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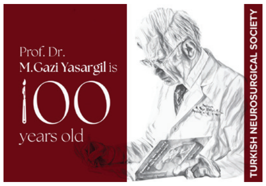

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Original Investigation

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Endoscopic Third Ventriculostomy plus Valveless Catheter in the Treatment of Low-Pressure Hydrocephalus

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ABSTRACT

AIM: To evaluate the outcomes in low-pressure hydrocephalus (LPH) following an endoscopic third ventriculostomy, and placement of a valveless ventriculoperitoneal or ventriculoatrial shunt catheter.

MATERIAL and METHODS: This novel surgical technique was assessed in a prospective case series at a single center between December 2020 and December 2022. Patients were selected for the hybrid procedure based on the Pang–Altschuler diagnostic criteria for LPH. Those with normal or high-pressure hydrocephalus or less than six months of follow-up were excluded. All patients were evaluated clinically (Karnofsky performance status [KPS]) and radiologically (standardized set of images) in the preoperative and postoperative period, and their outcome was categorized as excellent, temporary improvement, or poor.

RESULTS: This case series comprised 16 patients. The mean postoperative improvement in KPS was 56 points. All patients showed improved KPS. All follow-up scans showed radiological improvement. System dysfunction and the need for a shunt with a valve were detected in 18.75% of cases (n=3). The outcome was excellent in 81.25% of cases (n=13), and temporary improvement in 18.75% (n=3).

CONCLUSION: The presented series demonstrated that the hybrid procedure effectively treats LPH and has minimal number of complications.

KEYWORDS: Endoscopic, Hydrocephalus, Shunt, Low-pressure hydrocephalus, Valveless

ABBREVIATIONS: CSF: Cerebrospinal fluid, **CT:** Computed tomography, **ETV:** Endoscopic third ventriculostomy, **EVD:** External ventricular drainage, **KPS:** Karnofsky performance status, **LPH:** Low-pressure hydrocephalus, **MRI:** Magnetic resonance imaging, **STROBE:** Strengthening the reporting of observational studies in epidemiology, **VAS:** Ventriculoatrial shunt, **VPS:** Ventriculoperitoneal shunt.

INTRODUCTION

Over the past century, numerous techniques for diverting cerebrospinal fluid (CSF) have emerged, effectively addressing most hydrocephalus cases. However, managing complex hydrocephalus, such as low-pressure hydrocephalus (LPH), remains challenging (11).

A robust management protocol for LPH based on a systematic literature review has recently been published (11). Our

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team endeavored to implement this protocol in a peripheral hospital setting within a developing country. However, we encountered several difficulties during its execution, primarily because these protocols are typically developed in first-world countries with superior technological and human resources, which are scarce in our setting. While we have access to ventriculoperitoneal shunts (VPS), they are typically of the fixed-pressure type. Adjustable or ultra-low-pressure shunts may sometimes experience delays in availability due to logistical constraints.

Given these challenges, the authors have devised a simplified alternative surgical technique to treat LPH that is feasible in resource-limited settings: performing an endoscopic third ventriculostomy (ETV) and placing a valveless VPS or ventriculoatrial shunt (VAS). This study aimed to evaluate the outcomes achieved with this new technique in treating adult patients with LPH at a single center.

MATERIAL and METHODS

Study Design

A prospective case series of the new surgical technique was conducted from December 2020 to December 2022. All surgeries were performed by the same surgeon (JFV) at a single center. The study protocol was approved by the Ethics Committee of the institution at which the surgeries were performed. At the November 2020 meeting of the LINT Ethics Committee, the prospective study “Endoscopic Third Ventriculostomy plus Valveless Catheter in the Treatment of Low-Pressure Hydrocephalus” was authorized. Protocol version 1.0., and it was granted as number 18-2020. Informed consent was obtained from all patients to use their medical records and neuroimages in this study. This study adhered to the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines.

