*Original Article*

# Endoscopic treatment of complex multiloculated hydrocephalus in children, steps that may help to decrease revision rate

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## ABSTRACT

**Background:** Multiloculated hydrocephalus (MLH) is associated with increased intracranial pressure, with intraventricular septations, loculations, and isolation of parts of the ventricular system. Search continues for ideal surgical remedy capable of addressing the dimensions of the problem. We aimed to evaluate endoscopic septal fenestration and pellucidotomy combined with proximal shunt tube refashioning and further advancement into isolated loculations of the ventricular system containing choroid plexus.

**Methods:** This retrospective study was conducted on 55 patients with symptomatic complex MLH who underwent endoscopic surgery. The collected data included patients' age, gender, presenting manifestations, operative details, rate of remission of preoperative clinical and imaging signs, postoperative complications, redo surgery, or extra shunt hardware insertion. Patients were divided into Group A (underwent the standard technique of endoscopic multiseptal wide fenestration and final ventriculoperitoneal shunt insertion) and Group B (modified technique by adding extra side ports along the proximal shunt hardware).

**Results:** Groups A and B included 25 and 30 patients, respectively. The percentage of patients showing improvement of almost all manifestations was higher in Group B compared to Group A, with no significant difference ($P > 0.05$). Group B had lower rate of complications (20% vs. 36%, $P = 0.231$), insertion of two shunts (16.7% vs. 20%, $P = 1.000$), and redo surgery (20% vs. 44%, $P = 0.097$).

**Conclusion:** The modified technique was associated with better outcomes in terms of the use of single shunt and redo surgery. Launching randomized clinical trials to compare the two techniques are recommended to ascertain the efficacy of the modified technique.

**Keywords:** Multiloculated hydrocephalus, Neuroendoscopy, Reoperation, Ventriculostomy

## INTRODUCTION

Complex multiloculated hydrocephalus (MLH) is a clinical nonuniform ventriculomegaly associated with increased intracranial pressure mostly preceded by meningitis, ventriculitis, shunt infection, or intraventricular hemorrhage. This results in intraventricular septations, loculations, and isolation of parts of the ventricular system. Most neurosurgeons seek ideal surgical remedy capable of addressing the dimensions of problems. The surgical goals are normalization of the intracranial pressure using the least set of shunt hardware and minimization of redo and/or revision surgeries.[2-5,10,15,16]

Both microsurgical and endoscopic septal fenestration techniques have been described to serve the aforementioned surgical goals.[1,8,18,27,29,30] They can communicate the cysts to be eventually drained by a single shunt catheter. Little published data exist that assess both surgical approaches in details.[1,30] Endoscopic fenestration tends to lower the operative time and postoperative morbidity rate compared to complex shunting procedures.[22] Microsurgical fenestration helps creating larger holes across loculi to communicate the ventricular system, claiming better success though there is no statistical proof. Proponents of the endoscopic maneuver assert unproven lower complication rates from the surgery compared to microsurgical fenestration while achieving the same purpose.[18]

The present study was conducted to evaluate the surgeons' proposed effect of endoscopic septal fenestration and pellucidotomy combined with proximal shunt tube refashioning by adding extra side ports all around and further advancement into isolated loculations of the ventricular system containing choroid plexus. Further evaluation of clinical remission rate, keeping patient on single proximal shunt tube and the rate of revision and/or redo were also parts of the core of the study.

## MATERIALS AND METHODS

### Study design, settings, and ethical considerations

This retrospective cohort study was conducted on 55 patients presenting with symptomatic complex MLH and operated through pure endoscopic approach during October 1, 2017, through January 31, 2021. Ethical approval was obtained from the Institutional Review Board, Faculty of Medicine, Tanta University. Confidentiality of the patients' data was maintained by assigning code numbers to patients that were known only by the researchers.

### Eligibility criteria

The present study included patients with symptomatic complex MLH for whom endoscopic septal fenestration (including pellucidotomy) was performed with ventriculoperitoneal shunt inserted. The indication for surgery was based on clinical signs of increased intracranial pressure. Both computerized tomography and magnetic resonance imaging (1.5 Tesla) of the brain were performed for all patients.

### Data collection

The patients' data were thoroughly reviewed. The collected data included the patient's age, gender, and presenting manifestations including head enlargement, dilated scalp veins, tense fontanel, delayed milestones, vomiting,

papilledema, disturbed consciousness, weakness, and seizures. In addition, we recorded the postoperative details including the rate of remission of both preoperative clinical and imaging signs and complications. Any redo surgery or extra shunt hardware insertion was collected per case. Data of follow-up at 1, 6, and 12 months postoperatively were collected as regard any symptomatic recurrence.

