Original Article

Evaluation of Pediatric Hydrocephalus: Clinical, Surgical, and Outcome Perspective in a Tertiary Center

Abstract

Context: Pediatric hydrocephalus (PH) results in significant clinical and psychosocial morbidity in pediatric population. **Aims:** The aims of the study are to evaluate clinical, surgical, and outcome perspective of PH patients of age <12 years. **Settings and Design:** This is a retrospective cohort study. **Materials and Methods:** This study includes 117 pediatric patients (age ≤12 years) of hydrocephalus due to various etiology admitted in our department between September 2018 and December 2020. Demographic profile, etiology, clinical presentation, management, complications and postoperative outcome characteristics were evaluated. Survival analysis was done with respect to etiology and age group. **Statistical Analysis Used:** $P < 0.05$ was considered statistically significant. Unpaired t-test and Chi-square test were used. Kaplan–Meier curve plotting and survival analysis were also done. **Results:** Male-to-female ratio was 1.3:1. Most frequent etiology of PH was postinfectious (35%). Posterior fossa pilocytic astrocytoma (34.2%) was the most common neoplastic etiology. Surgical procedure performed for PH was ventriculoperitoneal shunting ($n = 103$), Ommaya reservoir ($n = 2$) placement, and endoscopic third ventriculostomy (ETV) ($n = 8$). Mortality was significantly ($P = 0.0139$) more in patients of neoplastic etiology. Cognitive deficits and delayed developmental milestones were significantly ($P < 0.05$) more in congenital hydrocephalus etiology. There was a nonsignificant difference in survival between age groups ($P = 0.1971$). However, a significant survival difference was evident ($P = 0.0098$) for etiology. **Conclusions:** Disease-specific mortality is main cause of mortality in PH. Neoplastic etiology PH has poor survival when compared to others. Life-long routine controls are required to avoid future possible complications and enhance better rehabilitation of the child.

Keywords: *Congenital hydrocephalus, endoscopic third ventriculostomy, pediatric hydrocephalus, postinfectious hydrocephalus, survival, ventriculoperitoneal shunt*

**Rahul Singh,
Ravi Shankar Prasad,
Ramit Chandra Singh,
Adarsh Trivedi[1],
Kulwant Singh Bhaikhel,
Anurag Sahu**

Department of Neurosurgery, Institute of Medical Sciences, Banaras Hindu University, Varanasi, Uttar Pradesh, [1]Department of Neurosurgery, Shri Shankracharya Institute of Medical Sciences, Bhilai, Madhya Pradesh, India

Introduction

Pediatric hydrocephalus (PH) (namely, congenital, prematurity germinal matrix bleed, postinfectious, and neoplastic) when compared to adult patients of hydrocephalus is more complicated and has significantly more developmental and cognitive morbidities. Hydrocephalus may be defined as "an active dilatation of the ventricles resulting from imbalance between cerebrospinal fluid (CSF) production in ventricles and its absorption to systemic circulation."[1]

Hydrocephalus in pediatric population is having high morbidity and mortality. The prevalence of hydrocephalus in pediatric population varies from 30 to 423 per 100,000 pediatric population in various reported studies[2-5] with prevalence been higher in developing nations in comparison to developed world. Congenital hydrocephalus contains heterogenous etiology comprising of primary aqueductal stenosis (PAS), Dandy–Walker malformation (DWM), germinal matrix hemorrhage (GMH) and intrauterine infections leading to gliosis, intraventricular space-occupying lesions, X-linked hydrocephalus and Chiari malformations, neural tube defects, and many other syndromic and genetic disorders.[6,7]

Acquired hydrocephalus in pediatric population is commonly attributed to intracranial infections, intracranial hemorrhage (especially intraventricular hemorrhage [IVH] and subarachnoid bleed), benign and neoplastic lesions.[6]

Computed tomography (CT) and magnetic resonance imaging (MRI) of brain are

the common radiological modalities for evaluating and diagnosing PH [Figure 1]. Measuring ventricle size on MRI or CT is quite helpful in cases of diagnostic dilemma.[8] MRI is superior for evaluating ventricle size, etiological diagnosis, endoscopic third ventriculostomy (ETV) patency, and parenchymal changes. Sensitivity of CT scan when compared to MRI is more for catheter tip localization[9] if it is used as an adjunct with neuronavigation.

