased. Only 21.57% (n = 11) of patients in this study population exhibited improvement through complete documented GCS and WS scores when assessing the neurorehabilitation outcome scores and only one patient out of 51 had all GCS and WS scores recorded during these three time points.

Table 6: Neurorehabilitation scale usage across neurological impairments.

	Overall	**Brain tumour**	**Hydrocephalus**	**Spina bifida**	**Traumatic brain injury**
GCS Use					
On admission	47	8	30	6	14
During hospitalisation	14	4	9	1	5
Upon discharge	14	4	9	1	5
All 3 recorded	13	4	9	1	4
WS Use					
On admission	17	6	6		9
During hospitalisation	12	4	4	1	5
Upon discharge	5	2			3
All 3 recorded	5	2			3

	Overall	Brain tumour	Hydrocephalus	Spina bifida	Traumatic brain injury
GOS-E Ped Use					
Upon discharge at SBAH	25	2	17	2	6
Upon discharge at TRH	4	2	1		1
Both recorded	4	2	1		1

3.3 REHABILITATION INTERVENTIONS

SBAH and TRH made use of occupational therapy, physiotherapy, and speech therapy. The required rehabilitation techniques were implemented for each neurological impairment needs, and well documented by each therapist (Appendix C).

Occupational therapists assessed treatment targets through individual therapy, group therapy, parental education, recommendations, and through continuous developmental monitoring as summarised in table 7:

Table 7: Occupational therapy treatment targets.

Occupational therapy intervention	**Treatment target**	**n (%)**
Individual therapy	Improving, establishing, or maintaining neuromusculoskeletal and movement related functions (muscle tone, ROM, postural mechanisms/postural control, coordination, grasp, and manipulation. Sensory stimulation, desensitization, and integration. Improving or maintaining mental functions (attention, memory, and higher order cognitive skills). Improving educational concepts (shape, colour number and letter concepts).	43 (84.31)
Group therapy	Social interaction Play and playfulness Emotional and behavioural regulation	29 (56.86)
Parent education/coaching	Health education Home program and self-management strategies Precautions	9 (17.65)
Recommendations, issuing and use of assistive devices	To aid in therapeutic activities, positioning and ambulation	14 (27.45)
Ongoing monitoring and evaluation	Monitoring progress, assessing developmental milestones	12 (23.53)

Psychological therapy was also implemented as part of the rehabilitation process and mostly included caregiver support and counselling.

In-house speech therapy included the following rehabilitation treatment: play and social stimulation consisting of play activities, social interactions, food play, and turn-taking during play; feeding and swallowing therapy focused on swallowing and sucking, transitioning between food consistencies, desensitization, dysphagia exercises, and tongue ROM exercises. Play and social stimulation (n = 25; 49.02%), as well as feeding and swallowing (n = 33; 64.71%) were the treatment targets most frequently implemented. Another important aspect of therapy included monitoring and screening, where the speech therapist has to keep track of feeding habits and liquid intake, and conduct audio screenings to assist with development. In this study 21 patients (41.18%) of the patients required formal monitoring in this area. Caregiver education in this domain focuses on teaching the caregiver proper feeding positions, developmental milestones, and how to provide effective support and care for the child. This type of education was only given to 3.92% of the caregivers in this population. Cognitive and memory stimulation was received by 7.84% of the patients to improve memory, problem solving, orientation, language skills, and processing time.

Nutritional therapy focused on weight monitoring, feeding monitoring and supplementation. This included malnutrition treatment, weight monitoring to note any weight changes, monitoring patients' tolerance of food, and the need for additional fluid administration to increase bowel movements. Nutritional discharge plans were also prepared, including the requirements for oral feeding with emphasis on the initiation of solid foods, oral puree intake, and incorporating a feeding schedule. Mother or caregiver education played a prominent role focusing on nutritional requirements and proper feeding techniques.

Physiotherapy rehabilitation treatment targets focused on manual therapy that involved chest physio, passive stretches of upper limbs (UL) and lower limbs (LL), chin tuck facilitation, joint compressions, percussions and vibrations, and weight bearing UL exercises. Caregiver education and monitoring educated the caregiver on developmental milestones and on the kangaroo mother care technique in cases where this was needed. Developmental progression techniques of head and trunk control was implemented using a variety of postures and positioning. Mobility training using

developmental progression of crawling to walking, rolling, and sitting to four-point kneeling was also facilitated. Play and therapeutic activities included playing with objects, play in sitting and standing positions, and tactile stimulation through playing. Tummy time and prone lying entailed tummy time with emphasis on head control, tummy time on propped blanket, prone lying over wedge to improve trunk control and strength, prone positioning over linen with weight bearing wrists and knees, and bed mobility. Additionally, milestone development consisted of motor function facilitation such as grasping and reaching. Manual therapy (n = 28; 54.90%) and mobility training (n=44; 86.27%) were the rehabilitation interventions that the physiotherapist integrated the most. Sitting and standing training were mostly required by TBI patients (73.33%). 93.33% of the TBI patients needed crawling and gait training. There is no record of the use of these interventions in patients with spina bifida patients.

Chapter 4: Discussion

Introduction and Background

Neurorehabilitation following neurological surgery or treatment of other neurological ailments in children forms the bedrock of physical and cognitive recovery. Brain tumours, hydrocephalus of various aetiologies, traumatic brain injuries, and neural tube defects all present with physical and cognitive deficits that most often require surgical intervention. In most cases, these children would require inpatient neurorehabilitation to improve their outcome. This rehabilitation process is underpinned by the use of established criteria to identify children who may require further inpatient rehabilitation[111, 112] and the use of neurorehabilitation scales to assess progress and outcomes at the designated facility.[113, 114] To ensure the adequacy of neurorehabilitation processes, an appraisal of these processes is necessary. Therefore, this study aimed to evaluate the criteria used to confirm eligibility for rehabilitation, patient transit care time, hospitalisation time, and clinical outcomes of these children using neurorehabilitation scales including the BSID- and- GOS-E Peds scales.

Patient Demographics and Medical Conditions

In lower income countries, like those in Sub-Saharan Africa, neurological disability following CNS injury is more common than in higher income countries, especially in children between the ages of 0-14 years.[115] The study findings show that the youngest participant was one month old, and the oldest was 11 years and four months old, with a mean age of 2 years and one month. By providing in-patient rehabilitation at an intensive rehabilitation facility has been shown to improve clinical outcomes and functionality, thus reducing strain on the family and caregivers.[116]

Studies in first and third world countries show that males are more likely to present with brain tumours, hydrocephalus, and traumatic brain injury, whereas females are more likely to present with spina bifida.[13, 27, 41, 58] In contrast, this study showed a predominance of females with brain tumours that included tectal plate tumours, posterior fossa tumours, intraventricular tumours, intramedullary spinal cord tumours, and medulloblastomas. [27] This difference could be due to genetic or environmental factors, as medulloblastomas are one of the most common cancer types among

children in South Africa, regardless of sex.[117] However, this sex disparity might be due to the small sample size of the study. Additionally, there were more females who were treated for TBIs than males in this study. As alluded to earlier, potential explanations for the higher incidence of TBIs among females in the study include variations in risk-taking behaviour, hormonal influences, and differences in injury mechanisms. Research suggests that males often engage in riskier activities, contributing to a higher likelihood of TBIs. Hormonal differences, particularly oestrogen fluctuations, may influence the severity and timing of TBIs in females. Additionally, variations in the types of accidents or injuries could contribute to the elevated number of female patients in the study.[118] Spina bifida was diagnosed in more males than in females, which contradicts earlier studies showing a higher prevalence of spina bifida in females.[41] This could possibly be due to the prevalence of folate deficiency among pregnant women in African countries resulting in the sex divergence.[119, 120] However, the effect of a small sample population cannot be discounted in this case. As recorded in previous studies, this study showed that hydrocephalus did affect more males than females.[58] One of the reasons why males could be more susceptible to hydrocephalus is due to the mutation in the L1CAM gene which results in structural malformations obstructing CSF flow. This phenomenon occurs in 10% of males with hydrocephalus.[54]

The literature confirms that spina bifida is the most prevalent congenital birth defect[121], while brain tumours are among the most common tumours in children after leukaemia[122], and hydrocephalus is one of the most common birth defects that affect the nervous system.[52] Notwithstanding, TBI prevalence can vary greatly and is based on factors such as age, sex, and activity levels.[118] This study revealed that hydrocephalus was the most prevalent condition, making it the most common neurological impairment requiring rehabilitation at TRH between 2019 and 2022. A total of 58.82% of the study population had hydrocephalus, including five of these patients (16.67%) who had MMC-associated hydrocephalus, three patients (10%) with brain tumours, and one patient (3.33%) with an associated traumatic brain injury. TBI was the second most common presentation.

Although spina bifida and hydrocephalus are different neurological conditions, hydrocephalus can be a common complication of spina bifida due to the disruption of normal CSF circulation.[52] When the open CSF circulation system is closed off as a result of the neural tube defect, a build-up of CSF ensues. This build-up can lead to

Chiari II malformation, in which the hindbrain descends into the foramen magnum. This phenomenon further increases CSF accumulation, resulting in hydrocephalus.[52, 123] This may explain the higher number of patients in the study who presented with both spina bifida, and hydrocephalus compared with brain tumours and TBI, respectively. Similarly, the pathogenesis of hydrocephalus in patients with brain tumours involves obstruction of cerebrospinal fluid (CSF) flow, typically when the neoplasm lies near ventricular regions. Tumours can impede the normal circulation of CSF, leading to its accumulation and subsequent elevation of intracranial pressure.[55] In TBIs, the pathogenesis of hydrocephalus is often linked to disruptions in CSF circulation caused by bleeding, swelling, or structural damage to the brain, leading to impaired CSF drainage.[85] Additionally, patients can develop post-traumatic hydrocephalus which is characterised by scarring or inflammation that obstructs the normal flow of CSF over time.[124]