LPH Diagnosis

Patients were selected for the hybrid procedure based on the diagnostic criteria for LPH, following the guidelines of Pang–Altschuler, which include (i) the presence of previous shunts or drains, (ii) ventriculomegaly despite low or normal pressures, (iii) clinical and radiologic response to drainage at negative pressures, and (iv) exclusion of other causes, such as system dysfunction (13). The LPH phenotype was also considered, considering the following three factors: (i) Patient history, such as a posterior fossa tumor, meningitis or other central nervous system infection, intraventricular/subarachnoid hemorrhage, radiotherapy, or previous history of shunt dysfunction. (ii) Clinic-radiological correlation: An incongruence between a minimal level of dilatation and a florid clinical of endocranial hypertension was considered, as well as in cases with considerable ventriculomegaly but negative intracranial pressure. (iii) CSF manometry, which was performed in two ways: after placing external ventricular drainage (EVD) and finding that it only drains sub-zero or negative (n=9) and after a lumbar puncture with values ≤5 cmH_2O or even subatmospheric (n=7).

Patients and Setting

Patients with normal or high-pressure hydrocephalus or less than six months of follow-up were excluded. The collected data was recorded in a coded Excel spreadsheet (version 15.13.3; Microsoft, Redmond, WA, USA) and included age, sex, underlying pathology, hydrocephalus type (if applicable), preoperative requirement for EVD or internal CSF shunt system, surgical time, postoperative Karnofsky Performance Status (KPS), postoperative requirement for an internal CSF shunt, and complications.

A rigid endoscope model (model: LOTTA; Karl Storz, Tuttlingen, Germany) with 30° optics connected to an advanced imaging modalities high-definition endoscopy camera (model: 1588; Stryker, Portage, MI, USA) was used for all cases. The surgical procedures were recorded using a video capture device (model: EzRecorder 130; AVerMedia, New Taipei City, Taiwan).

Follow-up and Clinical Outcome

A standardized set of images was obtained for all cases preoperatively and postoperatively, including brain magnetic resonance imaging (MRI) with gadolinium in sagittal T2 and T2-weighted planes and standard brain computed tomography (CT) with reconstruction in three planes. These imaging studies were performed preoperatively, on the first day postoperative, and then at 30 and 90 days and 6 and 12 months postoperative, if applicable. The minimum follow-up period was six months.

Clinical outcomes were evaluated by categorizing patients according to their KPS in the preoperative and postoperative periods. Radiological outcomes were assessed by comparing the preoperative and postoperative images. In cases with hydrocephalus, the ventricular system, including the lateral ventricles, third ventricle, temporal horns, and fourth ventricle, was measured.

The patients were categorized into three groups based on their clinical-radiological outcomes: (i) Excellent: Patients with improved KPS and postoperative MRI and not requiring further surgery. (ii) Temporary improvement: Patients with improved KPS and postoperative MRI but requiring further shunt surgery after the hybrid procedure. (iii) Poor: Patients with stable or worse KPS, no changes on postoperative MRI, and requiring further shunt surgery after the hybrid procedure.

Blinding and Bias Avoidance

The neurosurgeon who recorded patients’ preoperative and postoperative KPS did not participate in the surgeries. The neuroradiologist who measured the dimensions of the ventricles was blinded to the clinical outcomes.

Surgical Technique

The developed surgical technique involves performing an ETV and placing a valveless VPS or VAS catheter during the same surgical procedure (i.e., hybrid procedure: ETV plus VPS/VAS without a valve). A custom-made catheter, fabricated using a 7 French outer diameter methyl polyurethane probe measuring 120 cm in length, was used in all cases. The length and fenestration of the catheter were adapted according to the requirements of each case based on MRI measurements: the length of the intraventricular segment of the catheter was calculated, and the fenestrae were made to correspond to 60% of this segment. Our routine approach was to opt for a VPS. When a VPS was contraindicated, we used a VAS.

Background of the Technique

The hybrid technique emerged by combining the fundamental principles of previous techniques, including ETV (2,8,10,17,19), valveless catheter (1,15,16), custom-made catheter (9), VPS (18), VAS (14), and ventriculovenous shunt (3-7).

Statistical Analysis

The patients' demographic and clinical characteristics are summarized using descriptive statistics. Categorical variables are expressed as frequencies and percentages, while continuous variables are presented as means with standard deviations or medians with interquartile ranges, depending on their distribution. The clinical and radiological outcomes were analyzed separately. Clinical outcomes were assessed based on the preoperative to postoperative changes in KPS. Radiological outcomes were evaluated by comparing preoperative and postoperative neuroimaging studies. Complications are reported as frequencies and percentages. The data were analyzed using SPSS (version 25; IBM Corp., Armonk, NY, USA).