Surgical modalities such as ventriculoperitoneal (VP) shunt, ETV, and Ommaya reservoir (in selected cases) depend on surgeon's preference and indications.

In this study, we aim to evaluate clinical, surgical, and outcome perspective of PH patients of age <12 years. This study will hopefully serve the purpose of analyzing hydrocephalus in pediatric population and its effects on pediatric age groups.

Materials and Methods

This retrospective cohort study consisted of 117 pediatric patients (age ≤12 years) of hydrocephalus due to various etiologies admitted in our department between September 1, 2018, and December 30, 2020.

This retrospective cohort study was done in two phases: a cross-sectional phase where the patients included in the sample were evaluated for the following described variables and a follow-up phase at hospital discharge and at subsequent outpatient department (OPD) visits by the patient. Each patient was evaluated in terms of demographic profile, etiology of hydrocephalus, clinical presentation, management, CSF diversion procedures used, complications, and postoperative outcome characteristics. Survival analysis was also done with respect to etiology and age group of PH.

Medical and surgical records submitted in medical record section of our institute were used to collect data of these 117 patients retrospectively. Follow-up data were collected from OPD records.

Cerebrospinal fluid diversion procedure

We used medium pressure VP shunt (Chhabra shunt) either bacterial resistant (silver impregnated) or nonmedicated for VP shunting. Ommaya reservoir was used in few patients of septic meningitis and IVH with HCP which was converted to permanent shunt after resolution of IVH and CSF infection. ETV was done in some patient of PAS, neoplasm, and postinfectious hydrocephalus. Choice of CSF diversion procedure was decided by senior author preferences. All procedures were done under general anesthesia under neuronavigation guidance. CSF collected during the surgery was sent for analysis. Assessment of shunt function was done by history (headache, vomiting, convulsions), neurological examination (vision, motor, and sensory), local examination (inspection and palpation of shunt system and testing of shunt pump for refill), and CT/MRI scans. Shunt complications were managed accordingly.

Statistical analysis

The data were summarized using medians/mean and counts and percentages. Differences of significance were evaluated by unpaired *t*-test and Chi-square test. Kaplan–Meier curve was plotted for survival analysis with respect to age group and etiology of PH. Survival analysis was done using Log-rank (Mantel-Cox) test (MCT), Log-rank test for trends (LTT), and Gehan–Breslow-Wilcoxon test (GBW). Values with $P < 0.05$ were considered statistically significant. GraphPad Prism software was used for statistical analysis.

Results

A total of 117 pediatric patients (age ≤12 years) were admitted during the study period. Out of these patients, 50 patients were female and 67 patients were males and male-to-female ratio was 1.3:1. Number of pediatric patients with age ≤1 year was 23, between 1 and 6 years was 51 and between 6 and 12 years was 43. Most common etiology of PH was postinfectious (35%) (septic –9.4%; tubercular–25.6%) followed by neoplasm (32.5%) and aqueductal stenosis (12.8%) [Table 1]. Among neoplastic etiologies, posterior fossa pilocytic astrocytoma (13, 34.2%) was most common followed in succession by medulloblastoma (11, 28.9%), craniopharyngioma (6, 15.8%), intraventricular tumor (4, 10.5%), and brainstem glioma (4, 10.5%). Out of all patients, 12 patients of neoplasm, 14 patients of posttuberculous meningitis hydrocephalus, and 6 patients of shunt block were operated on emergency basis due to rapid neurological deterioration and features of raised intracranial tension. Emergency VP shunting was done in all of them.

Most common symptoms were general irritability (52.1%) and headache (49.6%) [Table 2]. Most common signs
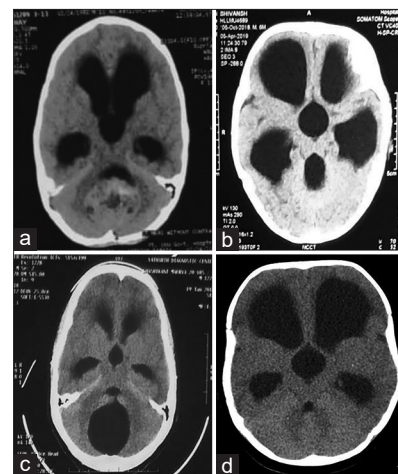
Figure 1: Noncontrast computed tomography scan axial sections of brain of a child showing. (a) Posterior fossa tumor compressing 4th ventricle leading to hydrocephalus; (b) Postinfectious hydrocephalus with dilatation of all ventricles; (c) Dandy–Walker malformation with large posterior fossa cyst communicating with 4th ventricle and hydrocephalus; (d) Primary aqueductal stenosis with dilatation of third and lateral ventricles but normal 4th ventricle

were progressive increase in head circumference (31.6%), bradycardia (27.3%), and hypertension (27.3%) [Table 2 and Figure 2].