### Surgical technique

In the current study, patients were divided into two groups based on chronological order of the surgery. Group A was operated upon using the standard technique of endoscopic multiseptal wide fenestration and final ventriculoperitoneal shunt insertion without proximal shunt tube modification (factory default), while we used all modifications in Group B.

All patients were operated on using the little Lotta® or Gaab® endoscopic system (Karl Storz Company, Tuttlingen, Germany) under general anesthesia with local lidocaine infiltration. Choice of the point of endoscope entry was dictated by preoperative imaging and best path of endoscope shaft gaining access to most loculi. The length of the proximal catheter was calculated based on the patient's preoperative image [Figure 1a-c]. Both image-guided [Figure 1d-f] and freehand endoscope insertion were used. Once the ventricular cavity was reached, the ependymal wall was identified, and the cysts were fenestrated using the bipolar probe. Cauterization was applied if the wall has some vascularity. The fenestram was then dilated using French Fogarty catheter size 3 or 4. Once patency was assured, the dilated opening was further widened using scissors to achieve maximum size. These steps were repeated until the target isolated loculi were fenestrated. Insertion of the factory default proximal shunt catheter was considered the last step in Group A, whereas some modifications were adopted in all Group B patients. The modifications included fenestration of the proximal shunt hardware by adding extra side ports tailored according to the required length of ventricular system drainage and made to simulate the 360° all-around ports of the factory default catheter, with the aim of improving its ability to drain. Moreover, the refashioned proximal catheter was advanced to reach the body and/or frontal horns of lateral ventricle and, if needed, down to isolated third and fourth ventricles, to reach areas of active choroid plexus secretion and incorporate it in a single proximal shunt tube [Figure 2a-j]. A proposed author algorithm for the management of complex MLH is illustrated in [Figure 3].

### Statistical analysis

Data were analyzed using Statistical Package for the Social Sciences (IBM SPSS Statistics) for Windows, version 26 (IBM Corp., Armonk, N.Y., USA). Age was abnormally distributed
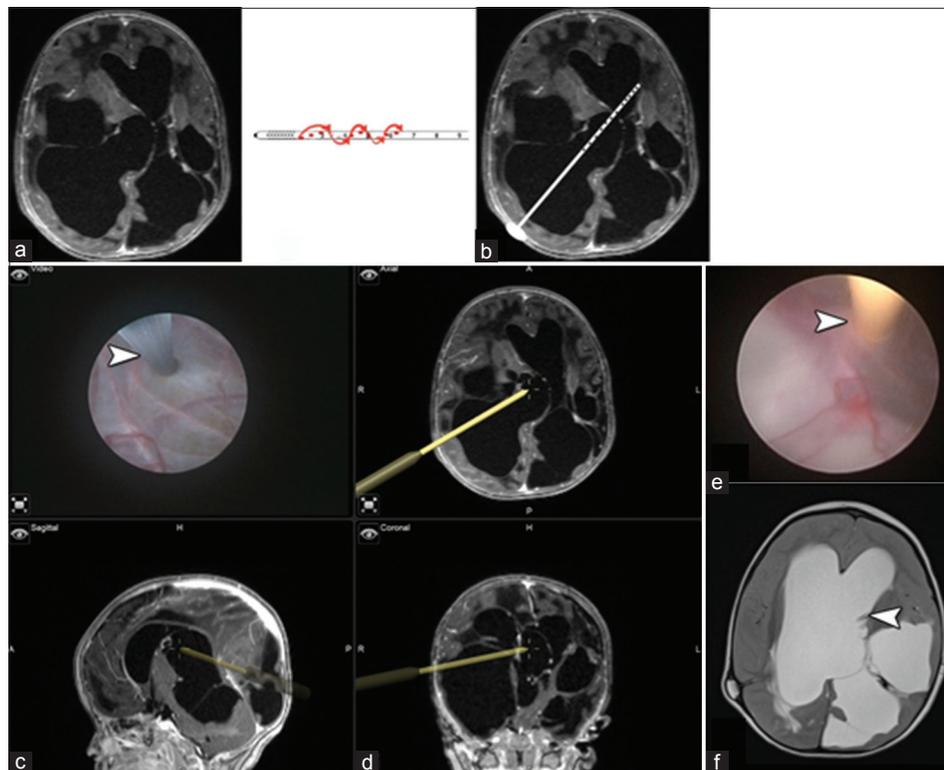
**Figure 1:** (a) Axial T1-weighted MRI showing multiloculated hydrocephalus with asymmetric ventriculomegaly and a midline shift to the left side. (b) An illustration showing shunt tube refashioning by adding extra ports in all around manner to mimic the factory fashion. (c) An illustration showing the intended pathway and advancement of the proximal catheter into the ventricular system. (d) A screenshot from the navigation platform with four quadrants, the left upper corner is an endoscopic linked live closer view of the septum pellucidum being fenestrated by monopolar probe (white arrowhead). The rest of the quadrants are axial, sagittal, and coronal images showing the path of endoscope sheath used as navigation tool after registration on the system. (e) Insertion of the refashioned antibiotic impregnated proximal catheter (white arrowhead). (f) An axial T2-weighted MRI 3 months following surgery showing the proximal catheter tip on the contralateral ventricle as targeted (white arrowhead).