RESULTS

This case series comprised 16 patients with a mean age of ±39.1 years, and nine were female. The patients' demographic characteristics, pathology type, previous shunt, and diagnostic criteria are presented in Tables I to IV. The clinical-radiological postoperative results of the hybrid procedure are presented in Table V.

The mean KPS score was 29 points preoperatively and 85 points postoperatively, with a mean improvement of 56 points. All cases showed an improvement in KPS. All follow-up scans showed radiological improvement. System dysfunction and the need for another surgery were detected in 18.75% of the cases (n=3).

The outcome was categorized as excellent in 81.25% of cases (n=13) and temporary improvement in 18.75% (n=3). Among the cases with a temporary improvement outcome, one (Case 3) experienced a reactivation of histoplasmosis with cardiac seeding through the atrial catheter. Another (Case 7) developed pneumonia and required orotracheal intubation,

Table I: Clinical Profile of Patients Before LPH

Case#	Sex / age	Primary diagnosis	Other Clinical Characteristics	Cause of Infection	Intrathecal Antibiotic	Type of Hydrocephalus
1	M/37	Exofitic brainstem glioma	CSF fistulae. Meningitis	GNB	linezolid	Infectious
2	F/65	Temporal high-grade glioma	Radiotherapy	(-)	(-)	Oncological
3	F/32	Aqueductal stenosis	Undiagnosis brain histoplasmosis	Histoplasm	(-)	Infectious
4	M/23	Prepontine cystic chondroma	4 previous surgeries of post fossa	(-)	(-)	Oncological
5	F/33	Slit ventricle	Supraselar arachnoid cyst	MRSA		Infectious
6	M/20	Pineal giant germinoma	Radiotherapy	(-)	(-)	Oncological
7	M/25	Severe traumatic brain injury	Post TBI hydrocephalus	MRSA	Vancomycin	Infectious
8	F/35	Shunt disfunction	Slit ventricle	GNB	(-)	Infectious
9	M/37	Shunt disfunction	Multiple shunt surgery (7)	MRSA	(-)	Infectious
10	M/56	Intraventricular ependymoma	Preoperative tumor bleeding	(-)	(-)	Hemorrhagic
11	F/17	Intraventricular SEGA	Anormal compliance	(-)	(-)	Oncological
12	M/21	Exofitic brainstem glioma	Hemorrhagic stroke	(-)	(-)	Hemorrhagic
13	F/62	Shunt disfunction	Brain metastasis from breast cancer. Radiotherapy and chemotherapy	(-)	(-)	Oncological
14	F/43	Pyoventriculitis	Intraventricular glioma surgery	GNB	(-)	Infectious
15	F/53	Insular glioma	Radiotherapy	(-)	(-)	Oncological
16	F/66	Atrial epidermoid tumor	Tumoral ventriculitis	(-)	(-)	Oncological

F: *Female,* ***M:*** *Male,* ***GNB:*** *Gram negative bacillus,* ***MRSA:*** *Methicillin resistant staphylococcus aureus.*

Table II: Previous Shunt and/or External Ventricular Drainage

Case#	Previous shunt	Previous shunt revisions	Duration of Stable shunted period [months]	Previous EVD
1	No	(-)	(-)	Yes
2	No	(-)	(-)	No
3	Yes	3	8	Yes
4	No	(-)	(-)	No
5	Yes	1	63	Yes
6	No	(-)	(-)	Yes
7	Yes	2	1	Yes
8	Yes	(-)	43	Yes
9	Yes	7	2	Yes
10	No	(-)	(-)	Yes
11	Yes	(-)	3	No
12	No	(-)	(-)	No
13	Yes	3	20	No
14	No	(-)	(-)	Yes
15	No	(-)	(-)	No
16	No	(-)	(-)	No

EVD: *External ventricular drainage.*

Table III: Diagnosis Method of Low-Pressure Hydrocephalus

Case	EVD Sub-atmospheric CSF drainage*	Lumbar puncture manometry
1	+	-
2	-	+
3	+	-
4	-	+
5	+	-
6	+	-
7	+	-
8	+	-
9	+	-
10	+	-
11	-	+
12	-	+
13	-	+
14	+	-
15	-	+
16	-	+

CSF: *cerebrospinal fluid.* ***** *Need to use sub-zero (i.e. negative) pressure to drain CSF with EVD.* ***EVD:*** *External ventricular drainage.*

