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Novel adaptation of the AxiEM electromagnetic neuronavigation system for intraoperative tracking of neuroendoscope during intraventricular surgery

Irene Say, Rachana Tyagi, Smit Shah

ABSTRACT

Introduction: Endoscopic third ventriculostomy is a minimally invasive neurosurgical procedure which is the most commonly used to treat hydrocephalus via creating an opening in the floor of the third ventricle which allows excess cerebrospinal fluid to flow into surrounding basal cisterns by bypassing obstructions. Use of electromagnetic (AxiEM) neuronavigation to assess precise anatomical landmarks intraoperatively is gaining more importance to achieve accurate results. Endoscopic third ventriculostomy and neuroendoscopic intraventricular surgery overcome the persistent risk of infection and hardware failure associated with ventriculoperitoneal shunting for the treatment of hydrocephalus. However, the surgical technique is associated with endoscopic third ventriculostomy (ETV) risks neurovascular catastrophe. Case Series: The aim of this case series is to assess the safety and effectiveness in surgical outcomes of adding neuronavigation tracking to endoscopic visualization for intraventricular surgery. A retrospective chart review (case series) of adult and pediatric patients treated with neuronavigation-guided endoscopic third ventriculostomy (ETV) or intraventricular cyst fenestration for radiographically confirmed and clinically significant congenital or acquired hydrocephalus in university hospital setting between 2012–2014; n = 21 patients was performed. Herein, we present our surgical outcomes and complications with an average follow-up of 20 months. Conclusion: Intraoperative neuronavigation provides a safe corridor for neuroendoscopy and avoids the complications of skull fixation in both adult and pediatric patients. Adding image guidance to neuroendoscopy increases safety margins for targeting accuracy, especially for patients with challenging anatomic landmarks.

Keywords: Electromagnetic, Endoscopic, Neuronavigation, Shunt, Ventriculoperitoneal, Ventriculostomy

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INTRODUCTION

Patients with hydrocephalus traditionally require surgical implantation of a ventricular shunt system for cerebrospinal fluid diversion and are at risk for early and late complications of shunt failure and infection. Hospital charges in the US related to these shunts exceed $2 billion per year and patients may suffer neurologic deficit, while losing quality of life and productivity. Ventriculoperitoneal shunts have the highest complication rate of any procedure in neurosurgery, and complications can have devastating outcomes including damage to fornices, hypothalamus, subdural hygromas and cranial nerve palsies [1]. Shannon et al. also showed patients had higher out of pocket expenditure for ventriculoperitoneal shunt failure which increases the financial burden on patients and their family [2, 3].

Endoscopic third ventriculostomy (ETV) has emerged as a promising answer to the problem of hydrocephalus, whereby an alternative pathway of cerebrospinal fluid (CSF) flow is created through a fenestration in the floor of third ventricle [4–6]. However, success with ETV and the neuroendoscope demands high technical skill given the acute, yet rare risks of catastrophic injury, including basilar artery injury, memory loss, and endocrine dysfunction. Advances in preoperative imaging have allowed for better patient selection and technical advances in neuroendoscopy have improved visualization of critical anatomy [2, 7–10]. However, there remains a higher need to improve patient outcomes of ETV by ensuring better accuracy, thus further reducing the risk of catastrophic neurovascular injury and providing patients with independence from ventricular shunt systems.

CASE SERIES

We performed a retrospective chart review of adult and pediatric patients treated with neuronavigation-guided endoscopic third ventriculostomy (ETV) or intraventricular cyst fenestration for radiographically confirmed, clinically significant congenital or acquired hydrocephalus between 2012–2014; n = 21 patients. All patients underwent successful completion of this procedure without clinically significant acute or long-term complications. IRB (Internal Review Board) approval was acquired and patient information was stored and retrieved from a password protected database.

We followed the standard procedure of registration of the Medtronic AxiEM electromagnetic tracking system to the preoperative MRI Stealth with contrast during which head was positioned in a gel donut without pin fixation under general anesthesia. The entry site was pre-planned to allow the best approach through skull, parenchyma and lateral ventricle through the foramen of Monroe to the floor of third ventricle avoiding injury to cortical vessels and the fornix in addition to targeting area anterior to the basilar artery without damaging it. A double-screen set-up allowed simultaneous endoscopy and neuronavigation, irrigation with lactated Ringer's, and balloon catheter set-up (Figure 1 and Figure 2). We cannulated the ventricle using live navigation with the AxiEM stylet in a 14F peel-away sheath (model # PLVW-16.0-38) using the Trajectory 1, Trajectory 2 and guidance views to maintain perfect alignment with the pre-planned trajectory. The projection is set to 10 mm as the tip of the stylet sits 1 cm proximal to the tip of the trocar. The endoscope is also 1 cm longer than the stylet and no further adjustment of the projection is required when navigating the endoscope. Once the ventricle is entered, the sheath is advanced to the tip of the trocar which is then removed. Cerebrospinal fluid return confirms appropriate placement.