and summarized as median and interquartile range (IQR; expressed as $25^{th}$–$75^{th}$ percentiles) and compared between the two groups using Mann–Whitney U-test. Categorical variables were summarized as frequencies. Pearson's Chi-square test for independence, Fisher's exact test, or Fisher-Freeman-Halton exact test were used to examine association between groups and categorical variables. $P < 0.05$ was adopted to interpret results of statistical tests.

## RESULTS

The present study was carried out on 55 patients who were enrolled into two groups: Group A (25 patients) and Group B (30 patients). [Table 1] summarizes patients' characteristics. The median age was 0.8 year in both groups, with no significant difference ($P = 0.892$). The gender distribution was similar in both groups ($P = 0.960$), with female patients accounting for 44% and 43.3% and male patients accounting for 56% and 56.7% in Groups A and B, respectively. The cause of multiloculation was either previous ventricular infection (56% in Group A and 53.3% in Group B) or hemorrhage

(44% in Group A and 46.7% in Group B), with no statistically significant difference ($P = 0.843$).

[Table 2] demonstrates preoperative clinical and radiological manifestations in the studied patients. The most common clinical manifestations in both groups included head enlargement and tense fontanelle (84% in Group A and 80% in Group B), vomiting (80% in Group A and 73.3% in Group B), seizure (60% and 63.3% in Groups A and B), dilated scalp veins (52% and 53.3% in Groups A and B), disjunction of sutures (48% and 50% in Groups A and B), and delayed milestones (32% and 36.7% in Groups A and B). Preoperative imaging showed that all cases had transependymal CSF permeation. obliterated cortical subarachnoid space was seen in 92% and 93.3% of Groups A and B. Midline shift was present in 84% of Group A and 80% of Group B patients. No significant differences were detected between the two groups ($P > 0.05$).

[Table 3] shows the operative details in both groups. Most patients had beforehand surgery (68% and 73.3% in Groups A and B) and surgery was free hand (72% and 70% in Groups A
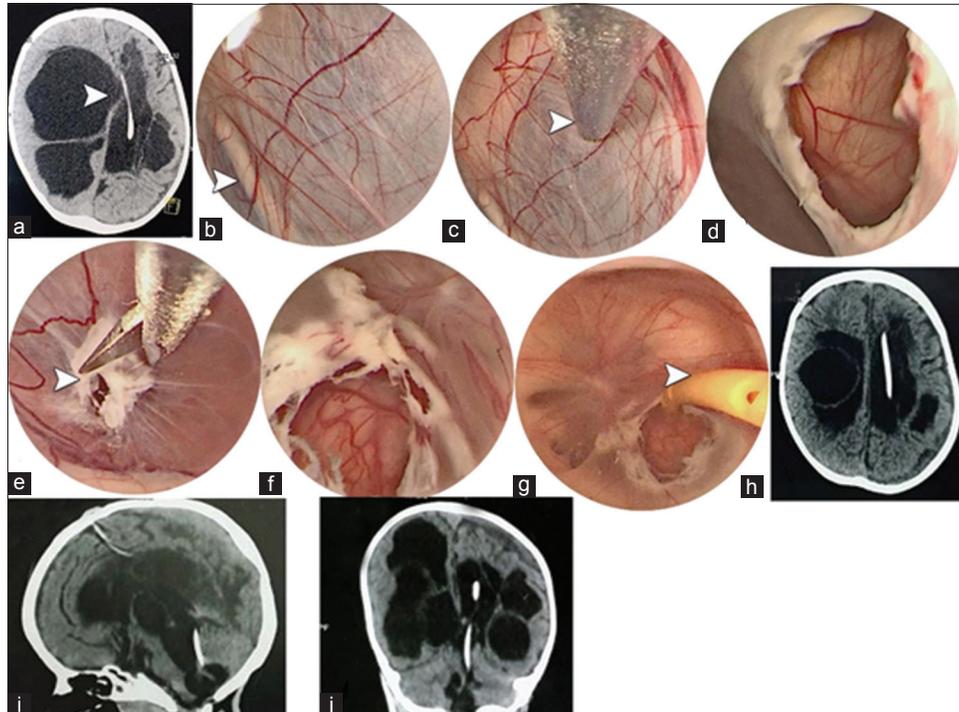
**Figure 2:** (a) Axial CT brain showing multiloculated hydrocephalus with distention of the right lateral ventricle toward left side proximal shunt catheter (white arrowhead). (b) An intraoperative endoscopic right side view showing the left side proximal catheter behind the septum pellucidum (white arrowhead). (c) The wall of the septum pellucidum is fenestrated using bipolar probe. (d) The fenesetram is widely dilated to show the second leaflet of the septum pellucidum needs fenestration. (e and f) Fenestration and wide dilatation are further progressed down across ependymal adhesions isolating the dilated third and fourth ventricles (white arrowhead). (g) Insertion of the refashioned antibiotic impregnated proximal catheter throughout fourth, third, and lateral ventricles (white arrowhead). (h-j) Postoperative images showing the path of the catheter through the ventricular system with a resolution of midline shift.