CSF accumulation can elevate ICP and sequentially reduce blood flow and cause brain herniation, as per the Monro-Kellie principle.[125] This principle indicates that the pressure within the cranium is maintained by an equilibrium between the volumes of brain tissue, cerebral blood flow, and CSF, and any change in any one of these components will affect the volume of the other components. An elevation in the volume of any of the components elevates ICP, which in turn affects cerebral perfusion pressure (CPP). This is due to the fact that cerebral perfusion pressure is determined by the mean arterial pressure (MAP) and ICP (CCP = MAP – ICP).[125] For example, a buildup of CSF can reduce cerebral blood flow, resulting in cerebral ischaemia. Thus, this buildup of CSF necessitates diversion via the use of a VP shunt in most cases to reduce elevated ICP and its detrimental effects. Extraventricular drain insertion is a CSF diversion technique used as a temporary measure to divert CSF in cases where a permanent diversion procedure such as VP shunt insertion may not be possible, for example, when the child is physically small or when there is any infection or blood in the CSF.[126] The EVD is usually converted to a VPS when it is safe to do so. A cystoperitoneal shunt, which assists in removing excess fluid from the brain to reduce ICP, can be used simultaneously with a VP shunt to assist with increased CSF drainage in patients with hydrocephalus and MMC-associated hydrocephalus.[126] VP shunt failures can increase the number of EVD and VP shunt surgeries. Surgical failure of VPS can be either aseptic or septic. Aseptic failure occurs when there is a

shunt malfunction, which may include shunt catheter obstruction, over-drainage, under-drainage, or occult shunt failure where the shunt needs to be revised for tube lengthening. Septic shunt failure is when the shunt is infected.[53] VPS failure of any cause is treated as a neurosurgical emergency.[53] As indicated earlier, EVD insertion is a temporary CSF diversion measure and part of acute neurosurgical care. Thus, patients with a VPS *in situ* will, in all likelihood, be referred for rehabilitation. The study also showed that patients with hydrocephalus presented with the majority of gastrointestinal complaints that affected hospital transit times. This may be due to the VPS insertion, where the distal end of the shunt catheter is inserted into the peritoneal space. These patients usually present with abdominal complications, such as abdominal pseudocysts, which are inflammatory reactions to the peritoneal membrane resulting in malabsorption of the diverted CSF. Symptoms may include abdominal pain, abdominal swelling, fever, and abdominal tenderness.[127]

Children with TBI who present with mild injury, denoted by a GCS of 13-15, usually require inpatient monitoring, but do not necessarily require surgical intervention.[128] Five patients in the study who presented with mild TBI had complications that required surgery; and all received rehabilitation in the cognitive and physical domains. Neurorehabilitation may still be required in mild TBI cases where physical impairment symptoms may be absent, but there may be cognitive and emotional impairments that require attention.[128] One patient with TBI, with an associated subdural hematoma, underwent a burr hole procedure to reduce elevated ICP.[129] Another TBI patient required a tracheostomy to open the airway to stabilize breathing.[130] This procedure is performed commonly in patients with severe TBI as early implementation has been shown to reduce intensive care time and mechanical ventilation time.[131] In this study, two TBI patients and one patient with a brain tumour underwent craniotomy procedures as part of their neurosurgical management.[132]

One patient with an intramedullary spinal cord tumour required a laminoplasty to enlarge the spinal canal and decompress the upper section of the spinal cord.[133] Patients with spina bifida may also undergo spinal closure surgery to close off the spinal cord defect to prevent leaking of spinal fluid and reduce the risk of infections.[134]

Hospitalisation and Transit Times

The study revealed that an average of 38 days was spent in SBAH and 56 days was spent in TRH. An average of 98 days was spent in the two hospitals. A recent study by Ullah *et al.* revealed that in Saudi Arabia, the length of neurorehabilitation was between 28 to 56 days for patients aged between 5 and 9,[135] and another study from Austria revealed that the average inpatient stay for neurologically impaired patients aged 1 to 19 was 108 days.[136] This would imply TRH have shorter or similar hospitalisation periods compared to international standards. Compared to patients with other neurological disabilities, those with hydrocephalus stayed at TRH the longest. The fact that most patients with hydrocephalus required VP shunt revision, contracted an infection, had a blocked shunt, or experienced shunt malfunction may be the cause of this protracted hospital stay (Table 5). There have also been instances where patients left the hospital on weekend passes or temporary release passes and returned with either a respiratory illness or other symptoms that required medical attention, lengthening their hospitalisation duration. While brain tumour patients in this research study had the fewest factors affecting transit time (refer to Table 5), they were admitted to SBAH for the longest period, potentially due to a need for extended examination and diagnostic procedures. Children with suspected brain tumours invariably require an MRI scan to confirm the diagnosis and plan treatment. This may take several weeks to attain in most cases. Patients diagnosed with spina bifida and TBI had the shortest hospitalisation stay, which may have been due to fewer shunt complications and the fact that some TBI patients did not require surgery, which shortened their overall hospitalisation time and recovery durations. Spina bifida patients with an associated MMC may have been easier to identify, as a sac with nerves protrudes from the spinal cord through an opening (Figure 1.1c), potentially shortening the examination and diagnosis time.[44, 46]

The study observed a notable upward trend in patient admissions to the rehabilitation facility, reflecting a 125% surge from 2019 to 2020, followed by an approximately 77.78% increase from 2020 to 2021, and a more moderate uptick of around 37.5% from 2021 to 2022. This indicates a substantial annual growth in admissions, with a consistent rise in numbers each year. Remarkably, this trend contrasts with findings by Rennert-May and Oseran, who reported significant decreases in hospital admission rates for various illnesses during the COVID-19 pandemic. [137, 138] The observed upward trend

in patient admissions to the rehabilitation facility, despite the reported decreases in hospital admission rates for various illnesses during the COVID-19 pandemic in other studies, suggests that the pandemic did not significantly impact the need for treatment of significant medical problems addressed by the rehabilitation facility. A possible cause for the increase, in relation to this particular study, could have been due to the increase in domestic violence that may have resulted in the higher TBI incidences when referring to figure 3.2.[139]

Neurorehabilitation Scale Usage

One of the main objectives of this study was to investigate whether the neurorehabilitation scale scores correlated with eligibility and outcome, and to provide an assessment of the neurorehabilitation scales at different time points to assess how often these scales are implemented. The investigation revealed that eligibility for transfer from the tertiary care facility to the rehabilitation unit was determined by individual evaluation and multidisciplinary team assessments, which included clinical judgement based on certain factors such as physical and cognitive function, GCS scores, and, in some cases, GOS-E Ped scores.[140] Twenty-five patients transferred from SBAH were assessed using GOS-E Ped. Of these patients, 21 patients had a GOS-E Ped score of 5/5, which indicates a good recovery with the patient able to resume a normal life.[100] However, in situations where a minor disability is evident, the patient may still encounter social challenges necessitating neurorehabilitation at psychological, nutritional (to address feeding capabilities or adjustments), and physiological levels for enhanced mobility in daily activities.[112] This underscores the consideration of additional criteria beyond functional recovery.

Only the GCS and WS scores were employed at TRH upon admission, during hospitalisation, and at discharge (Table 6). Interestingly, only one patient out of 51 had all GCS and WS scores recorded during these three time points, with varying use of these scales among the rest of the patient cohort. Although the GCS was assessed at admission at TRH, this is not an assessment that will determine physical functionality or assess functional improvement during rehabilitation. GCS is a measure of the level of consciousness; thus, it would be assumed that a patient would have to be cooperative and able to obey commands or respond to commands to start rehabilitation.[104] The WS assesses the risk of acquiring bed sores, which can, to a

degree, be a scale to assess functionality, but it will not help to determine which areas of cognitive function require improvement or the specific rehabilitation required. Thus, it cannot be implemented alone but rather in conjunction with other scales when used in neurorehabilitation.[107, 108] By assessing the neurorehabilitation scores (GCS and WS scores), only 21.57% of the patients showed cognitive and physical improvement. Even though these specific rehabilitation scales were implemented, discharge was determined by therapists' well-documented clinical judgement.

None of the patients had complete assessment record of the BSID scores used. These records show that the BSID scale was not used at the TRH. The reasons for this have not yet been documented or explained.

Rehabilitation Strategies and Therapies

The study showed that patients at TRH received continuous inpatient assessment and treatment from occupational therapists, physical therapists, and, in some cases, speech therapists. The rehabilitation techniques implemented by the occupational therapist will help improve overall hand functionality and overall sensory development, such as touch, vestibular, visual, auditory, proprioceptive, and tactile stimulation. Improving posture, balance, and overall body control is also a major focus point, as is caregiver education on understanding child development and care for neurological impairments. Certain equipment is used to help with the child's development and mobility; for example, the transition from sitting to crawling, standing, or walking in infants requires a great deal of postural control and balance. This transition affects the usage of their hands and limbs, which then at times makes children reach for supporting objects.[141] These supporting objects include buggies, wheelchairs, and frames. School and educational activities aid in cognitive stimulation and school readiness. Occupational therapists also focus on monitoring developmental progress, muscle tone, and flexibility.

A study by Riley *et al*. revealed that 36.4% of children underwent complete developmental screening according to the 2018–2019 National Survey of Children's Health in the USA. This could be due to reasons such as a lack of time and family distrust in the primary care system. This should present an opportunity for occupational therapists to implement initiatives to assess and identify what the community requires.[142] By providing optimal developmental monitoring early on during

neurorehabilitation, improvement in a child's school readiness and overall school performance in the future is more likely.[142]

Speech therapy focuses on different treatment interventions to improve language and feeding. Feeding and swallowing include treatment targets and exercises to improve swallowing, introduction of different textures, and enhancement of oral intake. Many children with hydrocephalus and spina bifida children received feeding and swallowing rehabilitation as dysphagia and feeding difficulties are prevalent in these conditions[45, 143]. Feeding and swallowing functions are regulated by nuclei in the medulla oblongata, and any abnormalities in these brain regions can impact feeding and swallowing processes.[144]

All brain tumour patients and almost all TBI patients received language stimulation rehabilitation, which aimed to improve language development, communication, and expressive and receptive language. The two main language centres reside in the frontal lobe where the Broca's area is located and in the temporal lobe where the Wernicke's area resides.[145, 146] Damage to these two lobes due to TBI or a brain tumour specifically to the Broca's area may result in delayed speech production or the patient will be unable to speak fluently.[146] Whereas damage to the Wernicke's area may affect the patient's ability to understand and comprehend speech.[145] Interactive play and socializing with peers are also key themes on which the speech therapists focused. Peer socialisation will help the patient develop norm-accepted skills and communication skills by allowing the child to freely communicate with a friend.[147]

Physiotherapy mainly focusses on manual therapy involving techniques to improve mobility and stretch of the UL, LL, and hips in children requiring neurorehabilitation. Sitting and standing training encompasses activities that enhance sitting and standing ability. It involves supported sitting, facilitated sitting tolerance and balance, and various methods to improve standing posture and weight bearing on different body parts. Crawling and gait training focuses on facilitating crawling and gait (walking) training. It includes supported crawling using tools such as rollers, gait training with assistive devices, and exercises to improve walking endurance, speed, and proper gait patterns. Both of these treatment targets are mostly required by patients with TBI. It is more common for children with TBI to undergo functional physiotherapy, especially mobilization and coordination interventions.[148] When the injury causes damage to the

frontal lobe where the motor cortex is situated, it will affect the patient's voluntary motor control and cause weakness.[149]

The following treatment targets were not a key focus in this specific study population, as only 23.53% of the patients received these types of physiotherapy. Play therapy and play-based interventions involve engaging in therapeutic play to stimulate motor and sensory development, including playing with objects, tactile stimulation, and incorporating play activities into the sitting and standing positions. Play therapy interventions have been proven to be beneficial in children pre- and postoperatively by improving their ability to cope with stress and reducing anxiety. This is because play therapy causes changes in the prefrontal cortex, which regulates emotions. It also improves communication skills on an inter- and intrapersonal level.[150] With this specific therapy, no patients with spina bifida received this form of rehabilitation. Limb strengthening and passive movements emphasize strength exercises for the upper and lower limbs, and passive ROM exercises. It also includes techniques to facilitate alternative leg movements to improve dissociation between limbs. Therapists make use of static stretches to further improve ROM, and the continuation of this intervention also reduces muscle spasticity.[151] Tummy time and prone lying activities involve strategies to encourage tummy time with an emphasis on head control, using wedges and props for support, and engaging in prone lying exercises to improve trunk control and mobility. None of the brain tumour patients received "tummy time" or prone-lying rehabilitation. "Tummy time" should also be a key treatment target, as it improves gross motor activity and reduces the risk of developing brachycephaly. Thirty minutes of "tummy time" per day provided better child growth and development.[152] A focus on facilitating and keeping track of various developmental milestones and motor functions was implemented in 25.49% of the study population. It includes interventions to enhance grasping, reaching, and fine motor skills, which are all crucial for overall motor and cognitive development. Caregiver education by the physiotherapist focuses more on understanding developmental milestones and teaching caregivers about developmental milestones and kangaroo mother care, which involves skin-to-skin contact and nurturing for infants.[153] Only five caregivers received education in this domain.

