The intra-neuroendoscopic technique: a new method for rapid removal of acute severe intraventricular hematoma
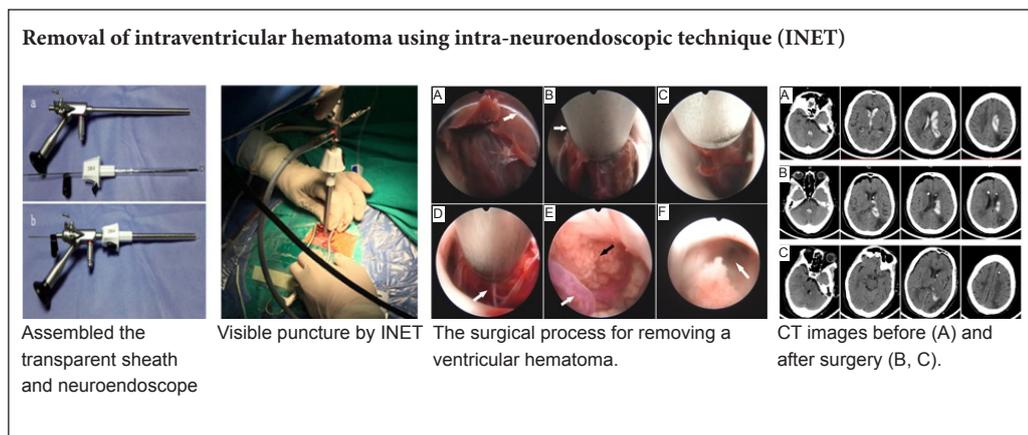
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Graphical Abstract

Removal of intraventricular hematoma using intra-neuroendoscopic technique (INET)

Assembled the transparent sheath and neuroendoscope

Visible puncture by INET

The surgical process for removing a ventricular hematoma.

CT images before (A) and after surgery (B, C).

Abstract

The mortality rate of acute severe intraventricular hematoma is extremely high, and the rate of disability in survivors is high. Intraventricular hematoma has always been a difficult problem for clinical treatment. Although minimally invasive endoscopic hematoma evacuation is widely used to treat this disease, the technique still has room for improvement. Equipment for the intra-neuroendoscopic technique (INET) consists of two of our patented inventions: a transparent sheath (Patent No. ZL 200820046232.0) and a hematoma aspirator (Patent No. ZL 201520248717.8). This study explored the safety and efficacy of INET by comparing it with extraventricular drainage in combination with urokinase thrombolytic therapy. This trial recruited 65 patients with severe intraventricular hemorrhage, including 35 (19 men and 16 women, aged 53.2 ± 8.7 years) in the INET group and 30 (17 men and 13 women, aged 51.5 ± 7.9 years) in the control group (extraventricular drainage plus urokinase thrombolytic therapy). Our results showed that compared with the control group, the INET group exhibited lower intraventricular hemorrhage volumes, shorter intensive care-unit monitoring and ventricular drainage-tube placement times, and fewer incidences of intracranial infection, secondary bleeding, and mortality. Thus, the prognosis of survivors had improved remarkably. These findings indicate that INET is a safe and efficient new method for treating severe intraventricular hematoma. This trial was registered with ClinicalTrials.gov (NCT02515903).

Key Words: nerve regeneration; ventricular hemorrhage; transparent sheath; extraventricular drainage; minimally invasive surgery; intra-neuroendoscopic technique; urokinase thrombolysis; prognosis; neural regeneration

Introduction

Intraventricular hemorrhage (IVH) is a common type of cerebral hemorrhage, accounting for 20–60% of spontaneous intracranial hemorrhagic diseases, and has a mortality rate of 50–80% (Coplin et al., 1998; Tuhrim et al., 1999; Rosen et al., 2007). IVH is most commonly caused by arteriosclerosis due to hypertension, aneurysm, moyamoya disease, or cerebral arteriovenous malformations (Chen et al., 2011; Du et al., 2014; Idris et al., 2014). Previous studies (Mayfrank et al., 1997; Kiymaz et al., 2005) have found that IVH volume was the main factor that affected patient prognosis, and rapid removal of the hematoma was considered the preferred treatment regimen. Classic extraventricular drainage (EVD) can rapidly control intracranial pressure, but the drainage tube is often blocked by blood clots. Additionally, long-term thrombolytic therapy can easily induce secondary bleeding and intracranial infection (Du et al., 2014). In recent years, the development of neuroendoscopic techniques has provid-