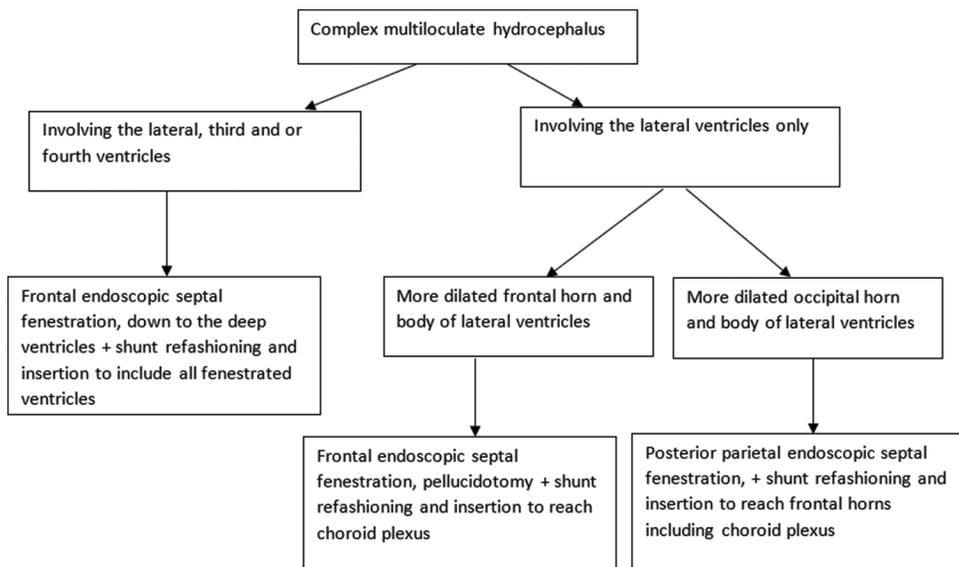**Figure 3:** Algorithm for the management of complex multiloculated hydrocephalus.

and B). A single burr hole was made in all cases. The burr hole location was mostly right precoronal (56% and 63.3% in Groups A and B), followed by left precoronal (36% and 30% in Groups A and B), then right posterior parietal (8% and 6.7% in Groups A and B). The shunt was replaced in 64% of cases in Group A and 70% of cases in Group B, whereas

**Table 1:** Patients' characteristics.

| | Group A (n = 25) | | Group B (n = 30) | | p |
|---|---|---|---|---|---|
| Age (years) | | | | | |
| Median [IQR] (Min-Max) | 0.8 [0.3–1.4] (0.1–3.2) | | 0.8 [0.4–1.2] (0.1–4.0) | | 0.892 |
| Gender | | | | | |
| Female | 11 | 44.0% | 13 | 43.3% | 0.960 |
| Male | 14 | 56.0% | 17 | 56.7% | |
| Cause of multiloculation | | | | | |
| Previous ventricular hemorrhage | 11 | 44.0% | 14 | 46.7% | 0.843 |
| Previous ventricular infection | 14 | 56.0% | 16 | 53.3% | |
| Imaging HCP shape | | | | | |
| Multilocular | 25 | 100.0% | 30 | 100.0% | NA |
| Cause of clinical | | | | | |
| Neonatal IVH | 1 | 4.0% | 1 | 3.3% | 0.879 |
| Neonatal meningoencephalitis | 7 | 28.0% | 7 | 23.3% | |
| Undershunting | 17 | 68.0% | 22 | 73.3% | |