The stylet is then placed in the working port of endoscope for simultaneous real-time multi-planar neuronavigation confirmation of the endoscope position relative to the pre-planned trajectory and visualized anatomic landmarks are obtained as well.

In our results we found that patients underwent either an ETV, ETV with cyst fenestration, or cyst fenestration alone for management of hydrocephalus with the majority of our patients undergoing only an ETV (Table 1). Clinical indications for ETV included obstructive hydrocephalus (OH), OH plus other clinical conditions including recurrent optic nerve cystic glioma

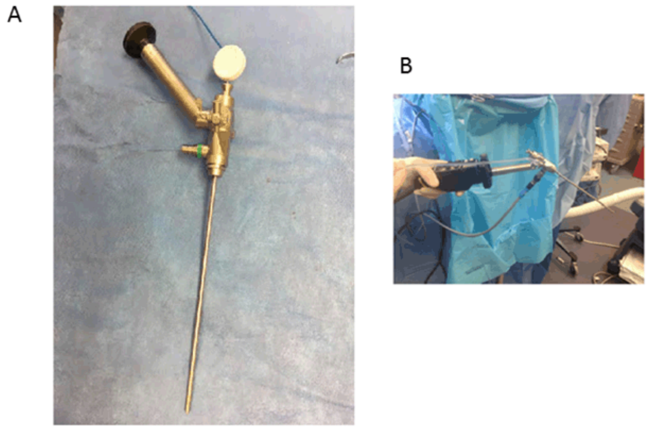

Figure 1: (A) Stylet in sheath and (B) Stylet with peel away trochar not in endoscope.

Figure 2: Double screen simultaneous neuroendoscopy and neuronavigation for continuous real time orientation. Tip of the endoscope is within the ventricle, oriented along the preplanned trajectory with a clear view of the planned fenestration site.

and myelomeningocele (Figure 3, Figure 4 and Figure 5). Of our 21 patients, 20 patients were complication free whereas one patient had temporary diabetes insipidus (Figure 6). Of the 21 patients who had surgery, 10 had a pre-existing shunt and 11 had never had a shunt placed. Of those that were shunted, 60% postoperatively were shunt-independent where as 40% were shunt-dependent. Of those patients who were shunt naive, 91% were shunt-independent and 9% required eventual shunt placement (Figure 7). Early and late complications associated with standard methods of ETV, such as basilar artery injury and memory loss, were not observed using this integrated technique with neuronavigation. Notably, our study included several patients with obstructive hydrocephalus secondary to multiple etiologies. Patients with hydrocephalus secondary to a colloid cyst, aqueductal stenosis, and adult post-hemorrhagic hydrocephalus with previous shunt infection all remained shunt free 41 months post-ETV without any complications. Other patients also demonstrated relief of cerebrospinal fluid obstruction in cases of loculated hydrocephalus or obstructive hydrocephalus from neoplasm.

One patient with loculated hydrocephalus with multiple previous shunts and infections from an outside

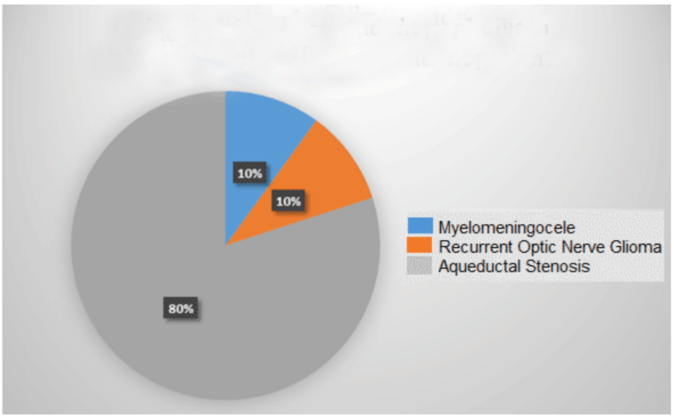

Figure 3: Etiology of obstructive hydrocephalus in patients. Causes range from myelomeningocele, recurrent optic nerve glioma and aqueductal stenosis.