Table 1 Comparison of baseline data between the INET and control groups

|	INET group (n = 35)	Control group (n = 30)	P value
Sex (male/female, n)	19/16	17/13	0.85
Age (year)*	53.2±8.7	51.5±7.9	0.21
GCS*	7.3±1.5	7.8±1.5	0.16
Graeb score*	8.1±1.5	7.8±1.4	0.38
IVH volume (mL)*	74.2±10.4	71.2±9.2	0.24
Bleeding causes			0.86
Hypertension, arteriosclerosis#	24(68.5)	21(70.0)	
Aneurysm/AVM#	5(14.3)	3(10.0)	
Moyamoya disease#	2(5.7)	1(3.3)	
Unexplained causes#	4(11.4)	5(16.7)	
Intraventricular hemorrhage sites			0.78
Whole ventricle system#	9(25.7)	6(20.0)	
Bilateral lateral ventricle, third ventricle#	10(28.6)	9(30.0)	
Unilateral lateral ventricle, third and fourth ventricles#	10(28.6)	7(23.3)	
Unilateral lateral ventricle, third ventricle#	6 (17.1)	8(26.7)	

*Data are expressed as the mean ± SD. #Data are expressed as number (percent). INET: Intra-neuroendoscopic technique; GCS: Glasgow Coma Scale; IVH: intraventricular hemorrhage; AVM: arteriovenous malformations.

ed new therapeutic approaches for the treatment of devastating types of stroke, such as IVH (Zhang et al., 2007; Nomura et al., 2010; Chen et al., 2011; Basaldella et al., 2012; Idris et al., 2014) and intracranial hemorrhage (Rennert et al., 2016; Pías-Peleteiro et al., 2017). However, these ventriculoscopy devices only contain a needle core and a metal guide sheath. The puncture process is blind, and the visibility in the ventricle is limited, thereby increasing the risk of endoscopic movement in the ventricle. We have invented a new transparent sheath that can fit on the distal endoscope seamlessly and avoid the shortcomings of the original technology. This study explores the safety and efficacy of intra-neuroendoscopic technique (INET) in the treatment of acute severe IVH by comparing its outcomes with those obtained using EVD plus urokinase thrombolytic (UT) therapy in prospective controlled studies.

Subjects and Methods

Design

This study was a non-randomized concurrent control trial, and patients were grouped according to their or their family's willingness to accept treatment. The protocol for this registered study was approved by the Institution Review Board (NFEC-2015-034) of Southern Medical University of China, and the trial was registered on ClinicalTrials.gov (NCT02515903). From July 2015 to March 2017, 65 patients met the inclusion criteria for the study and signed an agreement to enter the groups (35 in the INET group and 30 in the control EVD + UT group). The sample size of 65 was calculated based on the index of hematoma clearance in a preliminary experiment. All patients were enrolled from the neurosurgery department of Nanfang Hospital of China or the emergency center of Shenzhen People's Hospital of China. No statistically significant differences were observed be-
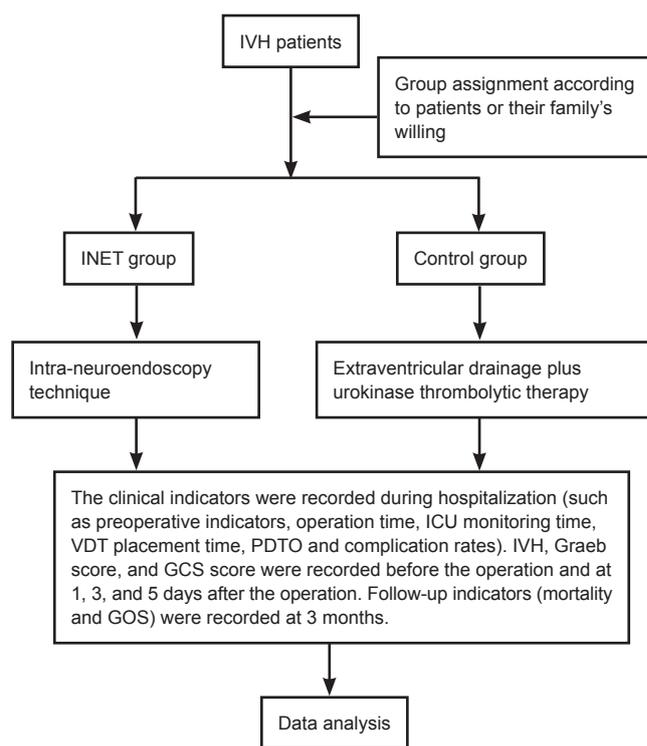