Of 117 patients, 114 patients (97.5%) underwent surgical intervention while three patients (2.5%) were managed conservatively (neonates with GMH leading to hydrocephalus). Most common surgical procedure performed for addressing hydrocephalus was VP shunting (n = 103, 90.3%) followed by Omaya reservoir (n = 2, 1.7%) and ETV (n = 8, 7%). Mean duration of follow-up was 7.2 months with range of 1–13 months.

Table 1: Etiology of pediatric (<12 years) hydrocephalus (*n*=117)

Etiology	Number of patients, *n* (%)
Neoplasm	38 (32.5)
Aqueductal stenosis	15 (12.8)
Dandy-Walker malformation	5 (4.3)
Postinfectious	41 (35)
Septic	11 (9.4)
Tubercular	30 (25.6)
Posttraumatic	3 (2.6)
GMH in premature infants	3 (2.6)
Failed shunt	11 (9.4)
Spina bifida with HCP	1 (0.9)

HCP – Hydrocephalus; GMH – Germinal matrix hemorrhage

Table 2: Clinical presentation

Clinical presentation	Number of patients, *n* (%)
Poor feeding	31 (26.5)
Vomiting/nausea	43 (36.7)
General irritability	61 (52.1)
Drowsiness	44 (37.6)
Seizure	27 (23.1)
Impaired eye movements	4 (3.4)
Bradycardia	32 (27.3)
Hypertension	32 (27.3)
Prominent scalp veins	29 (24.8)
Loss of vision	17 (14.5)
Headache	58 (49.6)
Double vision	2 (1.7)
Loss of bladder control	6 (5.1)
Personality changes	3 (2.6)
Loss of memory	13 (11.1)
Progressive increase in head circumference	37 (31.6)
Bulging of the fontanels	26 (22.2)
Neck pain	12 (10.3)
Transient blurring of vision	10 (8.5)
Spastic weakness of lower limbs	6 (5.1)
Failure of upward gaze	31 (26.5)
Sunset sign	31 (26.5)
Cranial nerve VI palsy	2 (1.7)

VI – Abducens nerve

Surgical outcome resulted in uneventful recovery of hydrocephalus in 60.5% patients. Patients with neoplastic etiology were either operated in the same setting (13, 34.2%) or operated in second setting after CSF diversion procedure (25, 65.8%). Most common shunt related complications were shunt obstruction (11.6%) followed by shunt infection (5.8%) and shunt extrusion (4.8%) [Table 3 and Figure 2b-d]. In this PH cohort, disease-specific mortality was 10.5% and shunt-related mortality was 1.7% [Table 3].

Chronic headache (18.8%), loss of vision (14.5%), seizure (11.1%), and cognition deterioration (11.1%) were common clinical morbidities that persisted after CSF diversion procedures or conservative management. Most common psychosocial outcome evident during follow-up was school drop (29%) [Table 3].

On analyzing PH outcome in relation to etiology, mortality was significantly (P = 0.0139) more in patients of neoplastic etiology. Cognitive deficits (P = 0.0151) and delayed developmental milestones (P < 0.0001) were significantly more in congenital hydrocephalus etiology (aqueductal stenosis and DWM). Shunt failure, shunt infection, recovery, neurological deficits, seizure, vision loss, and chronic headache were not significantly associated with etiology of PH [Table 4].

Aqueductal stenosis (P = 0.0445), DWM (P = 0.0022), and GMH (P = 0.0019) as an etiology to PH were significantly more in the age group of ≤1 year [Table 5]. Psychosocial morbidity was significantly (P = 0.0015) more in age groups 1–6 years and 6–12 years [Table 5]. There was no significant difference (P > 0.05) in terms of shunt complications, ETV failure, neurological morbidity, and mortality between the three age groups [Table 5].