Table IV: Signs and Symptoms of Low-Pressure Hydrocephalus Presentation

Case	Haedache	Nausea / Vomiting	Lethargy	Impaired upgaze	Gait Apraxia	Hypertonicity	Opisthotonus	Consciousness deficit
1	+	+	+	+	-	-	-	+
2	+	+	-	-	+	-	-	+
3	-	+	+	+	+	+	-	+
4	+	+	+	+	+	+	-	-
5	+	+	-	+	+	+	+	+
6	+	+	-	-	-	+	-	+
7	-	-	+	+	+	+	+	-
8	-	-	-	-	-	+	+	+
9	-	+	+	+	+	-	-	+
10	+	+	+	-	-	-	-	-
11	+	+	-	-	-	-	-	-
12	-	-	+	+	+	+	-	+
13	+	+	+	-	+	-	-	+
14	-	-	+	+	-	-	-	+
15	-	-	+	-	-	-	-	-
16	+	+	+	-	-	-	-	+

+ *Presented the symptom.*

Table V: Postoperative ETV Plus Valveless Catheter Hybrid Procedure Results

Case#	Hybrid procedure type	Preoperative KPS	Postoperative KPS	Improvement in postoperative imaging	Postoperative valve requirement	Results
1	Peritoneal	20	100	Yes	No	Excellent
2	Atrial	20	50	Yes	No	Excellent
3	Atrial	20	100	Yes	Yes	Temporary improvement
4	Peritoneal	20	90	Yes	No	Excellent
5	Atrial	50	90	Yes	No	Excellent
6	Atrial	10	90	Yes	No	Excellent
7	Atrial	10	90	Yes	Yes	Temporary improvement
8	Atrial	50	90	Yes	No	Excellent
9	Atrial	10	100	Yes	No	Excellent
10	Peritoneal	20	60	Yes	No	Excellent
11	Peritoneal	50	100	Yes	Yes	Temporary improvement
12	Peritoneal	10	50	Yes	No	Excellent
13	Peritoneal	40	80	Yes	No	Excellent
14	Peritoneal	20	70	Yes	No	Excellent
15	Peritoneal	70	100	Yes	No	Excellent
16	Peritoneal	50	100	Yes	No	Excellent

***KPS:** Karnofsky performance status.*

which led to increased pressure in the right atrium and subsequent mechanical dysfunction of the system. The final case (Case 11) was complicated by a mechanical dysfunction due to a blood clot in the proximal segment of the catheter and required shunt revision. Two illustrative cases from this series are shown in Figures 1 and 2.

DISCUSSION

Previous Concepts on LPH

LPH is a rare subtype of hydrocephalus that affects patients of all ages and with different underlying diagnoses. Its exact incidence is unknown, and various teams have proposed management strategies (11).

LPH is a contradiction in itself. Patients present with clinical symptoms resembling high-pressure hydrocephalus, but manometry reveals low or negative pressures. Therefore, it is often underreported, and when diagnosed, its management is challenging. Currently, there is no unified protocol for LPH. By referencing Pang and Altschuler's criteria for diagnosing LPH, we emphasized the unique pathophysiology that differentiates it from other forms of hydrocephalus. This foundational understanding underscores the need for tailored treatment strategies.

A Bias in Managing Complex Hydrocephalus

Hydrocephalus is such an eclectic pathology that attempts to simplify its treatment are rarely effective. Factors such as the patient's type of hydrocephalus, age, underlying pathology, and history of previous surgeries are usually considered when choosing the best treatment option. The authors believe these variables should be supplemented with the socioeconomic characteristics of the population and the healthcare center where follow-up is performed, which are often underestimated in published international studies.

Patients with complex hydrocephalus have often undergone multiple previous surgeries, and in some cases, the peritoneum loses its absorptive capacity. This issue is evident in our series, where 7 of the 16 patients required an atrial shunt for this reason. A Canadian team systematically reviewed the literature on LPH and proposed a management protocol based on their findings (11). It provides a stepwise framework involving diagnosis, stabilization, and treatment, which we referenced and adapted to resource-limited settings. We detail its applicability in this study below.