Figure 1 Flow chart of the study.
IVH: Intraventricular hemorrhage; INET: intra-neuroendoscopic technique; ICU: intensive care unit; VDT: ventricular drainage tube; PDTO: postoperative drainage tube obstruction; GCS: Glasgow Coma Scale; GOS: Glasgow Outcome Scale.

tween the two groups in sex ratio, age, preoperative Glasgow Coma Scale (GCS) score, preoperative Graeb score, preoperative IVH volume, etiology, or bleeding site (**Table 1**). All patients underwent brain CT to determine the diagnosis. Magnetic resonance angiography (MRA), computed tomo-

Figure 2 Transparent sheath and neuroendoscope before (upper) and after (lower) assembly.
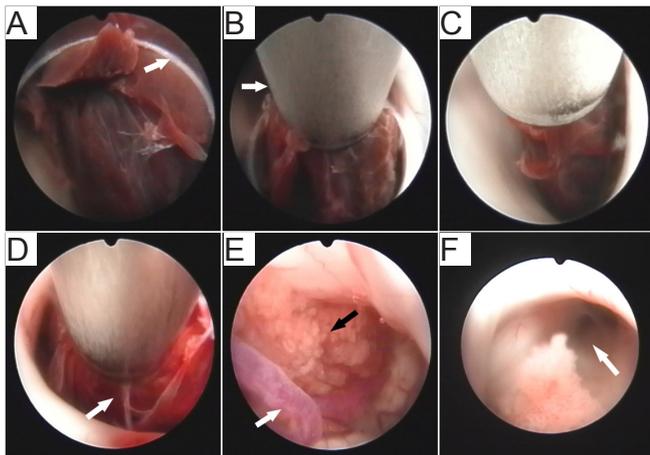
Figure 4 Surgical process for removing a ventricular hematoma.
(A) A hematoma in the lateral ventricle was clearly visible after endoscope implantation. Arrow: Edge of the transparent sheath. (B) Removal of a hematoma in the lateral ventricle body. Arrow: Head of the suction tube. (C) Removal of a hematoma in the occipital horn. (D) Removal of a hematoma in the third ventricle through the foramen of Monro. Arrow: Hematoma. (E) The choroid plexus and superior choroid vein were clearly visible after removal of a lateral ventricle hematoma. Black arrow: Choroid plexus; white arrow: superior choroid vein. (F) The bottom of the third ventricle was clearly visible after removal of the hematoma. Arrow: Bottom structure of the third ventricle.

graphic angiography (CTA), or digital subtraction angiography (DSA) was used to determine the cause of bleeding. **Table 1** shows the patients who had cerebral hemorrhage with unexplained causes, underwent MRA/CTA/DSA examinations, and who had no vascular malformations. They also had no history of hypertension, and their postoperative blood pressures were normal. A flow chart of the study is shown in **Figure 1**.