Together, occupational therapists and physiotherapists would attempt to improve the patient's posture control and mobility. When implementing these approaches,

therapists would occasionally take the patient outside or to a gym. Good posture occurs when the muscular and skeletal systems are in harmony. Posture should be adjusted to best support and shield the body from harm or deformity. Balance consists of coordination and the capacity to maintain the centre of gravity.[154] One would assume that posture control would ultimately go hand in hand with balance and mobility, but a study by Nagymáté *et al.* found no relationship between the two in children.[155] Interestingly, studies discovered that the ability to tolerate balance disruptions worsens if the link between posture and balance changes in the sagittal plane of the spine. [154]

Rehabilitation interventions sometimes require many repetitions before the child moves to the next milestone. Repeating an activity helps activate the hippocampus, and as the activity is continuously repeated, it also strengthens the link between the hippocampus and parahippocampal area. This will allow information acquired from different sources to become more relevant to one another,[156] connecting interventions from the different therapies learned.

The psychologist provided more support to the caregivers in this study, as seen in Appendix C; however, caregiver education was not a key focus area throughout the rehabilitation themes. Nutritional therapy plays a crucial role in a child's development and healing process.[3, 73, 74] 82.35% received a nutritional management plan to ensure proper nutritional intake so that the patients could either maintain their body weight or pick up weight. In this form of rehabilitation, there was only one documented case in which a caregiver was educated on nutritional management. Caregiver education is a key factor in aiding patients in achieving the best possible outcome during rehabilitation and at home. By providing education, it will also assist the caregiver to feel less anxiety, fear, and uncertainty while caring for the patients.[157]

Recommendations for Improvement

Neurorehabilitation is an educational process that involves not only the patient, but also their family, caregivers, and members of a multidisciplinary rehabilitation team. Therefore, setting clear and measurable goals for rehabilitation is crucial in ensuring improved functionality.[112] A fundamental guideline for neurorehabilitation involves evaluating a child's level of consciousness using the modified paediatric Glasgow Coma Scale and assessing factors such as pupillary response, limb movement,

strength, and vital signs. Additionally, obtaining a comprehensive developmental history and evaluating children based on age-appropriate norms and milestones is essential. [158] Regarding the Glasgow Outcome Scale Extended Paediatric (GOS-E Ped), strict criteria should be implemented at both SBAH and TRH to ensure accurate scores at discharge from SBAH, and re-evaluation following rehabilitation at TRH, if applicable. The Bayley Scale of Infant and Toddler Development (BSID) should be integrated into the TRH for initial assessments upon admission, aiding the multidisciplinary team to effectively focus their rehabilitation efforts. It is crucial to adapt these assessment tools to the social and cultural norms of Southern Africa to ensure comprehension of expectations. [95, 97]

The limited implementation of these assessments could be attributed to staffing challenges at SBAH and TRH, as well as challenges in integrating a web-based database into the hospital system, particularly for the BSID, which relies on software administration. Transitioning to a digital platform would greatly improve record-keeping, enhance information accessibility for medical professionals, staff, and students, and facilitate monitoring of multiple hospital visits and assessments.

Alignment with Sustainable Development Goals (SDGs)

These interventions will ultimately align with the Sustainable Development Goals (SDG), specifically SDG 3 and 4. SDG 3 is about “Ensuring a healthy life and promoting well-being for all ages,” and SDG 4 is to “Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all.” [159, 160] It is imperative that clear and rigorous criteria are established to confirm eligibility for neurorehabilitation and determine the appropriate transfer from tertiary hospitals to rehabilitation centres. Furthermore, comprehensive documentation of rehabilitation scales, including the Glasgow Outcome Scale Extended Paediatric (GOS-E Peds) and the Bayley Scale of Infant and Toddler Development (BSID), at critical junctures during a patient's rehabilitation journey, is essential. This approach will not only enhance the effectiveness of rehabilitation interventions, but also provide the means to measure and track tangible outcomes, ultimately ensuring the well-being and progress of the patient.

Chapter 5: Conclusion

The goal of neurorehabilitation is to support physical and cognitive recovery following injury to the central nervous system in order to improve overall functioning. Neurorehabilitation scales, such as the well-known BSID and GOS-E Ped scales, are frequently used to ensure that correct and essential rehabilitation methods are applied to identify areas requiring neurorehabilitation.

This retrospective study was the first to investigate the use of neurorehabilitation scales in paediatric neurosurgery patients in South Africa. This study showed that there are no formal documented criteria used to assess eligibility for transfer from a tertiary care facility to a rehabilitation facility. This decision is largely based on the clinical judgement of the multidisciplinary team. Interestingly, the rehabilitation facility does not use the BDIS as part of its inpatient rehabilitation program. However, the GCS and WS scores remain prominent features of this rehabilitation program, with the GOS-E Ped being employed inconsistently throughout the rehabilitation process. The former scales relate to measures of consciousness and the evaluation of the risk of acquiring bed sores, respectively, and do not assess cognitive and physical functioning holistically. The GOS-E Ped scores, which are more appropriate to measure the overall level of neurological impairment, did show improvement in the patients who had a complete assessment. However, this study has revealed that a more comprehensive assessment in the GOS-E Ped outcome descriptions is still required to recognise slight neurological impairments that require further neurorehabilitation. Nevertheless, the rehabilitation provided is exhaustive, as denoted by the provision of continuous inpatient physical, occupational, speech, and nutritional therapy, as well as psychology.

The assessment of neurological outcome improvement might be achieved by adhering to stringent guidelines to guarantee rehabilitation eligibility, applying the appropriate rehabilitation therapies, implementing more thorough assessments or more neurorehabilitation scales to have an extensive overview of the patient progress and requirements, to establish patient progress based on physical results and scores, and further shorten the total length of hospitalisation.

5.1 LIMITATIONS

The number of patients that were eligible for enrolment in the study was a limiting factor. Although a total of 81 paediatric patients were initially appraised, only 51 paediatric patients fulfilled the inclusion criteria. A total of 30 patients were excluded from the study for various reasons, including missing files (6 cases), different diagnoses than the inclusion criteria (15 cases), transfers from other hospitals to TRH for neurorehabilitation (6 cases), and patients admitted to TRH outside the study period (3 cases).

5.2 FUTURE STUDIES

Future studies should explore the benefits of establishing stringent neurorehabilitation eligibility criteria at tertiary hospitals, and comprehensively investigate the impact of implementing neurorehabilitation scales, particularly the Bayley Scale of Infant and Toddler Development (BSID) and the Glasgow Outcome Scale Extended Pediatric (GOS-E Ped), throughout the entire duration of a patient's rehabilitation journey. Furthermore, there is a need to expand these finding to other healthcare institutions, with varying demographics and populations, to ensure broader generalisability.

References

1. Heimans JJ, Reijneveld JC. Factors affecting the cerebral network in brain tumor patients. *Journal of Neuro-oncology. 2012; 108(2)*:231-7. doi:10.1007/s11060-012-0814-7

2. Long KR, Huttner WB. How the extracellular matrix shapes neural development. *Open Biology. 2019; 9(1)*:180216. doi:doi:10.1098/rsob.180216

3. Kolb B, Gibb R. Brain plasticity and behaviour in the developing brain. *Journal of the Canadian Academy of Child Adolescent Psychiatry. 2011; 20(4)*:265-76.

4. Rajagopalan V, Mariappan R. Developmental Anatomy and Physiology of the Central Nervous System in Children. In: Rath GP, editor. *Fundamentals of Pediatric Neuroanesthesia. Singapore: Springer Singapore; 2021.* p. 15-50.

5. Cramer SC, Sur M, Dobkin BH, O'Brien C, Sanger TD, Trojanowski JQ, et al. Harnessing neuroplasticity for clinical applications. *Brain. 2011; 134(Pt 6)*:1591-609. doi:10.1093/brain/awr039

6. Hubli M, Dietz V. The physiological basis of neurorehabilitation--locomotor training after spinal cord injury. *Journal of NeuroEngineering and Rehabilitation. 2013*; 10:5. doi:10.1186/1743-0003-10-5

7. Maris G. The Brain and How it Functions. *Emotional Intelligence. 2018.*

8. Araki T, Yokota H, Morita A. Pediatric Traumatic Brain Injury: Characteristic Features, Diagnosis, and Management. *Neurologia Medico Chirurgica (Tokyo). 2017; 57(2)*:82-93. doi:10.2176/nmc.ra.2016-0191

9. Soo C, Tate RL, Williams L, Waddingham S, Waugh MC. Development and validation of the Paediatric Care and Needs Scale (PCANS) for assessing support needs of children and youth with acquired brain injury. *Developmental Neurorehabilitation. 2008; 11(3)*:204-14. doi:10.1080/17518420802259498

10. Hiu Lam W, Mackersie A. Paediatric head injury: incidence, aetiology and management. *Pediatric Anesthesia. 1999; 9(5)*:377-85. doi:https://doi.org/10.1046/j.1460-9592.1999.00431.x

11. Galgano M, Toshkezi G, Qiu X, Russell T, Chin L, Zhao LR. Traumatic Brain Injury: Current Treatment Strategies and Future Endeavors. *Cell Transplant. 2017; 26(7)*:1118-30. doi:10.1177/0963689717714102

12. Haarbauer-Krupa J, Lee AH, Bitsko RH, Zhang X, Kresnow-Sedacca M-j. Prevalence of Parent-Reported Traumatic Brain Injury in Children and Associated Health Conditions. *Journal of the American Medical Association Pediatrics. 2018; 172(11)*:1078-86. doi:10.1001/jamapediatrics.2018.2740

13. Collins NC, Molcho M, Carney P, McEvoy L, Geoghegan L, Phillips JP, et al. Are boys and girls that different? An analysis of traumatic brain injury in children. *Emergency Medicine Jourrnal. 2013; 30(8)*:675-8. doi:10.1136/emermed-2011-200496

14. Khairat A, Waseem M. Epidural Hematoma. StatPearls. Treasure Island (FL): StatPearls Publishing

15. Daou B, Hasan D, Jabbour P. Chapter 93 - Clinical Aspects of Intraventricular Hemorrhage. In: Caplan LR, Biller J, Leary MC, Lo EH, Thomas AJ, Yenari M, et al., editors. *Primer on Cerebrovascular Diseases (Second Edition). San Diego: Academic Press; 2017*. p. 457-67.