IQR: Interquartile range, Max: Maximum, Min: Minimum, NA: Nonapplicable

**Table 2:** Preoperative clinical and radiological manifestations in the studied patients.

| | Group A (n=25) | | Group B (n=30) | | P |
|---|---|---|---|---|---|
| Preoperative clinical manifestations | | | | | |
| Head enlargement | 21 | 84.0% | 24 | 80.0% | 0.741 |
| Seizure | 15 | 60.0% | 19 | 63.3% | 0.800 |
| Tense fontanelle | 21 | 84.0% | 24 | 80.0% | 0.741 |
| Vomiting | 20 | 80.0% | 22 | 73.3% | 0.562 |
| Delayed milestones | 8 | 32.0% | 11 | 36.7% | 0.717 |
| Disjunction suture | 12 | 48.0% | 15 | 50.0% | 0.883 |
| Dilated scalp veins | 13 | 52.0% | 16 | 53.3% | 0.921 |
| Nerve palsy | 4 | 16.0% | 6 | 20.0% | 0.741 |
| Papilledema | 5 | 20.0% | 6 | 20.0% | 1.000 |
| Hypertonia | 4 | 16.0% | 5 | 16.7% | 1.000 |
| Disturbed consciousness | 3 | 12.0% | 3 | 10.0% | 1.000 |
| Headache | 0 | 0.0% | 2 | 6.7% | 0.495 |
| Preoperative radiological signs | | | | | |
| Midline shift | 21 | 84.0% | 24 | 80.0% | 0.741 |
| Obliterated cortical SA space | 23 | 92.0% | 28 | 93.3% | 1.000 |
| Transependymal CSF permeation | 25 | 100.0% | 30 | 100.0% | NA |

CSF: Cerebrospinal fluid, NA: Nonapplicable, SA: Subarachnoid space

*de novo* shunt insertion was performed in 36% of Group A patients and 30% of Group B. No significant difference was detected between the two groups (*P* > 0.05).

**Table 3:** Operative details in the studied patients.

| | Group A (n=25) | | Group B (n=30) | | P |
|---|---|---|---|---|---|
| Beforehand shunt | | | | | |
| Yes | 17 | 68.0% | 22 | 73.3% | 0.665 |
| No | 8 | 32.0% | 8 | 26.7% | |
| Navigation or freehand | | | | | |
| Freehand | 18 | 72.0% | 21 | 70.0% | 0.871 |
| Navigation | 7 | 28.0% | 9 | 30.0% | |
| Burr hole location | | | | | |
| Lt precoronal | 9 | 36.0% | 9 | 30.0% | 0.912 |
| Rt posterior parietal | 2 | 8.0% | 2 | 6.7% | |
| Rt precoronal | 14 | 56.0% | 19 | 63.3% | |
| Burr hole number | | | | | |
| Single | 25 | 100.0% | 30 | 100.0% | NA |
| Procedure performed | | | | | |
| Shunt insertion | 9 | 36.0% | 9 | 30.0% | 0.637 |
| Shunt replacement | 16 | 64.0% | 21 | 70.0% | |

NA: Nonapplicable

[Table 4] shows the resolution of clinical and radiological manifestations after surgery. The percentage of patients showing improvement of almost all manifestations was higher in Group B compared to Group A, with no significant difference (*P* > 0.05).

[Table 5] depicts the outcome of studied patients. The rate of complications was slightly lower in Group B than in Group A (16.7% vs. 20%, *P* = 1.000). A lower percentage of patients in Group B required the insertion of bilateral shunts (20% vs. 36%, *P* = 0.231). Redo surgery was performed in a higher percentage of patients in Group A once (36% vs. 20%) and twice (8% vs. 0%), but this difference did not reach statistical significance (*P* = 0.097).

Redo surgery was not significantly associated with the cause of MLH. In Group A, redo surgery was performed in 42.9% of postinfectious MLH compared to 45.5% of cases caused by hemorrhage (*P* = 1.000). In Group B, the rate of redo surgery was also higher in posthemorrhagic than in postinfectious cases (35.7% vs. 6.3%, *P* = 0.072). The presence of existing shunt was significantly associated with redo surgeries in Group A (*P* = 0.003), but nonsignificantly in Group B (*P* = 0.155) as all cases requiring redo surgery had preexisting shunt. The use of freehand versus intraoperative navigation was nonsignificantly associated with redo surgery in Groups A (50% vs. 28.6%, *P* = 0.407) and B (23.8% vs. 11.1%, *P* = 0.637).