Figure 2: (a) A child with progressive hydrocephalus showing increased head size and sunset sign; (b) Shunt migration and per rectal appearance in a child; (c) Distal ventriculoperitoneal shunt catheter extrusion in right hypochondrial region.; (d) Top view of head of an infant with shunt over drainage resulting in sunken fontanel

On comparing type of shunt and its complication, shunt infection was significantly less ($P = 0.0236$) in patients in whom silver-impregnated shunt was used when compared with standard shunt. No significant difference was observed with respect to shunt block, shunt extrusion, shunt disconnection, shunt migration, and shunt over drainage between the two types of shunt used [Table 6].

Table 3: Outcome of pediatric hydrocephalus management

Outcome characteristics	Number of patients, *n* (%)
Surgical outcome (*n*=114)	
Uneventful recovery	69 (60.5)
VP shunting (*n*=103)	
Shunt obstruction	12 (11.6)
Shunt infection	6 (5.8)
Shunt migration	2 (1.9)
Shunt extrusion	5 (4.8)
Shunt kinking	2 (1.9)
Shunt disconnection	1 (1)
Shunt over drainage	2 (1.9)
Subdural hematoma	1 (1)
ETV (*n*=8)	
ETV failure	2 (25)
Total mortality	
Disease specific	12 (10.5)
Shunt related	2 (1.7)
Clinical morbidity (*n*=117)	
Cognition deterioration	13 (11.1)
Motor system	9 (7.7)
Vision	17 (14.5)
Seizure	13 (11.1)
Chronic headache	22 (18.8)
Neuroendocrine problem	3 (2.6)
Psychosocial outcome	
School drop	34 (29)
Social integration impairment	23 (19.6)
Delayed developmental milestones	22 (18.8)

VP – Ventriculoperitoneal; ETV – Endoscopic third ventriculostomy

Age group in relation to mortality was plotted in Kaplan–Meier survival curve [Figure 3a]. There was nonsignificant survival difference between three age groups using MCT ($P = 0.1971$), LTT ($P = 0.0758$), and GBW test ($P = 0.4166$).

Etiology of PH in relation to mortality was plotted in Kaplan–Meier survival curve [Figure 3b]. Significant difference in survival between etiology was seen on using MCT ($P = 0.0098*$), LTT ($P = 0.0035*$), and GBW test ($P = 0.0254$).

Discussion

PH may affect normal brain development proportionate to time and duration of this pathology. HCP results in damage to ependymal layer, white matter ultrastructural changes, changes in cerebral circulation and metabolic activities, gliotic changes in the cortex, and injury to axons.[10,11]

In this study, male children were more commonly affected when compared with females and male-to-female ratio was 1.3:1. Various studies have reported male preponderance in cases of hydrocephalus in pediatric population.[12-15]

Most common causes of PH were postinfective (35%) followed by neoplasm (32.5%) in our study. Worldwide, postinfectious HCP is the most frequent etiology of neonatal and PH.[16,17] However, in developed countries, posthemorrhagic HCP is the most frequent etiology of neonatal HCP.[18]

HCP is present in more than half of pediatric brain tumor cases at diagnosis and as the second most common comorbidity at presentation.[18] We found that posterior fossa pilocytic astrocytoma (34.2%) was the most common neoplastic etiology causing PH followed by medulloblastoma (28.9%). Other causes of PH are ependymomas, choroid plexus tumors, pineal region tumors (also can cause aqueductal compression).[18] According to some authors, ETV is the intervention preferred for posterior fossa tumors with HCP after tumor resection. VP shunting should be done in case

Table 4: Outcome analysis based on etiology

Outcome characteristic	Neoplasm (38)	Aqueductal stenosis (15)	Postinfectious (41)	Posttraumatic (3)	DWM (5)	*P*
Shunt obstruction (12)	2	2	7	1	0	0.3055
Shunt infection (6)	1	0	5	0	0	0.3177
ETV failure (2)	0	1	1	-	-	0.1546
Uneventful recovery (69)	22	13	27	2	5	0.1596
Mortality (14)	11	0	3	0	0	0.0139*
Neurological deficit (9)	7	1	1	0	0	0.1214
Cognitive deficit (13)	3	3	4	0	3	0.0151*
Seizure (13)	9	1	2	1	0	0.0679
Vision loss (17)	11	2	5	0	0	0.1930
Delayed developmental milestones (22)	4	8	7	1	5	<0.0001*
Chronic headache (22)	11	1	8	1	1	0.4707