Figure 3 A 3-cm-base small curved flap.
Arrow: The drainage tube.
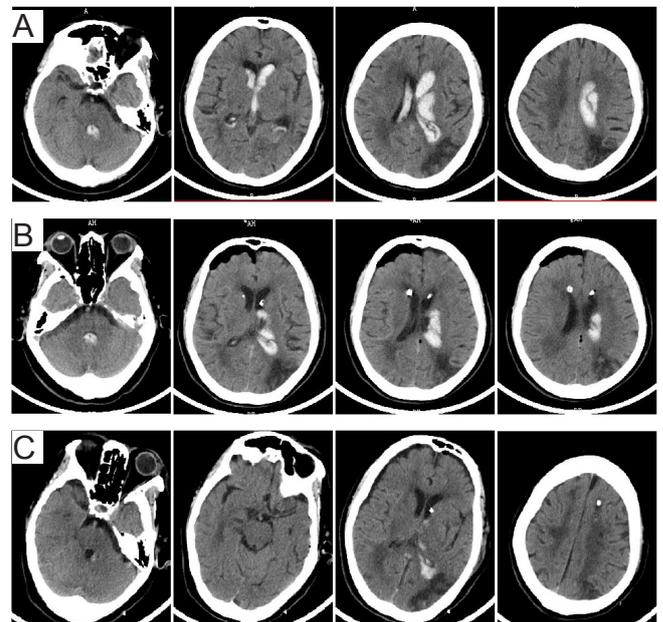
Figure 5 CT images before and after surgery.
A left thalamus hematoma had broken into the ventricle. (A) Before the operation. (B) Immediately after the operation. (C) CT scan 3 days after the operation.

Inclusion criteria

Patients who meet all of the following criteria were considered for study inclusion: (1) Age 18–75 years; (2) severe IVH, Graeb score > 5 points (Du et al., 2014); (3) primary or secondary IVH (Du et al., 2014) with brain parenchyma hematoma volumes ≤ 15 mL; (4) patients or their families agreed to surgery, entered the clinical study sequence, and signed the informed consent form.

Exclusion criteria

Patients who meet one or more of the following conditions were excluded from the study: (1) Severe systemic diseases such as heart, liver, lung, or kidney dysfunction; (2) abnormal coagulation function; (3) IVH due to cerebral aneurysm with an untreated cause; (4) IVH leading to respiratory and cardiac failure or recovery from cardiopulmonary resuscita-

Table 2 Comparison of surgical and follow-up indices between the INET and control groups

Group	Operation time (minute)	ICU monitoring time (day)	VDT placement time (day)	3-month mortality [%(n/N)]	3-month GOS
INET	86.8±15.2	5.0±0.8	2.9±0.7	2.9(1/35)	3.7±1.3
Control	39.7±9.2	16.2±5.3	12.6±5.8	23.3(7/30)	2.9±1.2
P-value	< 0.05	< 0.05	< 0.05	0.033	< 0.05

n = 35 and 30 in the INET and control groups, respectively. Data are expressed as the mean ± SD (*t*-test and chi-square test). INET: Intra-neuroendoscopic technique; ICU: intensive care unit; VDT: ventricular drainage tube; GOS: Glasgow Outcome Scale.

Table 4 Comparison of PDTO and complication rates between the INET and control groups

Group	PDTO rate	CSF leakage	Intracranial infection	Intracranial gas accumulation	Secondary bleeding
INET	0	4(11.4)	2(5.7)	29(82.9)	0
Control	9 (30)	7(23.3)	8(26.7)	6(20)	5(16.7)
P value	0.002	0.202	0.02	0	0.04

Data are expressed as number (percent) of 35 and 30 patients in the INET and control groups, respectively (chi-square test and Fisher's exact test). PDTO: Postoperative drainage tube obstruction; CSF: cerebrospinal fluid; INET: intra-neuroendoscopic technique.