Standard Treatment Versus the Hybrid Procedure

While there is currently no standardized treatment for LPH, we could consider the Canadian protocol the current "standard" (11). The "standard" treatment comprises three stages:

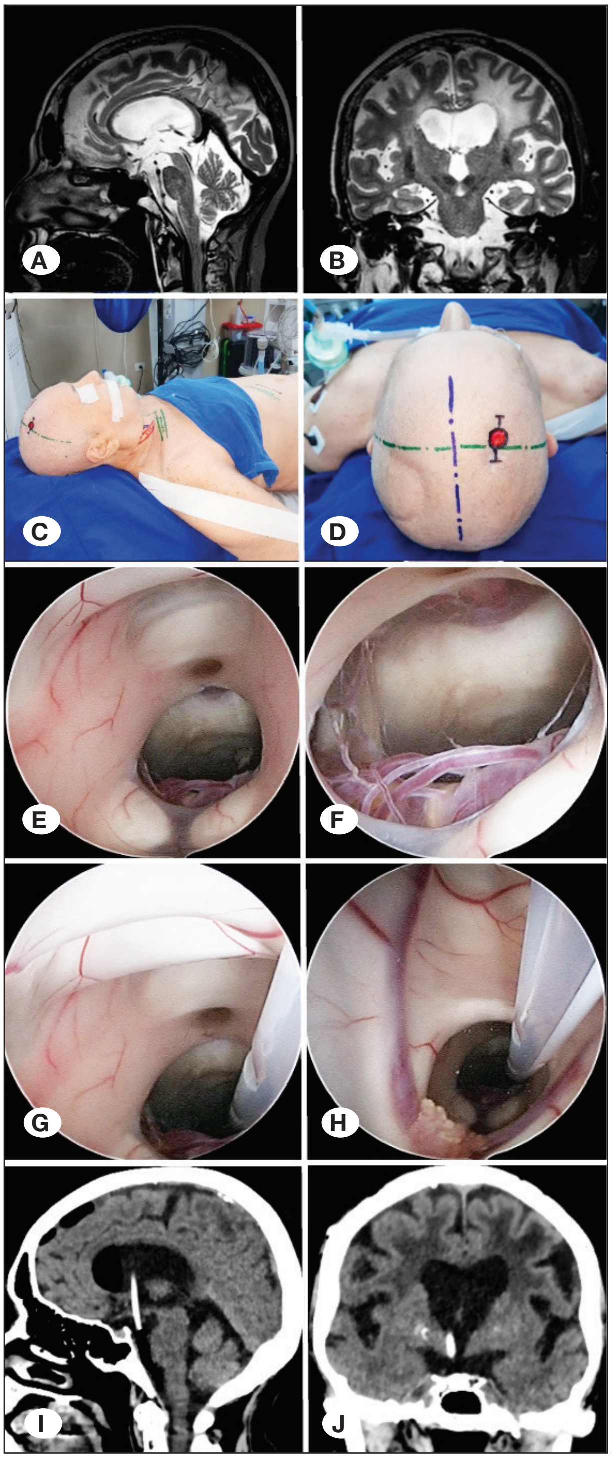

Figure 1: Case N°13. ETV with a ventriculoperitoneal valveless catheter. A, B) Preoperative T2-MRI neuroimaging study. **C, D)** Position and skin marking. **E-H:** Intraoperative intraventricular endoscopic procedure. After the ETV was completed, a valveless ventriculoperitoneal catheter was inserted under direct endoscopic vision. **I, J)** Postoperative CT scan. The radiological images illustrate the position of the catheter. Subtle radiological differences in the ventricular system are highlighted to correlate with clinical improvement.