16. Mesfin FB, Gupta N, Hays Shapshak A, Taylor RS. Diffuse Axonal Injury. StatPearls. Treasure Island (FL): StatPearls Publishing

17. Bax M, Romanov V, Junday K, Giannoulatou E, Martinac B, Kovacic JC, et al. Arterial dissections: Common features and new perspectives. *Frontiers in Cardiovascular Medicine. 2022; 9*:1055862. doi:10.3389/fcvm.2022.1055862

18. Gallucci GM. Carotid-cavernous sinus fistula: a case study. *Journal of Neuroscience Nursing. 2005; 37(4)*:200-2, 10. doi:10.1097/01376517-200508000-00005

19. Zyck S, De Jesus O, Gould GC. Dural Arteriovenous Fistula. StatPearls. Treasure Island (FL): StatPearls Publishing

20. Walsh DR, Lynch JJ, O' Connor DT, Newport DT, Mulvihill JJE. Mechanical and structural characterisation of the dural venous sinuses. *Scientific Reports. 2020; 10(1)*:21763. doi:10.1038/s41598-020-78694-4

21. Henry JC, Franz RW. Pseudoaneurysms of the Peripheral Arteries. *International Journal of Angiology. 2019; 28(1)*:20-4. doi:10.1055/s-0039-1677676

22. Marklund N, Tenovuo O. Pathophysiology of Severe Traumatic Brain Injury. In: Sundstrøm T, Grände P-O, Luoto T, Rosenlund C, Undén J, Wester KG, editors. *Management of Severe Traumatic Brain Injury: Evidence, Tricks, and Pitfalls. Cham: Springer International Publishing; 2020*. p. 35-50.

23. Junewick JJ. Pediatric Craniocervical Junction Injuries. *American Journal of Roentgenology. 2011; 196(5)*:1003-10. doi:10.2214/ajr.10.6051

24. Li L, Liu J. The effect of pediatric traumatic brain injury on behavioral outcomes: a systematic review. *Developmental Medicine and Child Neurology. 2013; 55(1)*:37-45. doi:10.1111/j.1469-8749.2012.04414.x

25. Aldape K, Brindle KM, Chesler L, Chopra R, Gajjar A, Gilbert MR, et al. Challenges to curing primary brain tumours. *Nature Reviews Clinical Oncology. 2019; 16(8)*:509-20. doi:10.1038/s41571-019-0177-5

26. Gumede NP, Langa SM, Enicker B. MRI characteristics of intracranial masses in the paediatric population of KwaZulu-Natal: A neuroimaging-based study. *SA Journal of Radiology. 2021; 25(1)*:2042. doi:10.4102/sajr.v25i1.2042

27. Shah MM, Khalid MU, Bajwa MH, Mirza FA, Anis SB, Akhunzada NZ, et al. Gender disparities in brain tumours: A Pakistan brain tumour epidemiology study analysis. *Journal of Pakistan Medical Association. 2022*; 72(Suppl 4)(11):S79-S84. doi:10.47391/jpma.11-s4-akub13

28. Subramanian S, Ahmad T. Childhood Brain Tumors. StatPearls. Treasure Island (FL): StatPearls Publishing

29. Udaka YT, Packer RJ. Pediatric Brain Tumors. *Neurologic Clinics. 2018; 36(3)*:533-56. doi:https://doi.org/10.1016/j.ncl.2018.04.009

30. Accogli A, Geraldo AF, Piccolo G, Riva A, Scala M, Balagura G, et al. Diagnostic Approach to Macrocephaly in Children. *Frontiers in Pediatrics. 2021*; 9:794069. doi:10.3389/fped.2021.794069

31. Salander P, Bergenheim AT, Hamberg K, Henriksson R. Pathways from symptoms to medical care: a descriptive study of symptom development and obstacles to early diagnosis in brain tumour patients. *Family Practice. 1999; 16(2)*:143-8. doi:10.1093/fampra/16.2.143

32. Shimony N, Martinez-Sosa M, Jallo GI. Chapter 69 - Supratentorial Tumors in the Pediatric Population: Multidisciplinary Management. *Schmidek and Sweet Operative Neurosurgical Techniques: Elsevier Inc.; 2022*. p. 820-41.

33. Muzumdar D, Ventureyra EC. Treatment of posterior fossa tumors in children. *Expert Review Neurotherapeutics. 2010; 10(4)*:525-46. doi:10.1586/ern.10.28

34. Barksdale EM, Jr., Obokhare I. Teratomas in infants and children. *Current Opinion in Pediatrics. 2009; 21(3)*:344-9. doi:10.1097/MOP.0b013e32832b41ee

35. Cheung AT, Li WHC, Ho LLK, Ho KY, Chiu SY, Chan CG, et al. Impact of brain tumor and its treatment on the physical and psychological well-being, and quality of life amongst pediatric brain tumor survivors. *European Journal of Oncology Nursing. 2019*; 41:104-9. doi:10.1016/j.ejon.2019.06.003

36. Vargo M. Brain tumor rehabilitation. *American Journal of Physical Medicine and Rehabilitation. 2011*; 90(5 Suppl 1):S50-62. doi:10.1097/PHM.0b013e31820be31f

37. Gotha L, Pruthi V, Abbasi N, Kulkarni AV, Church P, Drake JM, et al. Fetal spina bifida: What we tell the parents. *Prenatal Diagnosis. 2020; 40(12)*:1499-507. doi:https://doi.org/10.1002/pd.5802

38. Bakanienė I, Žiukienė L, Vasiliauskienė V, Prasauskienė A. Participation of Children with Spina Bifida: A Scoping Review Using the International Classification of Functioning, Disability and Health for Children and Youth (ICF-CY) as a Reference Framework. *Medicina. 2018; 54(3)*:40.

39. Oumer M, Taye M, Aragie H, Tazebew A. Prevalence of Spina Bifida among Newborns in Africa: A Systematic Review and Meta-Analysis. *Scientifica. 2020; 2020*:4273510. doi:10.1155/2020/4273510

40. Page DT, Coetzee BJ. South African adolescents living with spina bifida: contributors and hindrances to well-being. *Disability and Rehabilitation. 2021; 43(7)*:920-8. doi:10.1080/09638288.2019.1647293

41. René O, Romana R, Branislav K. Etiology and Pathophysiology of the Spina Bifida. In: Branislav K, Raffaella M, Valeria B, editors. *Spina Bifida and Craniosynostosis. Rijeka: IntechOpen; 2021*. p. Ch. 1.

42. Copp AJ, Adzick NS, Chitty LS, Fletcher JM, Holmbeck GN, Shaw GM. Spina bifida. *Nature Reviews Disease Primers. 2015*; 1:15007. doi:10.1038/nrdp.2015.7

43. Ramsundhar N, Donald K. An approach to the developmental and cognitive profile of the child with spina bifida. *SAMJ: South African Medical Journal. 2014*; 104:221-.

44. Ozaras N. spina bifida and Rehabilitation. *Turkish Journal of Physical Medicine and Rehabilitation. 2016*:65-9. doi:10.5152/tftrd.2015.98250

45. Brea CM, Munakomi S. Spina Bifida. StatPearls. Treasure Island (FL): StatPearls Publishing

Copyright © 2023, StatPearls Publishing LLC.; 2023.

46. Lemay P, De Marco P, Emond A, Spiegelman D, Dionne-Laporte A, Laurent S, et al. Rare deleterious variants in GRHL3 are associated with human spina bifida. *Human Mutation. 2017; 38(6)*:716-24. doi:https://doi.org/10.1002/humu.23214

47. Oakley GP. The Scientific Basis for Eliminating Folic Acid–Preventable Spina Bifida: A Modern Miracle from Epidemiology. *Annals of Epidemiology. 2009; 19(4)*:226-30. doi:https://doi.org/10.1016/j.annepidem.2009.01.016

48. Graham JM, Jr. Update on the gestational effects of maternal hyperthermia. *Birth Defects Research. 2020; 112(12)*:943-52. doi:10.1002/bdr2.1696

49. Burmeister R, Hannay HJ, Copeland K, Fletcher JM, Boudousquie A, Dennis M. Attention Problems and Executive Functions in Children With Spina Bifida and

Hydrocephalus. *Child Neuropsychology. 2005; 11(3)*:265-83. doi:10.1080/092970490911324

50. Fletcher JM, Brei TJ. Introduction: Spina bifida--a multidisciplinary perspective. *Development Disabilities Research Reviews. 2010; 16(1)*:1-5. doi:10.1002/ddrr.101

51. Kahle KTMD, Kulkarni AVMD, Limbrick DDMD, Warf BCD. Hydrocephalus in children. *The Lancet. 2016*; 387(10020):788-99. doi:10.1016/S0140-6736(15)60694-8

52. Morgado T, Figaji A. Hydrocephalus in spina bida. *Health and Medical Publishing Group; 2014*.

53. Vinchon M, Rekate H, Kulkarni AV. Pediatric hydrocephalus outcomes: a review. *Fluids and Barriers of the CNS. 2012; 9(1)*:18. doi:10.1186/2045-8118-9-18

54. Tully HM, Dobyns WB. Infantile hydrocephalus: a review of epidemiology, classification and causes. *European Journal of Medical Genetics. 2014; 57(8)*:359-68. doi:10.1016/j.ejmg.2014.06.002

55. Koleva M, De Jesus O. Hydrocephalus: StatPearls Publishing, Treasure Island (FL); 2022.

56. Dewan MC, Rattani A, Mekary R, Glancz LJ, Yunusa I, Baticulon RE, et al. Global hydrocephalus epidemiology and incidence: systematic review and meta-analysis. *Journal of neurosurgery. 2018*:1-15. doi:10.3171/2017.10.JNS17439

57. Muir RT, Wang S, Warf BC. Global surgery for pediatric hydrocephalus in the developing world: a review of the history, challenges, and future directions. *Neurosurgical Focus FOC. 2016; 41(5)*:E11. doi:10.3171/2016.7.Focus16273

58. Mulugeta B, Seyoum G, Mekonnen A, Ketema E. Assessment of the prevalence and associated risk factors of pediatric hydrocephalus in diagnostic centers in Addis Ababa, Ethiopia. *BioMed Central Pediatrics. 2022; 22(1)*:145. doi:10.1186/s12887-022-03212-6

59. Rohlwink UK, Donald K, Gavine B, Padayachy L, Wilmshurst JM, Fieggen GA, et al. Clinical characteristics and neurodevelopmental outcomes of children with tuberculous meningitis and hydrocephalus. *Developmental Medicine & Child Neurology. 2016; 58(5)*:461-8. doi:https://doi.org/10.1111/dmcn.13054

60. Puderbaugh M, Emmady PD. Neuroplasticity. StatPearls. Treasure Island (FL): StatPearls Publishing

Copyright © 2022, StatPearls Publishing LLC.; 2022.