## DISCUSSION

Patients with MLH are at high risk of morbidity due to the recurrent nature of the pathological septations, which frequently necessitates the placement of multiple shunts and/

**Table 4:** Resolution of manifestations after surgery in the studied patients.

| | | Group A (n=25) | | Group B (n=30) | | P |
|---|---|---|---|---|---|---|
| Postoperative clinical manifestations | | | | | | |
| Head enlargement | Unchanged | 15 | 71.4% | 14 | 58.3% | 0.709 |
| | Improved | 5 | 23.8% | 8 | 33.3% | |
| | Resolved | 1 | 4.8% | 2 | 8.3% | |
| Seizure | Unchanged | 3 | 20.0% | 1 | 5.3% | 0.407 |
| | Improved | 9 | 60.0% | 12 | 63.2% | |
| | Resolved | 3 | 20.0% | 6 | 31.6% | |
| Tense fontanelle | Unchanged | 4 | 19.0% | 1 | 4.2% | 0.313 |
| | Improved | 4 | 19.0% | 6 | 25.0% | |
| | Resolved | 13 | 61.9% | 17 | 70.8% | |
| Vomiting | Unchanged | 4 | 20.0% | 3 | 13.6% | 0.280 |
| | Improved | 5 | 25.0% | 2 | 9.1% | |
| | Resolved | 11 | 55.0% | 17 | 77.3% | |
| Delayed milestones | Unchanged | 7 | 87.5% | 7 | 63.6% | 0.338 |
| | Improved | 1 | 12.5% | 4 | 36.4% | |
| Disjunction suture | Unchanged | 5 | 41.7% | 4 | 26.7% | 0.609 |
| | Improved | 3 | 25.0% | 3 | 20.0% | |
| | Resolved | 4 | 33.3% | 8 | 53.3% | |
| Dilated scalp veins | Unchanged | 6 | 46.2% | 6 | 37.5% | 0.638 |
| | Improved | 7 | 53.8% | 10 | 62.5% | |
| Nerve palsy | Improved | 2 | 50.0% | 5 | 83.3% | 0.500 |
| | Resolved | 2 | 50.0% | 1 | 16.7% | |
| Papilledema | Improved | 2 | 40.0% | 0 | 0.0% | 0.182 |
| | Resolved | 3 | 60.0% | 6 | 100.0% | |
| Hypertonia | Unchanged | 1 | 25.0% | 3 | 60.0% | 0.524 |
| | Improved | 3 | 75.0% | 2 | 40.0% | |
| Disturbed consciousness | Improved | 1 | 33.3% | 0 | 0.0% | 1.000 |
| | Resolved | 2 | 66.7% | 3 | 100.0% | |
| Headache | Improved | 0 | 0.0% | 2 | 100.0% | NA |
| Postoperative radiological signs | | | | | | |
| Midline shift | Unchanged | 6 | 28.6% | 6 | 25.0% | 0.787 |
| | Improved/resolved | 15 | 71.4% | 18 | 75.0% | |
| Obliterated cortical SA space | Unchanged | 6 | 26.1% | 6 | 21.4% | 0.696 |
| | Improved/resolved | 17 | 73.9% | 22 | 78.6% | |
| Transependymal CSF permeation | Unchanged | 6 | 24.0% | 6 | 20.0% | 0.721 |
| | Improved/resolved | 19 | 76.0% | 24 | 80.0% | |
| Decreased size of loculated cysts | Unchanged | 17 | 68.0% | 21 | 70.0% | 0.873 |
| | Improved/resolved | 8 | 32.0% | 9 | 30.0% | |
| Reduced ventricle size | Unchanged | 15 | 60.0% | 19 | 63.3% | 0.800 |
| | Improved/resolved | 10 | 40.0% | 11 | 36.7% | |

NA: Nonapplicable

**Table 5:** Outcome in the studied patients.

| | Group A (n=25) | | Group B (n=30) | | P |
|---|---|---|---|---|---|
| Complications | | | | | |
| No | 20 | 80.0% | 25 | 83.3% | 1.000 |
| Yes | 5 | 20.0% | 5 | 16.7% | |
| Inguinal hernia | 3 | 12.0% | 3 | 10.0% | 1.000 |
| Transient postoperative low-grade fever | 2 | 8.0% | 2 | 6.7% | 1.000 |
| Success | | | | | |
| Failure (bilateral shunts) | 9 | 36.0% | 6 | 20.0% | 0.231 |
| Success (one shunt) | 16 | 64.0% | 24 | 80.0% | |
| Redo surgery | | | | | |
| No redo | 14 | 56.0% | 24 | 80.0% | 0.097 |
| Another redo 1 time | 9 | 36.0% | 6 | 20.0% | |
| Another redo 2 times | 2 | 8.0% | 0 | 0.0% | |

or redo surgeries or shunt revisions.[6] The search continues for a surgical technique that can normalize intracranial pressure and alleviate patients' manifestations, while minimizing the number of shunt hardware and redo/revision surgeries.[2-5,10,15,16]