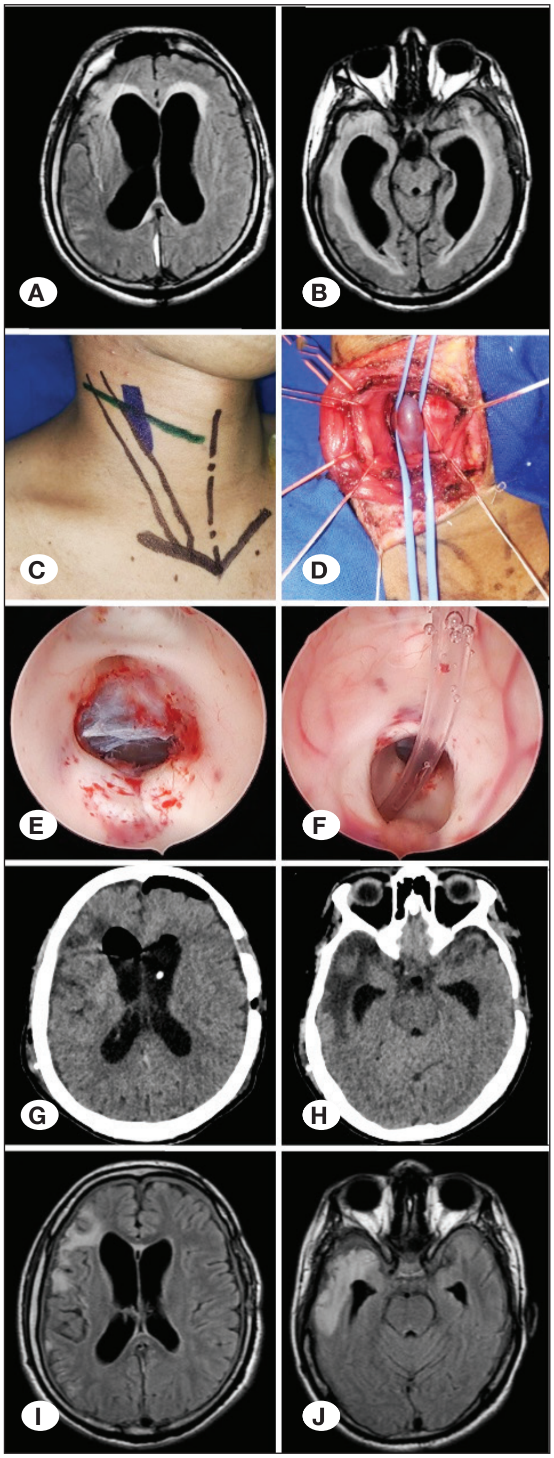

Figure 2: Case N°7. ETV with a ventriculoatrial valveless catheter. **A, B)** Preoperative MRI study. **C, D)** Internal jugular vein dissection. **E, F)** Intraoperative intraventricular endoscopic procedure. After the ETV was finished, a valveless ventriculoatrial catheter was inserted under direct endoscopic vision. **G, H)** Early postoperative CT scan. **I, J)** Postoperative MRI study at the six-month follow-up. The different protocols used for MRI acquisition are noted. The images highlight postoperative changes in the temporal horns of the lateral ventricles, which correlate with improved clinical outcomes.

diagnosis, stabilization of LPH, and definitive treatment. In all cases, it involves placing and manipulating EVD. Then, depending on the characteristics of the case, the drainage pressure with EVD, ETV, or a shunt with a valve is varied. Its advantage is that it allows a relatively accurate diagnosis of the pathology. Its disadvantages are: (i) Inadequate handling of the EVD catheter is associated with infections caused by in-hospital germs. (ii) The patient undergoes more than one surgery. (iii) It requires a team of specialists in hydrocephalus. (iv) Its usefulness has been proven in acute LPH but not chronic LPH.

The hybrid technique developed by the authors is presented as a new alternative. Its advantages are: (i) It avoids the need to place or remove an EVD. (ii) The patient undergoes a single surgery. (iii) The patient's postoperative management does not require specialized hydrocephalus equipment. (iv) It is useful in all cases of LPH. Its disadvantage is a possible small patient selection bias when the diagnosis is made through lumbar puncture. However, when the history of the LPH phenotype is considered, the bias is negligible. The hybrid procedure has significant benefits, particularly in resource-limited settings, by eliminating the need for multiple surgeries and complex EVD manipulations.

In this context, the hybrid procedure represents an alternative for centers where multiple surgeries can significantly increase the risk of complications, especially infections. While the "standard" treatment (Canadian protocol) is coherent (11), its implementation is feasible in institutions with specialized resources but very challenging in most hospitals in developing countries.

The Rationale for the Hybrid Technique

While no single theory currently clearly explains LPH, two pathophysiological mechanisms partly explain this particular nosological species: (i) There is a blockage to the free circulation of CSF between the ventricular system and the subarachnoid space, or (ii) the brain tissue is stiffer after the inflammatory process, which affects ventricular compliance, leading the ventricles develop a poor tolerance to dilatation. Therefore, the authors proposed a surgical treatment to address these two pathophysiological mechanisms in a single hybrid technique. ETV creates a new communication between the ventricles and the subarachnoid space. However, as is well known, ETV for non-resorptive hydrocephalus is a suboptimal solution in many cases and does not resolve the problem of poor compliance. This issue is instead addressed by placing a valve-free shunt that allows continuous CSF drainage, thus reducing ventricular size. ETV and valveless shunting act synergistically. ETV facilitates the redistribution of CSF to a compliant compartment, while the valveless shunt ensures continuous drainage, addressing both pathophysiological mechanisms simultaneously.