61. Hallett M. Neuroplasticity and rehabilitation. *Journal of Rehabilitation Research and Development. 2005*; 42(4):xvii-xxii.

62. Maslova OI. [Neurorehabilitation in pediatrics]. *Vestnik Rossiiskoi Akademii Meditsinskikh Nauk. 2011; (6)*:41-4.

63. Karol RL. Team models in neurorehabilitation: structure, function, and culture change. *NeuroRehabilitation. 2014; 34(4)*:655-69. doi:10.3233/nre-141080

64. Rafferty MR, Held Bradford EC, Fritz S, Hutchinson KJ, Miczak K, Resnick A, et al. Health Promotion and Wellness in Neurologic Physical Therapy: Strategies to Advance Practice. *Journal of Neurologic Physical Therapy. 2022; 46(2)*:103-17. doi:10.1097/npt.0000000000000376

65. Gutenbrunner C, Stievano A, Stewart D, Catton H, Nugraha B. ROLE OF NURSING IN REHABILITATION. *Journal of Rehabilitation Medicine- Clinical Communications. 2021*; 4:1000061. doi:10.2340/20030711-1000061

66. David Young RF, Kath Mares. Development of a consensus classification of physiotherapy interventions inpaediatric neurorehabilitation. *Journal- Association of Paediatric Chartered Physiotherapists. 2019; 10(2)*

67. Novak I, Honan I. Effectiveness of paediatric occupational therapy for children with disabilities: A systematic review. *Australain Occupational Therapy Journal. 2019; 66(3)*:258-73. doi:10.1111/1440-1630.12573

68. Rodger S, Brown GT, Brown A. Profile of paediatric occupational therapy practice in Australia. *Australian Occupational Therapy Journal. 2005; 52(4)*:311-25. doi:https://doi.org/10.1111/j.1440-1630.2005.00487.x

69. Beisbier S, Cahill S. Occupational Therapy Interventions for Children and Youth Ages 5 to 21 Years. *The American Journal of Occupational Therapy. 2021; 75(4)* doi:10.5014/ajot.2021.754001

70. James Law caJAD, and Jenna JV Charlton. Speech and language therapy interventions for children with primary speech and/or language disorders. *Cochrane Database Systematic Reviews. 2017; (1)* doi:10.1002/14651858.CD012490

71. Ebbels SH, McCartney E, Slonims V, Dockrell JE, Norbury CF. Evidence-based pathways to intervention for children with language disorders. *International Journal of Language and Communication Disorders. 2019; 54(1)*:3-19. doi:10.1111/1460-6984.12387

72. Azer SA, Kanugula AK, Kshirsagar RK. Dysphagia. StatPearls. Treasure Island (FL): StatPearls Publishing

73. Lee H. The Importance of Nutrition in Neurological Disorders and Nutrition Assessment Methods. *Brain & Neurorehabilitation. 2022*; 15 doi:10.12786/bn.2022.15.e1

74. Parrott M, Greenwood C. Is there a role for diet in cognitive rehabilitation? *Cognitive Neurorehabilitation 2015*. p. 272-92.

75. Qureshi AZ, Jenkins RM, Thornhill TH. Percutaneous endoscopic gastrostomy versus nasogastric tube feeding during neurorehabilitation. Ifs, ands, or buts. *Neurosciences Journal. 2016; 21(1)*:69-71. doi:10.17712/nsj.2016.1.20150013

76. Kaufman JN, Lahey S, Slomine BS. Pediatric rehabilitation psychology: Rehabilitating a moving target. *Rehabilitation psychology. 2017; 62(3)*:223-6. doi:10.1037/rep0000169

77. Queally JT, Barnes MA, Castillo H, Castillo J, Fletcher JM. Neuropsychological care guidelines for people with spina bifida. *Journal of Pediatric Rehabilitation Medicine. 2020; 13(4)*:663-73. doi:10.3233/prm-200761

78. Simpson G, Hyzak KA, Hawley L, Vunkhanching M, Mantell A. Psychosocial assessment in brain injury: An international social work survey. *Brain Injury. 2023; 37(6)*:517-24. doi:10.1080/02699052.2023.2183258

79. van den Broek MD. Why Does Neurorehabilitation Fail? *The Journal of Head Trauma Rehabilitation. 2005; 20(5)*:464-73.

80. Young RR, Sarkarati M. 11 - Acute and long-term care of patients with spinal cord injury or impairment. In: Young RR, Delwaide PJ, editors. *Principles and Practice of Restorative Neurology: Butterworth-Heinemann; 1992*. p. 125-35.

81. Königs M, Beurskens EA, Snoep L, Scherder EJ, Oosterlaan J. Effects of Timing and Intensity of Neurorehabilitation on Functional Outcome After Traumatic Brain Injury: A Systematic Review and Meta-Analysis. *Archives of Physical Medicine and Rehabilitation. 2018; 99(6)*:1149-59.e1. doi:10.1016/j.apmr.2018.01.013

82. Giordana MT, Clara E. Functional rehabilitation and brain tumour patients. A review of outcome. *Neurological Sciences. 2006; 27(4)*:240-4. doi:10.1007/s10072-006-0677-9

83. Khan F, Amatya B, Ng L, Galea M. Rehabilitation outcomes in persons with spina bifida: A randomised controlled trial. *Journal of Rehabilitation Medicine. 2015; 47(8)*:734-40. doi:10.2340/16501977-1999

84. Karimzadeh P. Management of Hydrocephalus. *Hydrocephalus 2012*.

85. Castellani GB, Miccoli G, Cava FC, Salucci P, Colombo V, Maietti E, et al. From Shunt to Recovery: A Multidisciplinary Approach to Hydrocephalus Treatment in Severe Acquired Brain Injury Rehabilitation. *Brain Science. 2021; 12(1)* doi:10.3390/brainsci12010003

86. van Lindert EJ, Arts S, Blok LM, Hendriks MP, Tielens L, van Bilsen M, et al. Intraoperative complications in pediatric neurosurgery: review of 1807 cases. *Journal of Neurosurgery: Pediatrics PED. 2016; 18(3)*:363-71. doi:10.3171/2016.3.Peds15679

87. Fugate JE. Complications of Neurosurgery. Continuum: *Journal of Media and Cultural Studies. 2015*; 21(5 Neurocritical Care):1425-44. doi:10.1212/con.0000000000000227

88. Alam A, Hana Z, Jin Z, Suen KC, Ma D. Surgery, neuroinflammation and cognitive impairment. *EBioMedicine. 2018*; 37:547-56. doi:10.1016/j.ebiom.2018.10.021

89. Noetzel M, Dosenbach N. Pediatric Neurorehabilitation Medicine. Swaiman's Pediatric Neurology: *Principles and Practice: Sixth Edition 2017*. p. 1248-55.

90. Del Rosario C, Slevin M, Molloy EJ, Quigley J, Nixon E. How to use the Bayley Scales of Infant and Toddler Development. *Archives of Disease in Childhood*

*Education and Practice Ed. 2021; 106(2):*108-12. doi:10.1136/archdischild-2020-319063

91. Peyton C, Msall ME, Wroblewski K, Rogers EE, Kohn M, Glass HC. Concurrent validity of the Warner Initial Developmental Evaluation of Adaptive and Functional Skills and the Bayley Scales of Infant and Toddler Development, Third Edition. *Developmental medicine and child neurology. 2020; 63(3)*:349-54.

92. Lennon EM, Gardner JM, Karmel BZ, Flory MJ. Bayley Scales of Infant Development☆. In: Benson JB, editor. *Encyclopedia of Infant and Early Childhood Development (Second Edition). Oxford: Elsevier; 2020*. p. 139-46.

93. Nagy BE, Kenyhercz F. Adaptive Behavioral, Social-Emotional, and Neurodevelopmental Outcomes at 2 Years of Age in Hungarian Preterm Infants Based on Bayley III. *Developmental Neurorehabilitation. 2021; 24(1)*:18-24. doi:10.1080/17518423.2020.1764651

94. Chelo Del R, Slevin M, Molloy EJ, Quigley J, Nixon E. How to use the Bayley Scales of Infant and Toddler Development. Archives of Disease in Childhood. *Education and Practice Edition. 2021; 106(2)*:108-12. doi:https://doi.org/10.1136/archdischild-2020-319063

95. Torras-Mañá M, Guillamón-Valenzuela M, Ramírez-Mallafré A, Brun-Gasca C, Fornieles-Deu A. Usefulness of the Bayley scales of infant and toddler development,third edition, in the early diagnosis of language disorder. *Psicothema. 2014; 26(3)*:349-56. doi:10.7334/psicothema2014.29

96. Azari N, Soleimani F, Vameghi R, Sajedi F, Shahshahani S, Karimi H, et al. Determination of validity and reliability of the Bayley scales in infant and toddler development. *Koomesh. 2016*; 18:189-96.

97. Ballot D, Ramdin T, Rakotsoane D, Agaba F, Davies V, Chirwa T, et al. Use of the Bayley Scales of Infant and Toddler Development, Third Edition, to Assess Developmental Outcome in Infants and Young Children in an Urban Setting in South Africa. *International Scholarly Research Notices. 2017*; 2017:1-5. doi:10.1155/2017/1631760

98. Borgaro SR, Prigatano GP. Modification of the Patient Competency Rating Scale for use on an acute neurorehabilitation unit: the PCRS-NR. *Brain Injury. 2003; 17(10)*:847-53. doi:10.1080/0269905031000089350

99. Biester RC. Chapter 12 - Outcome Scales and Neuropsychological Outcome. In: Le Roux PD, Levine JM, Kofke WA, editors. *Monitoring in Neurocritical Care. Philadelphia: W.B. Saunders; 2013*. p. 107-13.e2.

100. Wilson L, Boase K, Nelson LD, Temkin NR, Giacino JT, Markowitz AJ, et al. A Manual for the Glasgow Outcome Scale-Extended Interview. *Journal of Neurotrauma. 2021; 38(17)*:2435-46. doi:10.1089/neu.2020.7527

101. Boase K, Machamer J, Temkin NR, Dikmen S, Wilson L, Nelson LD, et al. Central Curation of Glasgow Outcome Scale-Extended Data: Lessons Learned from TRACK-TBI. *Journal of Neurotrauma. 2021; 38(17)*:2419-34. doi:10.1089/neu.2020.7528

102. Beers SR, Wisniewski SR, Garcia-Filion P, Tian Y, Hahner T, Berger RP, et al. Validity of a pediatric version of the Glasgow Outcome Scale-Extended. *Journal of Neurotrauma. 2012; 29(6)*:1126-39. doi:10.1089/neu.2011.2272

103. Silvia D. Vaca B, 1,2 Linda W. Xu, MD,1,2 Juliet Nalwanga, MBChB, MMed Surg,3, Christine Muhumuza M, 4, Benjamin J. Lerman B, 1,2 Joel Kiryabwire, MBChB, MMed Surg,3, Hussein Ssenyonjo M, MMed Surg,3, John Mukasa M, MMed Surg,3, Michael Muhumuza M, MMed Surg,3, et al. Long-term follow-up of pediatric head trauma patients treated at Mulago National Referral Hospital in Uganda. *Journal of Neurosurgery Pediatrics. 2019*; 23:125-32. doi:10.3171/2018.7.PEDS17601.