Several treatment strategies have been assessed for managing MLH including multiple shunt insertion into each dilated loculation, fenestration of cysts by open surgery or endoscopy, or a combination of these techniques.[20,26] The placement of multiple shunts was associated with high rate of complications and shunt revision. Malfunctioning of the shunt occurs due to collapse of the ependymal wall enclosing the catheter tip. In addition, shunt infection further complicates the condition and results in more gliosis, septation, and cyst formation.[12] Fenestration of isolated parts with or without insertion of ventriculoperitoneal shunt has been associated with relatively good outcomes, with proponents claiming the superiority of craniotomy or endoscopic approach. While the endoscopic approach carries the advantages of reduced bleeding as well as shorter both operative and postoperative time, craniotomy is claimed to provide better visualization in managing intraoperative bleeding.[27,28,31]

The goal of the fenestration procedure is to make communication between the maximal possible number of isolated parts of the ventricular system creating openings in the septal walls so as CSF drainage will be achieved by the minimal number of shunts; this, in turn, will lessen the frequency of shunt revisions.[1,8,18,27,29,30]

The present study aimed at assessing the potential added benefit of a modified technique of endoscopic fenestration of cysts. The present study was carried out on 55 patients who either underwent the standard technique (Group A)

or the modified technique (Group B). The two groups were similar as regards the preoperative characteristics and clinical manifestations. In Group B, patients underwent septal fenestration and pellucidotomy combined with proximal shunt tube refashioning by adding extra side ports all around and further advancement into isolated loculations of the ventricular system containing choroid plexus. Zohdi[32] described shunt refashioning by adding extra ports combined with fenestration of the septa and optional redirection of the shunt system as treatment option in complex MLH. He proposed an aim in such cases to minimize the number of surgeries (endoscopic/shunt procedures). Another study[11] has assessed a refashioned multiperforated catheter in management of 18 patients with trapped fourth ventricle, reporting good neurological outcomes.

The etiology of MLH was previous ventricular infection in more than half the patients in either group, while the remaining cases were attributed to intraventricular hemorrhage. Ventriculitis, either due to infection or chemical irritation by intraventricular hemorrhage, leads to inflammation and damage of the ependyma. Consequently, gliosis develops with protrusion of glial tufts into the ventricular cavities that are composed of fibroglial tissue and inflammatory cells.[14,24] Progression of the condition will result in formation of septa which divide the ventricular cavity into isolated cysts that are separated from each other.[24,30,33]

Intraoperative navigation was used in the current study in only 28% and 30% of patients in Groups A and B, respectively. Intraoperative navigation has been recommended to improve localization of the cysts in complex MLH and to define the surgical approach and path to the targeted cysts.[17,33] However, the value of navigation with endoscopic fenestration in MLH is potentially undermined by the anticipated brain shift that will follow the fenestration of cysts.

In both Groups A and B, the goal was wide fenestrations in the septal walls. First, the septa were cauterized, and then, the fenestrations were enlarged with Fogarty balloon and scissors. The aim of these steps was to reduce the likelihood of reclosure of the fenestrations which occurs frequently with small openings due to the low-pressure differential across loculated walls. The same precautions were recommended by El-Ghandour[8] and Zuccaro and Ramos.[33]

The use of endoscopic approach has been associated with reduced rate of perioperative morbidity due to the minimal invasiveness compared to open surgery through craniotomy. However, intraoperative bleeding which is less efficiently managed during endoscopy represents a concern that can affect the outcome of surgery.[1,3] The results of the present study showed that the rate of postoperative complications was slightly lower in Group B compared to Group A (16.7% vs. 20%, $P = 1.000$). The low rate and severity of complications

observed in our patients are in line with the previous studies which concluded that complications following endoscopic approach were usually minor and were mostly treated conservatively.[8,9,12,13,17,25,29]

Spennato et al.[29] found that five out of 30 patients suffered complications after endoscopic surgery to treat MLH, including CSF infection in three cases, CSF leak in one case, and thalamic hematoma with transient akinetic mutism in one case.

El-Ghandour[8] described a series of 32 MLH patients treated with endoscopic fenestration of cysts. The reported complications were also mild in nature in the form of transient CSF leakage (two patients), minor intraoperative bleeding (two patients), and bilateral subdural hematoma in only one patient who had intraoperative bleeding. The author stated that these complications did not necessitate termination of the procedure or shift to open surgery, and they resolved with conservative treatment.