Is There Reflux in a Valveless System?

Our team preferentially places the distal end of the catheter in the peritoneum. However, patients with LPH often have contraindications for peritoneal shunt placement (e.g., multiple previous shunts or multiple abdominal surgeries). In such cases, the distal end of the catheter is placed in the right atrium or jugular vein.

Traditionally, it was believed that placing a valveless catheter in the atrium, where the intracardiac pressure is higher than the ventricular pressure, would create reflux through the catheter into the ventricular system, leading a clot to form that would cause shunt dysfunction. Moreover, the negative or very low intraventricular pressure of these patients could be considered a predisposing factor for reverse flow.

However, two facts challenge this theory. Firstly, during ETV, the CSF flow from the cisterns to the ventricular system may counteract the low pressure, meaning hydrocephalus undergoes a metamorphosis from "low or negative pressure" to "not-so-low pressure." Secondly, a physical phenomenon postulated by Liebau can explain why fluids should circulate toward the right atrium and not in the opposite direction (12).

Do the ETV and Shunt Compete?

Given the classic CSF circulation scheme, performing ETV and placing a shunt is contradictory. Logic would suggest that when the shunt works, the ostomy in the floor of the III ventricle will be disused and thus be closed, as in the context of intraventricular CSF hypertension. The authors believe the ostomy will not be obturated in the short term, as there will be a flow from the cistern into the ventricular system. However, the pressure in the ventricles is low in LPH. This positivization of intraventricular pressure will thus help CSF drainage through the catheter. In this case, the ETV and shunt will not compete; they will instead act synergistically.

Significant Improvement in KPS: Multifactorial Considerations

The substantial improvement in KPS observed in our case series, with a mean increase of 56 points, is notable. However, it is important to recognize that this improvement may not solely reflect the efficacy of the hybrid surgical technique. Many of the included cases had significant comorbid conditions (e.g., infections, prior surgeries, or other intracranial pathologies) that were actively treated or resolved during this study. Therefore, the improvement in KPS could be attributed, at least partly, to the natural course or successful management of these comorbidities rather than the surgical intervention alone.

This multifactorial nature of KPS improvement introduces a potential bias in interpreting the outcomes. While the hybrid surgical intervention likely played a key role, the contribution of other factors cannot be excluded. To address this limitation, future studies with larger sample sizes and better controlling confounding variables, such as the resolution of prior conditions or concurrent treatments, are needed to delineate the specific impact of the hybrid surgical technique on functional outcomes.

Limitations

This study had limitations that warrant consideration. Firstly, its small sample size limits the generalizability of its findings and the ability to perform robust statistical analyses. Secondly, the use of separate measurement methods, including EVD and lumbar puncture, may introduce variability in intracranial pressure readings, particularly in patients with compartmentalized CSF dynamics. Thirdly, the lack of a control group receiving valveless shunting without ETV prevents direct comparison and further understanding of the individual contributions of each technique to the observed outcomes. Fourthly, the patients were not systematically studied with CSF flow imaging in preoperative and postoperative MRI, which could provide deeper insights into the physiological effects of the hybrid procedure. Future studies with larger cohorts, standardized diagnostic protocols, and control groups are needed to confirm and extend our findings, such as evaluating each specific pathological subtype.

CONCLUSION

The developed hybrid surgical technique based on ETV with a valveless catheter efficiently treated our series of cases with LPH. Therefore, it could be considered for treating this complex pathology at institutions in developing countries.

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Declarations

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Availability of data and materials: The datasets generated and/or analyzed during the current study are available from the corresponding author by reasonable request.

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Consent for Publication: All patients voluntarily consented to the publication of the research results and photographic material.

AUTHORSHIP CONTRIBUTION

Study conception and design: JFV
Data collection: AS
Analysis and interpretation of results: JIP, JFV
Draft manuscript preparation: JIP, MGA
Critical revision of the article: SD
Other (study supervision, fundings, materials, etc...): ALC, LMC, GC, AC, JFV
All authors (JFV, AS, JIP, ALC, MGA, SD, AC, LMC, GC) reviewed the results and approved the final version of the manuscript.

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