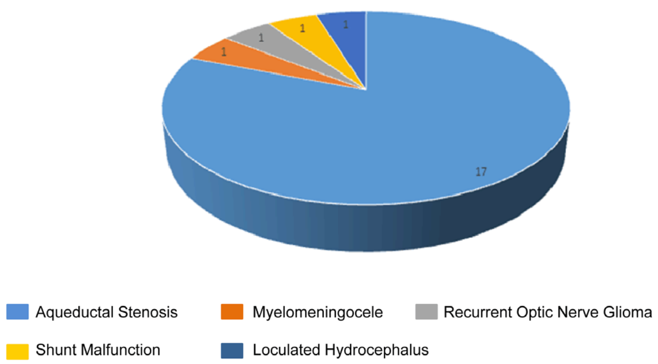

Figure 4: Distribution of patients by initial diagnosis: (N=21). Preoperatively shunt-dependent patients with aqueductal stenosis, recurrent optic nerve glioma, loculated hydrocephalus, myelomeningocele and shunt malfunction.

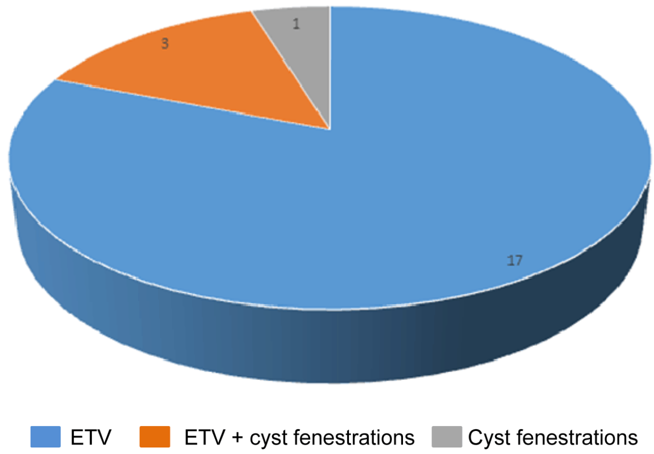

Figure 5: Various types of procedures in patients; most of them being cyst fenestrations.

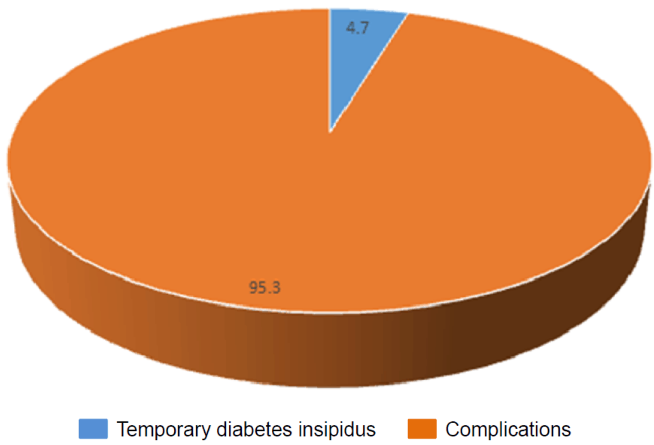

Figure 6: Twenty patients were complication free postoperatively except one patient who had temporary diabetes insipidus.

institution underwent an endoscopic cyst fenestration with a single catheter shunt placement rather multiple catheters for separate cysts. Outcome was decrease in the multiple cyst size and no complications at >1 year follow up (Figure 8).

We calculated patients' endoscopic third ventriculostomy success score (ETVSS) using the rubric (Figure 3 and Figure 4), excluding our loculated hydrocephalus patient who did not have an ETV performed. We found that average predicted ETVSS score in our patient population to be 59.04 (Table 2 and Table 3). Furthermore, we also found that most of patients with higher ETVSS, i.e., above 50 had no postoperative complications. Of patients with ETVSS score greater than equal to 50, 16 were shunt-independent and one was shunt-dependent postoperatively with long-term follow-up.