*Significant (*P*<0.05). DWM – Walker malformation; ETV – Endoscopic third ventriculostomy

Table 5: Age distribution in relation to etiology, management, and outcome

Patients characteristics	≤1 year (23)	1-6 years (51)	6-12 years (43)	*P*
Etiology				
Neoplasm (38)	4	21	15	0.1353
Aqueductal stenosis (15)	6	7	2	0.0445*
DWM (5)	4	1	0	0.0022*
Postinfectious (41)	6	15	20	0.1350
Posttraumatic (3)	0	1	2	0.4894
Germinal matrix				
Hemorrhage (3)	3	0	0	0.0019*
Failed shunt (11)	0	5	4	0.3021
Spina bifida with HCP (1)	0	1	0	0.5207
Management				
Conservative (3)	3	0	0	0.8149
Surgical (114)				
Ventriculoperitoneal				
Shunt (103)	18	45	41	
Ommaya reservoir (2)	0	1	1	
ETV (8)	2	5	1	
Complications				
Shunt obstruction (12)	1	6	5	0.5809
Shunt infection (6)	0	2	4	0.2304
Shunt extrusion (5)	1	3	2	0.9472
Neurological morbidity (9)	2	4	3	0.9679
ETV failure (2)	0	1	1	0.5134
Mortality				
Disease specific (12)	1	4	7	0.2358
Shunt related (2)	0	1	1	0.7725
Psychosocial morbidity (34)	0	16	18	0.0015*

*Significant (*P*<0.05). DWM – Walker malformation; ETV – Endoscopic third ventriculostomy; HCP – Hydrocephalus

Table 6: Shunt complication analysis in relation to type of shunt catheter used

Shunt complications	Silver impregnated shunt (51)	Standard shunt (63)	*P*
Shunt block (12)	5	7	0.8211
Shunt infection (6)	0	6	0.0236*
Shunt extrusion (5)	2	3	0.8275
Shunt disconnection (1)	0	1	0.3662
Shunt migration (2)	1	1	0.8800
Shunt over drainage (2)	1	1	0.8800

*Significant (*P*<0.05)

of ETV failure.[19] However, we prefer to do VP shunting in all posterior fossa tumors with HCP presenting in emergency before tumor resection. We do simultaneous VP shunting in elective surgery of posterior fossa tumor with HCP or ETV for HCP persisting after postfossa tumor resection depending on senior author preference.

In our study, 27.3% of patients underwent emergency VP shunting. Most common etiology implicated in emergency shunting was postinfective (43.75%) followed by neoplastic (37.5%) due to features of raised Intracranial tension (ICT). Various studies have also shown increased rates of emergency VP shunting in postinfective and neoplastic PH.[20]
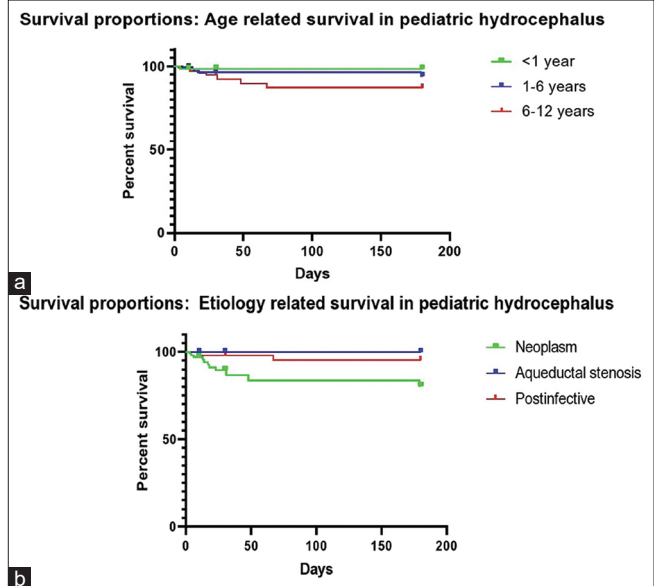
Figure 3: Kaplan–Meier survival curve (a) Age-related survival; (b) Etiology-related survival

More common presentations of PH in our study were irritability, headache, drowsiness, vomiting, and progressive increase in head size. Clinical manifestations depend on the status of cranial sutures and fontanels.