Eshra[12] described minor complications in three out of 14 patients, consisting of CSF leakage in two patients and wound infection in only one patient.

Kim et al.[17] encountered postoperative complications in two of their eight patients after endoscopic surgery. One patient had subdural hematoma while the other had shunt displacement which did not affect drainage and both patients were managed conservatively.

El-Tantawy[9] reported on 20 patients with postinfectious MLH who underwent endoscopic fenestration and found that complications were minor, including mild intraoperative bleeding in two patients, circulatory overload in one patient, and seizure in one patient. Fadl et al.[13] stated that none of their 30 MLH patients who underwent endoscopic management suffered from intra- or postoperative complications.

Piyachon et al.[25] mentioned that complications were encountered in two out of 20 patients in their series following endoscopic fenestration of cysts. The two patients suffered transient subdural hematoma which was resolved by conservative management. They also mentioned that death occurred in one patient due to severe brainstem dysfunction after developing infratentorial compartmentalization following multiple endoscopic procedures.

As regard the resolution of clinical and radiological manifestations after surgery, Group B showed a higher rate of improvement of almost all manifestations of increased intracranial pressure compared to Group A, but the difference was not statistically significant. The degree of improvement in achieving milestones was less evident, which is anticipated in these cases. Previous reports stated that the improvement in cognitive function and intelligence quotient

did not parallel the rapid improvement in manifestations of increased intracranial pressure.[17,33] It has been estimated that approximately 90% of MLH patients suffer from severe cognitive deficits which necessitate assistance with daily activities.[8,33]

Minimizing the number of inserted shunts can impact patients' outcome. The presence of more than 1 shunt complicates the identification of a malfunctioning part. Moreover, the likelihood of shunt infection correlates with the number of shunts. Consequently, the insertion of a single shunt is preferable to avoid these complications.[7,22,27] We found that a lower percentage of patients in Group B ended up with two shunts (20% vs. 36%, $P = 0.231$). The rate of success of single shunt in our patients (64% in Group A and 80% in Group B) is nearly similar to rates reported in the literature following standard endoscopic technique which ranged from 61.8% to 100%.[7,9,12,22,23,25,33]

Another important outcome in cases of MLH is the need for redo surgeries or shunt revisions. The recurrent nature of the disease prevents the complete avoidance of these procedures. Redo surgery was performed in a lower percentage of patients in Group B (20% vs. 44%), but this difference did not reach statistical significance. The rate of redo surgeries widely varied among previous studies. A low rate of 16.7% (five patients) was reported by Fadl et al.,[13] but their sample size was small rendering underestimation of the true rate a possibility. Spennato et al.,[29] El-Ghandour,[8] Akbari et al.,[1] and Piyachon et al.[25] reported redo rates for endoscopic surgery of 30.4%, 33%, 38.5%, and 35%, respectively. Zuccaro and Ramos[33] found that 53% of their patients required another operative intervention. However, El-Tantawy[9] reported a much higher rate of 90%, attributing this to the inclusion of postinfectious MLH patients and the potential more progressive, less controlled nature of this entity of MLH. Interestingly, the cause of MLH was not significantly associated with the rate of redo surgery in our patients regardless of the group.

All patients in the current study who required redo surgery had existing shunts before endoscopic fenestration. This is conforming with Piyachon et al.[25] who found that a higher rate of redo endoscopic fenestration was detected among patients with prior shunt insertion, but with no significant difference. Some studies suggested that conditions related to neurosurgical interventions and shunt may play important role in causing septation and loculation, such as shunt-related infection,[16,21] direct ependymal trauma during catheter insertion,[10] and intracranial surgery.[19]

## CONCLUSION

The current study introduced a novel modified technique of endoscopic fenestration of cysts for the management of MLH. Although statistical significance was not detected between the two groups, the clinical significance of the reduced number of inserted shunts and redo surgery suggests an advantage of the modified technique while no added risk was detected. Consequently, we consider that the proposed modified technique has a promising potential of improving outcomes of MLH patients. Shunt hardware manufacturers can also participate in better management of these cases by providing dedicated factory longer fenestrated proximal catheters. The retrospective nature of the study might have impacted the results, and a randomized trial with special factory longer fenestrated proximal tube is recommended, taking into consideration the inclusion of adequate sample size to detect the differences between the tested techniques in terms of the number of inserted shunts and redo surgeries.

**Declaration of patient consent**

Institutional Review Board (IRB) permission obtained for the study.

**Conflicts of interest**

There are no conflicts of interest.

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