Table 1: Case series data

Patient Number	Age range	Previous Shunt	Previous Infection	Procedure	Outcome	First Post operative Follow Up (months)	Latest Post Operative Follow Up (months)	Complications	Surgical Indication	ETVSS
1	1 year to 10 year	N	N	ETV + Cyst Fenestration	SI	5	18	N	OH + recurrent optic nerve cystic glioma	60
2	>10 years	Y	Y	ETV	SD	4	24	N	OH	60
3	>10 years	Y	N	ETV	SD	5	24	Temporary DI	Shunt Malfunction and congenital hydrocephalus	60
4	>10 years	Y	Y	ETV + Cyst Fenestration	SD	5	24	N	OH	60
5	>10 years	N	Y	ETV	SI	4	18	N	OH	70
6	>10 years	Y	Y	ETV	SI	5	24	N	OH	60
7	>10 years	Y	N	ETV	SI	5	24	N	OH	60
8	>10 years	Y	Y	ETV	SI	5	24	N	OH	60
9	>10 years	Y	Y	ETV	SI	5	18	N	OH	60
10	>10 years	Y	N	ETV	SI	5	18	N	OH	60
11	>10 years	Y	N	ETV + Cyst Fenestration	SI	3	16	N	OH	60
12	>10 years	N	N	ETV	SI	5	18.5	N	OH	70
13	>10 years	Y	N	Cyst Fenestration	SD	5	14	N	Loculated Hydrocephalus	60
14	>10 years	N	N	ETV	SI	5	19.5	N	OH	70
15	>10 years	N	N	ETV	SI	5	21	N	OH	70
16	1 year to 10 year	N	N	ETV	SD	5	23.5	N	OH	60
17	6 months to 1 year	N	N	ETV	SI	5	22.5	N	OH + Myelomeningocele	50
18	6 months to 1 year	N	N	ETV	SI	5	24	N	OH	50
19	1 year to 10 year	N	N	ETV	SI	4	17.5	N	OH	60
20	6 months to 1 year	N	N	ETV	SI	5	15	N	OH	50
21	1 month to 6 months	N	N	ETV	SI	5	17	N	OH	30
						4.761904762	20.21428571			

SI: Shunt Independent, SI: Shunt Independent, SD: Shunt Dependent, OH: Obstructive Hydrocephalus

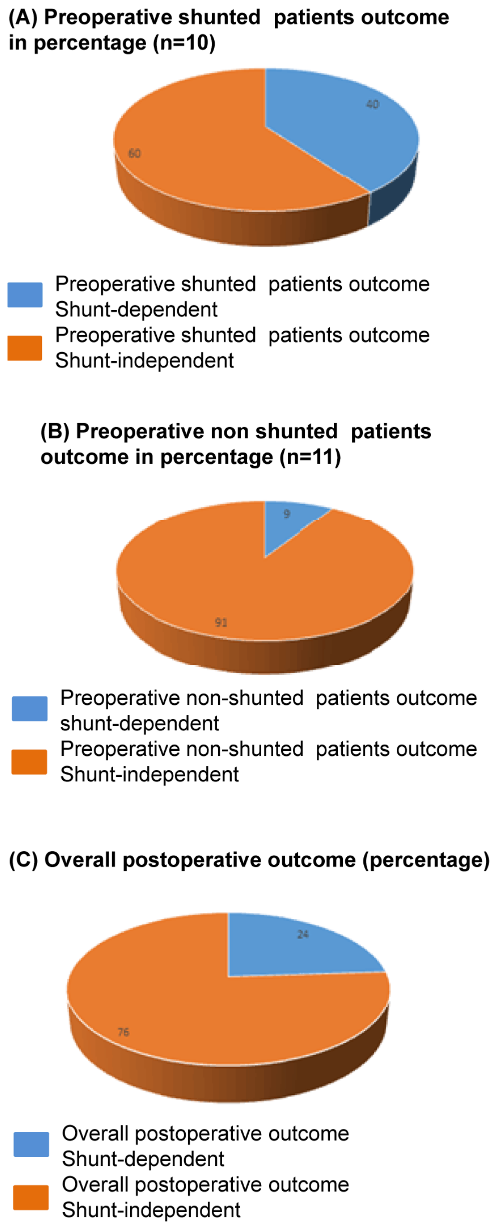

Figure 7: (A–C) Preoperative versus postoperative shunt -dependency, 76% of patients were shunt-independent postoperatively.

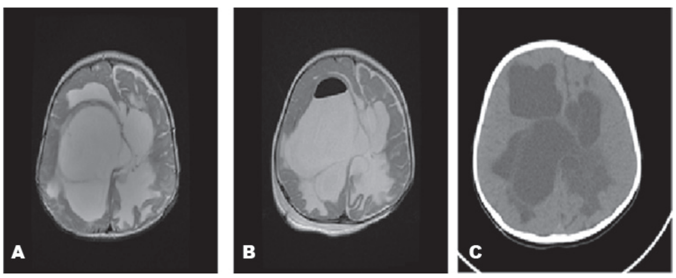

Figure 8: Imaging of one patient with (A, B) loculated hydrocephalus with multiple previous shunts and infections from an outside institution underwent an endoscopic cyst fenestration with a single catheter shunt placement rather multiple catheters for separate cysts. (C) Outcome was decrease in the multiple cyst size and no complications at >1 year follow-up.