104. Braine ME, Cook N. The Glasgow Coma Scale and evidence-informed practice: a critical review of where we are and where we need to be. *Journal of Clinical Nursing. 2017*; 26(1-2):280-93. doi:https://doi.org/10.1111/jocn.13390

105. Amirtharaj A, Lazarus Rathinasamy E, Alzaabi O. Assessing validity and reliability of Glasgow coma scale and full outline of unresponsiveness score: A systematic review. *International journal of health sciences. 2022*; doi:10.53730/ijhs.v6nS2.8259

106. Nayar SK, Li D, Ijaiya B, Lloyd D, Bharathan R. Waterlow score for risk assessment in surgical patients: a systematic review. *Annals of the Royal Collage of Surgeons of England. 2021*; 103(5):312-7. doi:10.1308/rcsann.2020.7136

107. Charalambous C, Koulori A, Vasilopoulos A, Roupa Z. Evaluation of the Validity and Reliability of the Waterlow Pressure Ulcer Risk Assessment Scale. *Medical Archives. 2018; 72(2)*:141-4. doi:10.5455/medarh.2018.72.141-144

108. Torra i Bou J-E, García-Fernández FP, Pancorbo-Hidalgo PL, Furtado K. Risk Assessment Scales for Predicting the Risk of Developing Pressure Ulcers. *Science 2006*. p. 43-57.

109. Luo WJ, Zhou XZ, Lei JY, Xu Y, Huang RH. Predictive risk scales for development of pressure ulcers in pediatric patients admitted to general ward and intensive care unit. *World Journal of Clinical Cases. 2021*; 9(35):10956-68. doi:10.12998/wjcc.v9.i35.10956

110. Walsh B, Dempsey L. Investigating the Reliability and Validity of the Waterlow Risk Assessment Scale: A Literature Review. *Clinical Nursing Research. 2011; 20(2)*:197-208. doi:10.1177/1054773810389809

111. Qureshi AZ, Jenkins RM, Williamson LF. The Broken Link: Admission Criteria for Inpatient Rehabilitation and Some Common Misconceptions. *Saudi Journal of Medicine and Medical Sciences. 2016; 4(3)*:233-7. doi:10.4103/1658-631x.188257

112. Barnes MP. Principles of neurological rehabilitation. Journal of Neurology, Neurosurgery & *Psychiatry. 2003*; 74(suppl 4):iv3-iv7. doi:10.1136/jnnp.74.suppl_4.iv3

113. Freeman JA, Hobart JC, Playford ED, Undy B, Thompson AJ. Evaluating neurorehabilitation: lessons from routine data collection. *Journal of Neurology, Neurosurgery & Psychiatry. 2005; 76(5)*:723-8. doi:10.1136/jnnp.2004.035956

114. Lincoln N, das Nair R. Outcome measurement in cognitive neurorehabilitation. *Cognitive neurorehabilitation: Evidence and application, 2nd ed. New York, NY, US: Cambridge University Press; 2008*. p. 91-105.

115. Kawakatsu Y, Kaneko S, Karama M, Honda S. Prevalence and risk factors of neurological impairment among children aged 6–9 years: from population based cross sectional study in western Kenya. *BioMed Central Pediatrics. 2012; 12(1)*:186. doi:10.1186/1471-2431-12-186

116. Madi SM, Alraddadi NI. Association Between Pediatric Inpatient Rehabilitation Services and Children's Functional Outcomes: King Fahad Medical City Experience. *Rehabilitation Process Outcome. 2020*; 9:1179572720928394. doi:10.1177/1179572720928394

117. Arnold-Day C. Paediatric brain tumours: The University of Cape Town experience from 1996 - 2017 2019.

118. Munivenkatappa A, Agrawal A, Shukla DP, Kumaraswamy D, Devi BI. Traumatic brain injury: Does gender influence outcomes? *International Journal of Critical Illness and Injury Science. 2016; 6(2)*:70-3. doi:10.4103/2229-5151.183024

119. Bationo F, Songré-Ouattara LT, Hama-Ba F, Baye K, Hemery YM, Parkouda C, et al. Folate Status of Women and Children in Africa – Current Situation and Improvement Strategies. *Food Reviews International. 2020; 36(1)*:1-14. doi:10.1080/87559129.2019.1608558

120. Ingram CF, Fleming AF, Patel M, Galpin JS. Pregnancy- and lactation-related folate deficiency in South Africa--a case for folate food fortification. *South African Medical Journal. 1999; 89(12)*:1279-84.

121. Hassan AS, Du YL, Lee SY, Wang A, Farmer DL. Spina Bifida: A Review of the Genetics, Pathophysiology and Emerging Cellular Therapies. *Journal of Development Biology. 2022; 10(2)* doi:10.3390/jdb10020022

122. Bleyer WA. Epidemiologic impact of children with brain tumors. *Child's Nervous System. 1999; 15(11-12)*:758-63. doi:10.1007/s003810050467

123. Paschereit F, Schindelmann KH, Hummel M, Schneider J, Stoltenburg-Didinger G, Kaindl AM. Cerebral Abnormalities in Spina Bifida: A Neuropathological Study. *Pediatric and Developmental Pathology. 2022; 25(2)*:107-23. doi:10.1177/10935266211040500

124. Svedung Wettervik T, Lewén A, Enblad P. Post-traumatic hydrocephalus - incidence, risk factors, treatment, and clinical outcome. *British Journal of Neurosurgery. 2022; 36(3)*:400-6. doi:10.1080/02688697.2021.1967289

125. Benson JC, Madhavan AA, Cutsforth-Gregory JK, Johnson DR, Carr CM. The Monro-Kellie Doctrine: A Review and Call for Revision. *American Journal of Neuroradiology. 2022*; doi:10.3174/ajnr.A7721

126. Kimura T, Shimoji K, Miyajima M, Arai H. Chapter 12 - Shunt Techniques—Cystoperitoneal Shunt. In: Wester K, editor. *Arachnoid Cysts: Academic Press; 2018*. p. 165-72.

127. Ferreira Furtado LM, Da Costa Val Filho JA, Moreira Faleiro R, Lima Vieira JA, Dantas Dos Santos AK. Abdominal Complications Related to Ventriculoperitoneal Shunt Placement: A Comprehensive Review of Literature. *Cureus. 2021; 13(2)*:e13230. doi:10.7759/cureus.13230

128. Li LM, Dilley MD, Carson A, Twelftree J, Hutchinson PJ, Belli A, et al. Management of traumatic brain injury (TBI): a clinical neuroscience-led pathway for the NHS. *Clinical Medicine Journal - London. 2021; 21(2)*:e198-e205. doi:10.7861/clinmed.2020-0336

129. Pierre L, Kondamudi NP. Subdural Hematoma. StatPearls. Treasure Island (FL): StatPearls Publishing

Copyright © 2023, StatPearls Publishing LLC.; 2023.

130. Epstein SK. Anatomy and physiology of tracheostomy. *Respiratory Care. 2005; 50(4)*:476-82.

131. Selvakumar S, Chan K, Ngatuvai M, Newsome K, Ang D, Bilski T, et al. Timing of tracheostomy in patients with severe traumatic brain injuries: The need for tailored practice management guidelines. *Injury. 2022; 53(8)*:2717-24. doi:https://doi.org/10.1016/j.injury.2022.06.031

132. Fernández-de Thomas RJ, Munakomi S, De Jesus O. Craniotomy. StatPearls. Treasure Island (FL): StatPearls Publishing

Copyright © 2023, StatPearls Publishing LLC.; 2023.

133. Weinberg DS, Rhee JM. Cervical laminoplasty: indication, technique, complications. *Journal of Spine Surgery. 2020; 6(1)*:290-301. doi:10.21037/jss.2020.01.05

134. Heuer GG, Adzick NS, Sutton LN. Fetal myelomeningocele closure: technical considerations. *Fetal Diagnosis and Therapy. 2015; 37(3)*:166-71. doi:10.1159/000363182

135. Ullah S, Qureshi A, Sami A, Ilyas W, Tantawy A, Alqatari S. Trends in Length of Stay: Experience From a Tertiary Care Pediatric Rehabilitation Unit in Saudi Arabia. *Internet Journal of Allied Health Sciences and Practice. 2023*; 21

136. Berger E, Wörgötter G, Oppolzer A, Kessler J, Vavrik K, Fiala S. Neurological rehabilitation in children and adolescents. *Pediatric Rehabilitation. 1997;1(4)*:229-233. doi:10.3109/17518429709167363

137. Oseran AS, Nash D, Kim C, Moisuk S, Lai PY, Pyhtila J, et al. Changes in hospital admissions for urgent conditions during COVID-19 pandemic. *American Journal of Managed Care. 2020; 26(8)*:327-8. doi:10.37765/ajmc.2020.43837

138. Rennert-May E, Leal J, Thanh NX, Lang E, Dowling S, Manns B, et al. The impact of COVID-19 on hospital admissions and emergency department visits: A population-based study. *Public Library of Science. 2021; 16(6)*:e0252441. doi:10.1371/journal.pone.0252441

139. Mahlangu P, Gibbs A, Shai N, Machisa M, Nunze N, Sikweyiya Y. Impact of COVID-19 lockdown and link to women and children's experiences of violence in the home in South Africa. *BMC Public Health. 2022; 22(1)*:1029. doi:10.1186/s12889-022-13422-3

140. Gutenbrunner C, Nugraha B. Decision-Making in Evidence-Based Practice in Rehabilitation Medicine: Proposing a Fourth Factor. *American Journal of Physical Medicine Rehabilitation. 2020; 99(5)*:436-40. doi:10.1097/phm.0000000000001394

141. Thurman SL, Corbetta D. Changes in Posture and Interactive Behaviors as Infants Progress From Sitting to Walking: A Longitudinal Study. *Frontiers in Psychology. 2019*; 10:822. doi:10.3389/fpsyg.2019.00822

142. Riley BRW, de Sam Lazaro SL. Role of Occupational Therapy in Pediatric Primary Care: Promoting Childhood Development. *The American Journal of Occupational Therapy. 2021; 75(6)* doi:10.5014/ajot.2021.756002

143. Jo KW, Kim Y, Park GY, Park IS, Jang Y, Gyun SD, et al. Oropharyngeal dysphagia in secondary normal pressure hydrocephalus due to corticobulbar tract compression: cases series and review of literature. *Acta Neurochirurgica. 2017; 159(6)*:1005-11. doi:10.1007/s00701-017-3157-5

144. Lang IM. Brain stem control of the phases of swallowing. *Dysphagia. 2009; 24(3)*:333-48. doi:10.1007/s00455-009-9211-6

145. Javed K, Reddy V, J MD, Wroten M. Neuroanatomy, Wernicke Area. StatPearls. Treasure Island (FL): StatPearls Publishing

146. Stinnett TJ, Reddy V, Zabel MK. Neuroanatomy, Broca Area. StatPearls. Treasure Island (FL): StatPearls Publishing

147. Idnani S, Lillis T, Gerhart J. Peer Socialization. Encyclopedia of Evolutionary *Psychological Science: Springer International Publishing : Cham; 2018*. p. 1-3.