Before their closure, the child mainly presents with progressively increasing head circumference and bulging of the fontanels. After their closure, the chief presentations are related to raise intracranial pressure levels manifesting as headache nausea/vomiting, bradycardia, hypertension, and loss of vision.[21]

In our study, we managed three patients of GMH in premature neonate conservatively which resolved spontaneously. Intraventricular hemorrhage in premature babies results in posthemorrhagic ventricular dilation. Some cases may get self-resolved and may not require any procedural intervention if resolution of IVH occurs without any secondary changes in CSF pathways. Temporary intraventricular reservoirs with intermittent CSF tapping may be used in neonates with progressively increasing HCP and IVH. Rate of conversion to VP shunting depends on the degree of posthemorrhagic PH with about 20% of grade 3 and 40% of grade 4 hemorrhage requiring VP shunting.[22]

Most common surgical intervention used in our study was VP shunting (90.3%) followed by ETV in eight patients and Ommaya reservoir in two patients. VP shunts are the most common CSF diversion devices available. Although it significantly improves the outcome of PH patients, the complication rates with resultant increased mortality or morbidity remain high at present.[10,23,24] ETV is also gaining popularity for PH. Early infancy, postinfectious hydrocephalus, and patients with partial choroid plexus cauterization (CPC) may show less favorable results to endoscopic treatment.[25] When compared with VP shunting, ETV is having higher failure with relative risk being 40% higher than VP shunting at 3-month follow-up.[26] ETV with CPC has shown decreased chance of ultimate VP shunt dependence by 26%.[25]

In our study, post-CSF diversion procedures, majority (60.5%) of patients showed uneventful resolution of hydrocephalus. Etiology of the disease process guided the ultimate outcome in these cases.

Shunt complications range from mechanical problems (namely, shunt blockage, shunt migration, shunt extrusion, and shunt disconnection); flow- related issues (CSF over drainage) resulting in subdural hematoma/hygroma, low-pressure headache, cranial deformity, slit ventricle syndrome, and secondary craniostenosis; abdominal end complications, namely ascites, pseudocyst, hydrocele, and visceral perforations; to shunt infections.[27-30] In our study, most common shunt complication was shunt obstruction (11.6%), followed by shunt infection (5.8%) and shunt extrusion (4.8%). Studies had reported that shunt infection rates vary from 3% to 15%.[31,32] Overall shunt failure rates at 1 month and 1 year are about 13% and 29%, respectively.[25]

In our study, the use of silver-impregnated shunt (BR Chhabra shunt) was having significantly less shunt infection when compared with standard shunts. However, there was no difference in terms of shunt block, shunt extrusion, shunt disconnection, shunt migration, and shunt over drainage between the two types of shunt used. Shunt catheters may be standard, silver impregnated or antibiotic impregnated. Evidence regarding their comparative effectiveness is lacking[33] and choice of shunt catheter depends on economic condition of the patient and surgeons' preferences. However, a meta-analysis had showed results favoring less shunt infection in the antibiotic-impregnated VP shunt group.[34]

In our study, mortality due to primary pathology was 10.5% and mortality due to shunt complications was 1.7%. Studies have shown overall mortality in PH to be 1.22% to 14.6%,[35,36] nonneoplastic mortality to be 8.6% to 13.7%,[37,38] and shunt-related mortality 0%–3.65%.[39,40] Neoplastic etiology, in our study, was significantly having more mortality as compared to others which may correlate with disease-specific mortality.

Congenital hydrocephalus patients showed significantly higher psychosocial deficits, cognitive impairment, and delayed developmental milestones. Psychosocial morbidity was significantly more in age groups 1 to 6 years and 6–12 years in our study. School drop rates (29%) and poor social interaction and integration (19.6%) were significant. Delayed developmental milestones (18.8%) in these hydrocephalus patients may be due to white matter changes in these disorders due to raised intraventricular pressure. School drops/difficulties may be more commonly due to cognitive deficit and also due to repeated hospital admissions. Ultimate outcome of PH is evident by child psychosocial outcome and community integration to lead a normal productive life in society.

On doing survival analysis, we could not find any difference in survival in these patients with respect to age groups. Patients with neoplastic etiology were having significant poor survival when compared to benign and congenital etiologies. This can be obviously attributed to higher disease-specific mortality in neoplastic etiology of PH. Life-long routine controls are required to avoid future possible complications and enhance better rehabilitation of the child. Optimization of neuropsychological support to such a child is an imperative component of the management of PH.