Table 2: Endoscopic third ventriculostomy success score calculation guide

Score	Age	Etiology	Previous shunt
0	<1 month	Post Infectious	Yes
10	1 month to 6 months	Myelomeningocele, colloid cyst, non tectal brain tumor	No
20			
30	6 months to 1 year	Aqueductal stenosis, tectal tumor and other	
40	1 year to 10 years		
50	>10 years		

Data derived from Kulkarni et al. [11, 12]

Table 3: Endoscopic third ventriculostomy success score (ETVSS) calculation from our study. Average ETVSS score for all patients is 59.04

Patient Number	ETVSS
1	60
2	60
3	60
4	60
5	70
6	60
7	60
8	60
9	60
10	60
11	60
12	70
13	60
14	70
15	70
16	60
17	50
18	50
19	60
20	50
21	30

DISCUSSION

In our experience, using simultaneous neuroendoscopy along with neuronavigation provides confirmatory surgical precision to reduce the number of common complications of ETV. Continuous re-orientation allows us to overcome unexpected intraoperative challenges due to abnormal anatomy throughout the procedure. Most importantly, our technique has provided durable shunt-independence, thus improving our patients' quality of life and reducing the socioeconomic burden of shunt hardware.

Of note, at long-term follow-up of average 41 months, there was no observed incidence of basilar artery injury, infection, CSF leak, or forniceal injury. Failure to identify the location of the basilar artery with the endoscope can increase the risk of vascular injury, particularly with abnormal ventricular anatomy. Excessive manipulation and traction of the parenchyma while exploring the ventricles can lead to CSF leak, or forniceal injury [11–13]. The added neuronavigation provides the ability to confirm accurate localization even without normal anatomic landmarks to reduce the intraoperative risks.

Published success rates for ETV [14, 15], as measured by shunt-independence are about 73% as compared to our rate which is 76% during first postoperative average follow-up of 4.76 months. To further validate this, we will have to perform more ETV cases and also follow up patients over a longer time period to gauge our improvement. As compared to on our calculation of predicted ETVSS of 59.04%, our actual postoperative ETV success rate was 81% (17/21). However, we would still like to optimize and validate our success score by performing more cases and getting more surgical experience in patients with different variety of indication of obstructive hydrocephalus.

This surgical technique can also be used in a larger patient population including those with myelomeningocele [5]. Our future studies will evaluate the long-term cost-effectiveness of this quality improvement technique by examining the length of stay, length of surgery, and rate of re-hospitalization.

CONCLUSION

From the perspective of surgical quality improvement, adapting frameless electromagnetic neuronavigation provides real-time, multi-planar orientation during neuroendoscopic intraventricular surgery and reduces the risk of injury to critical brain structures such as the fornix and intracerebral vessels, which are typically vulnerable during standard endoscopic third ventriculostomy techniques. Intraoperative navigation provides a safe corridor for neuroendoscopy and avoids many complications of skull fixation in both adult and pediatric patients. Adding image guidance to neuroendoscopy increases safety margins for targeting accuracy, especially for patients with challenging anatomic landmarks. This available, safe addition to the recent advances in endoscopic neurosurgery will augment our access to critical regions of the brain for tumor resection and treatment of hydrocephalus, while reducing the risk of known common complications such as basilar artery rupture, cerebrospinal fluid leak and infections.

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SUGGESTED READING

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Author Contributions

Irene Say – Substantial contributions to conception and design, Acquisition of data, Analysis and interpretation of data, Drafting the article, Revising it critically for important intellectual content, Final approval of the version to be published

Rachana Tyagi – Substantial contributions to conception and design, Acquisition of data, Analysis and interpretation of data, Drafting the article, Revising it critically for important intellectual content, Final approval of the version to be published

Smit Shah – Substantial contributions to conception and design, Acquisition of data, Analysis and interpretation of data, Drafting the article, Revising it critically for important intellectual content, Final approval of the version to be published

Guarantor of Submission

The corresponding author is the guarantor of submission.

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None

Conflict of Interest

Authors declare no conflict of interest.