148. Corten L, van As AB, Rahim S, Kleinsmith J, Kleyn A, Kwinana T, et al. Physiotherapy in children hospitalized with traumatic brain injury in a South African tertiary paediatric hospital. *Physiotherapist Research International. 2020; 25(4)*:e1860. doi:10.1002/pri.1860

149. Carron SF, Alwis DS, Rajan R. Traumatic Brain Injury and Neuronal Functionality Changes in Sensory Cortex. *Frontiers in Systems Neuroscience. 2016*; 10:47. doi:10.3389/fnsys.2016.00047

150. Koukourikos K, Tsaloglidou A, Tzeha L, Iliadis C, Frantzana A, Katsimbeli A, et al. An Overview of Play Therapy. *Materia Socio-Medica. 2021; 33(4)*:293-7. doi:10.5455/msm.2021.33.293-297

151. Craig J, Hilderman C, Wilson G, Misovic R. Effectiveness of Stretch Interventions for Children With Neuromuscular Disabilities: Evidence-Based Recommendations. *Pediatric Physical Therapy. 2016; 28(3)*:262-75. doi:10.1097/pep.0000000000000269

152. Hewitt L, Kerr E, Stanley RM, Okely AD. Tummy Time and Infant Health Outcomes: A Systematic Review. *Pediatrics. 2020*; 145(6) doi:10.1542/peds.2019-2168

153. Chan GJ, Valsangkar B, Kajeepeta S, Boundy EO, Wall S. What is kangaroo mother care? Systematic review of the literature. *Journal of Global Health. 2016; 6(1)*:010701. doi:10.7189/jogh.06.010701

154. Azevedo N, Ribeiro JC, Machado L. Balance and Posture in Children and Adolescents: A Cross-Sectional Study. *Sensors (Basel). 2022; 22(13)* doi:10.3390/s22134973

155. Nagymáté G, Takács M, Kiss RM. Does bad posture affect the standing balance? *Cogent Medicine. 2018; 5(1)*:1503778.

156. Zhan L, Guo D, Chen G, Yang J. Effects of Repetition Learning on Associative Recognition Over Time: Role of the Hippocampus and Prefrontal Cortex. *Frontiers in Human Neuroscience. 2018*; 12:277. doi:10.3389/fnhum.2018.00277

157. Williams AM. Education, Training, and Mentorship of Caregivers of Canadians Experiencing a Life-Limiting Illness. *Journal of Palliative Medicine. 2018; 21*(S1):S45-s9. doi:10.1089/jpm.2017.0393

158. Sean Hopkins JV, Dawn Tymianski, Dr. Tina Petrelli, Elisabeth White. GUIDELINES FOR BASIC PAEDIATRIC NEUROLOGICAL OBSERVATION. *Critical Care Services Ontario. 2016*; 1

159. México V, Guégan J-F, Suzan G, Kati Coulibaly S, Didier N, Bonpamgue, et al. Sustainable Development Goal #3, "health and well-being", and the need for more integrative thinking. *Veterinaria Mexico. 2018*; 5 doi:10.21753/vmoa.5.2.443

160. Boeren E. Understanding Sustainable Development Goal (SDG) 4 on “quality education” from micro, meso and macro perspectives. *International Review of Education. 2019;* 65 doi:10.1007/s11159-019-09772-7

Appendices

APPENDIX A: OUTCOME DESCRIPTION OF GOS-E PEDS

Definition	Component of GOS-E Peds Score	Restriction (s)
Good (Favorable) Neurological Recovery	Upper good recovery	No problems related to injury that affect daily life (socially and functionally)
	Lower good recovery	Age-appropriate functional capacity (home, work, or school) Occasional (<1/ week) typical posttraumatic personality changes or nonspecific problems after head injury (headaches, dizziness, tiredness, sensitivity to noise or light, slowness, memory failures, concentration problems, or other problems) Participates a bit less (($\geq$ 50% of preinjury) in social and leisure activities
Less Favorable Neurological Recovery	Upper moderate disability	Significantly reduced work or school capacity Frequent typical but tolerable posttraumatic personality changes ($\geq$ 1/ week) < 50% of preinjury participation in social and leisure activities
	Lower moderate disability	Able to work only in a sheltered workshop or noncompetitive job or in a school setting for severely impaired children or tutored at home, or currently unable to go to work or go to school (if previously schooling) Daily and intolerable typical posttraumatic personality changes (quick temper, irritability, anxiety, aggressive acts, insensitivity to others, mood swings, depression, age-inappropriate unreasonable or childish behaviour) Unable or rarely participates in social and leisure activities (able to pre-injury)
	Upper severe disability	Needs assistance but not frequent or full-time help (independent preinjury) Younger patient does not need frequent help from caretaker to accomplish age-appropriate tasks Unable to shop and travel without assistance (able to preinjury) Younger patient does not behave age appropriately outside home
	Lower severe disability	Requires daily assistance for activities of daily living (independent preinjury) Younger patient dependent on caretaker more than expected based on age
	Vegetative	Unable to obey simple commands or communicate (able to preinjury) Younger patient unable to interact or react beyond reflexes
	Death	--

APPENDIX B: MEAN AGE ACROSS NEUROLOGICAL IMPAIRMENTS

Overall mean age

Years	Months	Decimal format
0	6	0,5
3	0	3
0	5	0,41666667
4	0	4
1	3	1,25
0	10	0,83333333
1	7	1,58333333
0	4	0,33333333
1	4	1,33333333
1	3	1,25
1	3	1,25
0	10	0,83333333
4	7	4,58333333
3	2	3,16666667
0	5	0,41666667
0	4	0,33333333
0	2	0,16666667
8	2	8,16666667
3	7	3,58333333
1	4	1,33333333
8	3	8,25
0	1	0,08333333
0	3	0,25
1	8	1,66666667
2	10	2,83333333
2	4	2,33333333
2	0	2
3	0	3
0	7	0,58333333
0	2	0,16666667
0	6	0,5
0	3	0,25
0	10	0,83333333
4	10	4,83333333
0	4	0,33333333
0	1	0,08333333
11	4	11,3333333
1	11	1,91666667
2	9	2,75
1	0	1
Average: 2,08333333 **2 Years 1 Month**		

Mean age of brain tumour patients

Years	Months	Decimal Format
3	0	3
0	5	0,41666667
8	2	8,16666667
1	3	1,25
2	9	2,75
Average: 3,11666667 **3 Years 1 Month**		

Mean age of hydrocephalus patients

Years	Months	Decimal format
0	6	0,5
4	0	4
1	3	1,25
0	10	0,83333333
1	7	1,58333333
0	4	0,33333333
1	4	1,33333333
1	3	1,25
1	3	1,25
4	7	4,58333333
3	2	3,16666667
0	5	0,41666667
0	4	0,33333333
0	2	0,16666667
8	2	8,16666667
1	4	1,33333333
0	3	0,25
1	8	1,66666667
2	10	2,83333333
0	7	0,58333333
0	6	0,5
0	3	0,25
0	4	0,33333333
0	1	0,08333333
1	0	1
1	6	1,5
Average: 1,51923077 **1 Year 5 Months**		

Mean age of spina bifida patients

Years	Months	Decimal format
0	6	0,5
0	5	0,41666667
0	1	0,08333333
0	3	0,25
0	2	0,16666667
0	3	0,25
Average: 0,27777778 **0 Years 3 Months**		

Mean age of TBI patients

Years	Months	Decimal format
1	7	1,58333333
0	10	0,83333333
3	7	3,58333333
8	3	8,25
2	4	2,33333333
2	0	2
3	0	3
0	10	0,83333333
4	10	4,83333333
11	4	11,3333333
1	11	1,91666667
8	0	8
Average: 4,04166667 **4 Years**		

APPENDIX C: REHABILITATION INTERVENTIONS

The following tables include the various therapy types and treatment targets implemented for each neurological impairment.

In-house occupational therapy treatment targets across the neurological impairments

Categories	Overall	BT	HCP	SB	TBI
Hand Function and Grasping: Hand function lacking Bilateral hand use Facilitated hand control and rolling Grasping Hand-eye coordination	18	3	9	3	7
Sensory Stimulation: Sensory stimulation (touch) Sensory stimulation and play vestibular stimulation Visual stimulation Auditory stimulation Proprioceptive stimulation Tactile stimulation Oral stimulation Sensory group stimulation	23	5	14	3	5
Milestone Development: Delayed milestones Facilitate development of milestones	12	5	6	3	2
Posture and Body Control: Poor posture Poor standing balance Head and neck control strengthening Facilitated head control in prone and sitting Prone over roller Prone positioning Supported long sitting Trunk control sitting 4-point kneeling Facilitated crawling Trunk activation Propped prone endurance Facilitated 2-point and 4-point head control Reflexes	38	6	22	7	11
Caregiver Education and Involvement: Teac passive stretches Caregiver training Caregiver education about premature birth Educating mothers on feeding	9	1	6	1	2

Categories	Overall	BT	HCP	SB	TBI
Equipment and Assistive Devices: Buggy Wheelchair Standing frame	18	3	8		8
Cognitive and School-Related Activities: Basic concept learning (colours, counting) School activities (math and alphabetizing) Cognitive stimulation Memory, attention School readiness	8	2	2		5
Behavioural and Emotional Support: Group play therapy Addressing impulsive behaviour Improving emotional response Social stimulation	11	3	4	1	5
Sensory Desensitization: Desensitization of feet Desensitizing hands with different textures	2	1	2		
Monitoring and Assessment: Monitor developmental milestones Monitor progress	5	1	4	1	
Muscle Tone and Range of Motion (ROM): Contracture on both ankles Passive stretches Facilitating tone Improve ROM	20	3	13	3	4

In-house speech therapy treatment targets across the neurological impairments

Categories	Overall	BT	HCP	SB	TBI
Play and Social Stimulation: • Play • Social stimulation, turn-taking • Social interaction during play, increase interaction during play • Play with ball, bubbles, food play, interactive play, pretend play • Food play to encourage intake	25	4	12	4	9

Categories	Overall	BT	HCP	SB	TBI
Feeding and Swallowing: • Swallowing and sucking from bottle • Video swallow test • PEG insertion • Liquid feeding, puree intro • Spoon feeding, cup drinking, NGT feeding • Increase oral intake, tolerance, and swallowing exercises • Thermal stimulation • Desensitization to spoon • Tactile stimulation • Non-nutritive stimulation (NNS) for feeding • Facilitated feeding • Dysphagia exercises • Aspiration monitoring, elicit swallow • Increase food tolerant intake • Tongue ROM to increase bolus manipulation • Breast feeding with good sucking • Desensitization to oral feeding	33	3	23	7	7
Monitoring and Screening: • Hearing screening/audio screening • Monitor feeding, and water intake • Monitor liquids, formula, or puree intake, feeding with bottle	21	3	12	1	7
Caregiver Education: • Mother education on feeding positions • Caregiver education on developmental milestones	2	1	1		
Cognitive and Memory Stimulation: • Memory • Orientation • Problem-solving • Behaviour modification • Increase memory processing, • Processing time and language skills	4	1	1		2