Conclusions

PH results in significant clinical and psychosocial morbidity. Neoplastic etiology having highest mortality rate in PH. Postinfective HCP is the most common cause of PH. Pilocytic astrocytoma and medulloblastoma are most common neoplastic etiology causing PH. Most common shunt complications are shunt obstruction, shunt infection, and shunt extrusion. BR shunts have significantly less shunt infection rates as compared to their nonmedicated shunt. Psychosocial and developmental delays are more common

in congenital hydrocephalus group. Neoplastic etiology PH has poor survival when compared to other etiologies.

Acknowledgment

This study was self-funded.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

References

1. Rekate HL. The definition and classification of hydrocephalus: A personal recommendation to stimulate debate. Cerebrospinal Fluid Res 2008;5:2.
2. Abdullah J, Naing NN. Hydrocephalic children presenting to a Malaysian community-based university hospital over an 8-year period. Pediatr Neurosurg 2001;34:13-9.
3. Al Salloum AA, El Mouzan MI, Al Omar AA, Al Herbish AS, Qurashi MM. The prevalence of neurological disorders in Saudi children: A community-based study. J Child Neurol 2011;26:21-4.
4. Cavalcanti DP, Salomão MA. Incidence of congenital hydrocephalus and the role of the prenatal diagnosis. J Pediatr (Rio J) 2003;79:135-40.
5. Harmat G, Jójárt G, Rubecz I. Coordinated ultrasound screening of infants: Hungary experience. Eur J Ultrasound 2001;12:209-19.
6. Kahle KT, Kulkarni AV, Limbrick DD Jr., Warf BC. Hydrocephalus in children. Lancet 2016;387:788-99.
7. Tully HM, Dobyns WB. Infantile hydrocephalus: A review of epidemiology, classification and causes. Eur J Med Genet 2014;57:359-68.
8. Warf B, Ondoma S, Kulkarni A, Donnelly R, Ampeire M, Akona J, *et al.* Neurocognitive outcome and ventricular volume in children with myelomeningocele treated for hydrocephalus in Uganda. J Neurosurg Pediatr 2009;4:564-70.
9. Krishnan P, Raybaud C, Palasamudram S, Shroff M. Neuroimaging in pediatric hydrocephalus. Indian J Pediatr 2019;86:952-60.
10. Raybaud C. MR assessment of pediatric hydrocephalus: A road map. Childs Nerv Syst 2016;32:19-41.
11. Vinchon M, Rekate H, Kulkarni AV. Pediatric hydrocephalus outcomes: A review. Fluids Barriers CNS 2012;9:18.
12. Kutscher A, Nestler U, Bernhard MK, Merkenschlager A, Thome U, Kiess W, *et al.* Adult long-term health-related quality of life of congenital hydrocephalus patients. J Neurosurg Pediatr 2015;16:621-5.
13. Zahl SM, Wester K. Routine measurement of head circumference as a tool for detecting intracranial expansion in infants: What is the gain? A nationwide survey. Pediatrics 2008;121:e416-20.
14. Wiig US, Zahl SM, Egge A, Helseth E, Wester K. Epidemiology of benign external hydrocephalus in Norway – A population-based study. Pediatr Neurol 2017;73:36-41.
15. Naddawi MN, Hameed NN, Rasheed AA. Demographic and clinical presentations of pediatric hydrocephalus in medical city. Iraqi Acad Sci J 2011;10:139-44.
16. Warf BC, East African Neurosurgical Research Collaboration. Pediatric hydrocephalus in East Africa: Prevalence, causes,