In-house physiotherapy treatment targets across the neurological impairments

Categories	Overall	BT	HCP	SB	TBI
Chest Physiotherapy and Stretches: • Chest physio • Passive stretches of upper limb, lower limb (UL, LL, and hips • Trunk stretches • Facilitation of chin tuck • Joint compressions • Percussions and vibrations • Weight bearing UL	28	3	19	5	8
Caregiver Education and Monitoring: • Educating caregiver for developmental milestones • Monitor patient's progress • Caregiver education on kangaroo mother care	5		4	2	1
Head and Neck Control: • Facilitation of head and neck control • Active head movements facilitated through tactile touch • Passive neck stretches • Neck control exercises	22	3	16	5	3
Prone Positioning and Rolling: • Facilitated rolling • Prone lying, puppy prone • Supported prone positioning • Facilitated neck in semi-prone lying • Proning over wedge • Prone play	27	3	18	5	7
Sitting and Standing Training: • Supported sitting • Facilitated sitting tolerance and balance • Max supported standing • Facilitated standing • Supported standing in standing frame • Standing with max assistance • Weight bearing on left side in side-lying and sitting with outstretched arms • Sitting to standing, standing to 2-point kneeling • Weight bearing on knees in prone • Weight bearing on LL in supported sitting • Supported long sitting • Posture correction • Supported 2-point kneeling	30	5	15	3	11

Categories	Overall	BT	HCP	SB	TBI
Crawling and Gait Training: • Facilitated crawling • Supported crawling using roller • Supported 4-point kneeling • Gait training with rollator • Gait training on incline and decline • WB on LL in standing • Gait without aid under supervision for 50m • Walking endurance and speed improvement • Gait training while pushing a toy lawnmower • Assisted crawling • Standing with walker • Facilitation of crawling and walking (using atlas walker) • Facilitation of gait with reverse walker • Supported gait training • Stair climbing on rails	32	6	15		14
Play and Therapeutic Activities: • Play therapy • Play stimulation • Play with objects • Play in sitting and standing • Play on plinth • Tactile stimulation through play	12	3	5		5
Limb Strengthening and Passive Movements: • UL and LL strengthening exercises • Active and passive ROM exercises for UL and LL • Facilitation of alternative leg movement to increase dissociation	12	3	6	2	4
Tummy Time and Prone Lying: • Tummy time with emphasis on head control • Tummy time on wedge with WB UL • Tummy time on propped blanket • Prone lying over wedge to improve trunk control and strength • Proning over linen with WB on wrists and knees • Prone positioning with no head control • Bed mobility	12		10	2	2
Facilitation of Developmental Milestones: • Facilitation of milestones and motor functions • Facilitation of grasping, reaching • Facilitation of fine motor skills	13	1	9	4	2

In-house psychological therapy treatment targets across the neurological impairments

Category	Overall	BT	HCP	SB	TBI
Caregiver support	5	2	3		
Caregiver counselling	1				1
Caregiver support group	1				1
Total	7	2	3	0	2

In-house nutrition therapy treatment targets across the neurological impairments

Category	Overall	BT	HCP	SB	TBI
Weight Monitoring, feeding monitoring, and Supplementation: • Malnutrition treatment • Weight increased • Weight relatively constant • Weight increase on puree feeds • Significant weight loss • Maintain food intake and weight • Monitor weight and intake • Initiation of supplements • Severely dehydrated • On puree, changed to lactogen 2 • Monitor tolerance to feeds • Additional fluid included in feeding to increase bowel movement • Prepare for Planned discharge • Prepare for discharge	42	7	28	5	14
Oral Feeding and Solid Foods: • Oral feeding with a feeding schedule • Initiation of solid foods • Oral puree with poor intake • Assist with transition feeding	2	1	1		
Educating the Mother: • Educating the mother on nutrition and feeding	1	1			

APPENDIX D: RESEARCH ETHICS COMMITTEE APPROVAL CERTIFICATE

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Health Sciences

Institution: The Research Ethics Committee, Faculty Health Sciences, University of Pretoria complies with ICH-GCP guidelines and has US Federal wide Assurance.

- FWA 00002567, Approved dd 18 March 2022 and Expires 18 March 2027.
- IORG #: IORG0001762 OMB No. 0990-0278 Approved for use through August 31, 2023.

Faculty of Health Sciences **Research Ethics Committee**

24 November 2022

Approval Certificate
New Application

Dear Miss N Smit

Ethics Reference No.: 558/2022
Title: Investigating the use of neurorehabilitation scales in paediatric neurosurgical patients at a tertiary academic hospital in Gauteng

The **New Application** as supported by documents received between 2022-09-19 and 2022-11-23 for your research, was approved by the Faculty of Health Sciences Research Ethics Committee on 2022-11-23 as resolved by its quorate meeting.

Please note the following about your ethics approval:

- Ethics Approval is valid for 1 year and needs to be renewed annually by 2023-11-24.
- Please remember to use your protocol number (558/2022) on any documents or correspondence with the Research Ethics Committee regarding your research.
- Please note that the Research Ethics Committee may ask further questions, seek additional information, require further modification, monitor the conduct of your research, or suspend or withdraw ethics approval.

Ethics approval is subject to the following:

- The ethics approval is conditional on the research being conducted as stipulated by the details of all documents submitted to the Committee. In the event that a further need arises to change who the investigators are, the methods or any other aspect, such changes must be submitted as an Amendment for approval by the Committee.

We wish you the best with your research.

Yours sincerely

On behalf of the FHS REC, Professor Werdie (CW) Van Staden
MBChB, MMed(Psych), MD, FCPsych(SA), FTCL, UPLM
***Chairperson**: Faculty of Health Sciences Research Ethics Committee*

The Faculty of Health Sciences Research Ethics Committee complies with the SA National Act 61 of 2003 as it pertains to health research and the United States Code of Federal Regulations Title 45 and 46. This committee abides by the ethical norms and principles for research, established by the Declaration of Helsinki, the South African Medical Research Council Guidelines as well as the Guidelines for Ethical Research: Principles Structures and Processes, Second Edition 2015 (Department of Health)

Research Ethics Committee
Room 4-60, Level 4, Tswelopele Building
University of Pretoria, Private Bag x323
Gezina 0031, South Africa
Tel +27 (0)12 356 3084
Email: deepeka.behari@up.ac.za
www.up.ac.za

Fakulteit Gesondheidswetenskappe
Lefapha la Disaense tša Maphelo

APPENDIX E: NHRD APPROVAL LETTER

GAUTENG PROVINCE
HEALTH
REPUBLIC OF SOUTH AFRICA

STEVE BIKO ACADEMIC HOSPITAL

Enquiries: Dr JS Mangwane
Tel No: +2712 3452018
Fax No: +2712 354 2151
E-mail: joseph.mangwane@gauteng.gov.za

For attention: Nicoleen Smit

NHRD Ref Number: GP_202212_009

Re: REQUEST FOR PERMISION TO CONDUCT RESEARCH AT STEVE BIKO ACADEMIC HOSPITAL

TITLE: Investigating the use of neurorehabilitation scales in paediatric neurosurgical patients at a tertiary academic hospital in Gauteng

Permission is hereby granted for the above-mentioned research to be conducted at Steve Biko Academic Hospital. This is done in accordance to the "Promotion of access to information act No 2 of 2000".

Please note that in addition to receiving approval from Hospital Research Committee, the researcher is expected to seek permission from all relevant department. Furthermore, collection of data and consent for participation remain the responsibility of the researcher.

The hospital will not incur extra cost as a result of the research being conducted within the hospital.

You are also required to submit your final report or summary of your findings and recommendations to the office of the CEO.

STATUS OF APPLICATION: Approved

Date: 2022-12-11

Dr. J S. Mangwane
Manager: Medical Service

APPENDIX F: TRH RESEARCH APPROVAL DOCUMENT

GAUTENG PROVINCE
HEALTH
REPUBLIC OF SOUTH AFRICA

TSHWANE REHABILITATION HOSPITAL
RESEARCH COMMITTEE
TEL: 012-354-6163/012-354-6804

REQUEST FOR PERMISSION TO CONDUCT RESEARCH AT TSHWANE REHABILITATION HOSPITAL

STATUS OF UNIVERSITY ETHICS COMMITTEE APPROVAL (Tick applicable box)	Yes	No
In progress		
Obtained (Form attached)	✓	

STATUS OF OBTAINING REFERENCE NUMBER FOR REGISTRATION ON NATIONAL HEALTH RESEARCH DATABASE(NHRD) (Tick applicable box)	Yes	No
In progress		
Obtained	✓	
Reference number for NHRD	GP_202212_009	

NAME OF RESEARCHER: Nicoleen Smit

TITLE OF RESEARCH PROJECT:
Investigating the use of neurorehabilitation scales in paediatric neurosurgical patients at a tertiary academic hospital in Gauteng.

PROPOSAL ATTACHED: YES ✓ | NO

COSTS IMPLICATION TO HOSPITAL:
There will be no cost implications.

SERVICE IMPLICATION TO HOSPITAL:
Will be making use of patient files as this is a retrospective study.

You will be obligated to present your research to Tshwane Rehabilitation Hospital upon completion of your study and provide the hospital with a write-up of your study for the Hospital's Research Database.

APPLICANT SIGN: ..... DATE: 23/12/2022

EMAIL (applicant): u17001014@tuks.co.za TEL NO (applicant): 072 243 2576

GAUTENG PROVINCE
HEALTH
REPUBLIC OF SOUTH AFRICA

FOR OFFICIAL PURPOSES ONLY (not to be completed by applicant)

Completed once reviewed by the Tshwane Rehabilitation Hospital Research Committee

TICK APPROPRIATE BOX	OUTCOME	COMMENT
	1. **Pre-authorization** to be utilized for ethics approval/NHRD registration number.	The researcher will be required to produce University Ethics Approval and NHRD registration number prior to commencing data collection at Tshwane Rehabilitation Hospital with nil material changes to proposal. Please note: Consent forms to be made available in both English and Sepedi.
	2. **Approved**	
	3. **Approved with amendment**	The patients' file have to be retrieved via the Administration and logistics Department at Tshwane Rehabilitation Hospital
	4. **Not Approved**	

RECOMMENDATIONS:

....

....

....

PRINT NAME OF MANCO: V. PAOATACXM **SIGNATURE OF MANCO:** ....

PRINT NAME OF EXCO: DR R MATHEBULA **SIGNATURE OF EXCO:** ....

Chairperson of the Research Committee: ....

Date: 30/01/2023

CEO Tshwane Rehabilitation Hospital: ....

Date: 30/01/2023

Page 2 of 2

REQUEST FOR PERMISSION TO CONDUCT RESEARCH AT TSHWANE REHABILITATION HOSPITAL