17. treatments, and strategies for the future. World Neurosurg 2010;73:296-300.
17. Wright Z, Larrew TW, Eskandari R. Pediatric hydrocephalus: Current state of diagnosis and treatment. Pediatr Rev 2016;37:478-90.
18. McAllister JP 2nd, Chovan P. Neonatal hydrocephalus. Mechanisms and consequences. Neurosurg Clin N Am 1998;9:73-93.
19. Wong TT, Liang ML, Chen HH, Chang FC. Hydrocephalus with brain tumors in children. Childs Nerv Syst 2011;27:1723-34.
20. Ferras M, McCauley N, Stead T, Ganti L, Desai B. Ventriculoperitoneal shunts in the emergency department: A review. Cureus 2020;12:e6857.
21. Lotfinia I. A review in pediatric hydrocephalus: Physiology, classification, clinical presentation, imaging and treatment. JSM Pediatr Neurol 2017;1:1002.
22. Riva-Cambrin J, Shannon CN, Holubkov R, Whitehead WE, Kulkarni AV, Drake J, *et al.* Center effect and other factors influencing temporization and shunting of cerebrospinal fluid in preterm infants with intraventricular hemorrhage. J Neurosurg Pediatr 2012;9:473-81.
23. Stone JJ, Walker CT, Jacobson M, Phillips V, Silberstein HJ. Revision rate of pediatric ventriculoperitoneal shunts after 15 years. J Neurosurg Pediatr 2013;11:15-9.
24. Hanak BW, Bonow RH, Harris CA, Browd SR. Cerebrospinal fluid shunting complications in children. Pediatr Neurosurg 2017;52:381-400.
25. Dewan MC, Naftel RP. The global rise of endoscopic third ventriculostomy with choroid plexus cauterization in pediatric hydrocephalus. Pediatr Neurosurg 2017;52:401-8.
26. Pan IW, Harris DA, Luerssen TG, Lam SK. Comparative effectiveness of surgical treatments for pediatric hydrocephalus. Neurosurgery 2018;83:480-7.
27. Sridhar K, Karmarkar V. Peroral extrusion of ventriculoperitoneal shunt: Case report and review of literature. Neurol India 2009;57:334-6.
28. Vuyyuru S, Ravuri SR, Tandra VR, Panigrahi MK. Anal extrusion of a ventriculo peritoneal shunt tube: Endoscopic removal. J Pediatr Neurosci 2009;4:124-6.
29. Bhatnagar V, George J, Mitra DK, Upadhyaya P. Complications of cerebrospinal fluid shunts. Indian J Pediatr 1983;50:133-8.
30. Kumar R, Singh V, Kumar MV. Shunt revision in hydrocephalus. Indian J Pediatr 2005;72:843-7.
31. Kestle JR, Riva-Cambrin J, Wellons JC 3rd, Kulkarni AV, Whitehead WE, Walker ML, *et al*. A standardized protocol to reduce cerebrospinal fluid shunt infection: The Hydrocephalus Clinical Research Network Quality Improvement Initiative. J Neurosurg Pediatr 2011;8:22-9.
32. McGirt MJ, Leveque JC, Wellons JC 3rd, Villavicencio AT, Hopkins JS, Fuchs HE, *et al.* Cerebrospinal fluid shunt survival and etiology of failures: A seven-year institutional experience. Pediatr Neurosurg 2002;36:248-55.
33. Jenkinson MD, Gamble C, Hartley JC, Hickey H, Hughes D, Blundell M, *et al.* The British antibiotic and silver-impregnated catheters for ventriculoperitoneal shunts multi-centre randomised controlled trial (the BASICS trial): Study protocol. Trials 2014;15:4.
34. Thomas R, Lee S, Patole S, Rao S. Antibiotic-impregnated catheters for the prevention of CSF shunt infections: A systematic review and meta-analysis. Br J Neurosurg 2012;26:175-84.
35. Kao CL, Yang TF, Wong TT, Cheng LY, Huang SY, Chen HS, *et al.* The outcome of shunted hydrocephalic children. Zhonghua Yi Xue Za Zhi (Taipei) 2001;64:47-53.

36. Heinsbergen I, Rotteveel J, Roeleveld N, Grotenhuis A. Outcome in shunted hydrocephalic children. Eur J Paediatr Neurol 2002;6:99-107.

37. Tuli S, Tuli J, Drake J, Spears J. Predictors of death in pediatric patients requiring cerebrospinal fluid shunts. J Neurosurg 2004;100:442-6.

38. Lumenta CB, Skotarczak U. Long-term follow-up in 233 patients with congenital hydrocephalus. Childs Nerv Syst 1995;11:173-5.

39. Kokkonen J, Serlo W, Saukkonen AL, Juolasmaa A. Long-term prognosis for children with shunted hydrocephalus. Childs Nerv Syst 1994;10:384-7.

40. Heinsbergen I, Rotteveel J, Roeleveld N, Grotenhuis A. Outcome in shunted hydrocephalic children. Eur J Paediatr Neurol 2002;6:99-107.