Table 3 IVH volume (mL), Graeb score, and GCS score before surgery and at 1, 3, and 5 days after the operation

	Before operation	1 day	3 days	5 days
IVH volume				
INET group	74.2±10.4	8.6±1.9	3.4±1.0	1.5±0.5
Control group	71.2±9.2	45.5±6.7	31.2±5.9	24.8±4.7
Graeb score				
INET group	8.0±1.6	3.4±1.3	1.4±0.6	0.8±0.5
Control group	7.8±1.4	6.1±0.9	5.0±0.7	4.1±0.8
GCS score				
INET group	7.6±1.6	9.6±1.9	11.4±1.6	12.4±1.7
Control group	7.8±1.5	6.4±1.5	8.6±1.8	8.9±2.1

Data are expressed as the mean ± SD of 35 and 30 patients in the INET and control groups, respectively (repeated-measures analysis of variance). IVH: Intraventricular hemorrhage; GCS: Glasgow Coma Scale; INET: intra-neuroendoscopic technique.

tion; (5) unstable vital signs or brain hernia.

This study was a non-randomized concurrent control trial, and patients were grouped according to their or their family's willingness to accept either treatment.

Surgical techniques
The control group was treated with EVD + UT therapy.

Technical equipment used for INET
The INET equipment used in this study consists of a high-definition imaging system, cold light source, Zeppelin large-working-channel endoscope, endoscope-dedicated bipolar coagulator (ZNE-242BIP, Zeppelin), and two of our patented inventions: a transparent sheath (State Intellectual Property Office of P.R.China; website: http://cpquery.sipo.gov.cn; ZL 200820046232.0) and a hematoma aspirator (State Intellectual Property Office of P.R.China; website:

http://cpquery.sipo.gov.cn; ZL 201520248717.8). The Zeppelin large-working-channel endoscope (model number: NEH/30-177-6.5) has a 177-mm working length, 6.5 mm body diameter, and a 0° or 30° angle of view. The endoscope has a working channel diameter of 3.7 mm, and two integrated 1.5-mm suction/flushing channels. The transparent sheath can be seamlessly fit to the neuroendoscope, and its outer diameter is 7 mm with a length scale. A transparent tip and a fixed device were also designed for the sheath. After successful endoscope-guided puncture, the tip of the sheath can be removed, together with the endoscope (**Figure 2**). The diameter of the hematoma aspirator, which contains a spiral suction device, is 2.2 mm, and it can be connected to a power system.

Surgical methods used for INET
Patients underwent the INET operation after general anesthesia. The puncture-point positions were 2.5 cm anterior to the coronal seam and 2.5 cm adjacent to the midline. The surgical incision created a 3-cm-based small curved flap (**Figure 3**), and the diameter of the bone hole was 0.8–1.0 cm. The endoscope and the transparent sheath were assembled, and the puncture was visualized. After puncturing the correct location, the endoscope and the tip of the sheath were removed together. The neuroendoscope was then re-implanted into the sheath and the hematoma aspirator was inserted through the working channel of the endoscope to remove the hematoma (**Figure 4** and **Additional video 1**). Small amounts of bleeding were stopped by flushing fluid with continuous rinsing, and bleeding at other sites was stopped by endoscopy-dedicated bipolar coagulation. The flushing fluid consisted of saline maintained at 39°C. The negative suction of the hematoma aspirator was generally set at 35–45 kPa in the lateral ventricle and 8–10 kPa in the third ventricle. The preferred method for removing hemato-

mas in the third ventricle involved pulling them from the foramen of Monro into the lateral ventricle and then increasing the negative suction pressure to remove the hematoma. For IVH patients presenting with hematomas in bilateral lateral ventricles and the third ventricle, we found that the preferred method to remove third intraventricular hematomas involved removing them from both sides at different times. When the hematoma was removed and the flushing liquid became clear, the surgery was completed. Puncture tract bleeding was stopped *via* a bipolar coagulator inserted through the endoscope working channel when the transparent sheath was removed from the ventricle. The standard INET treatment used in this study required the removal of all bilateral and third ventricle hematomas during the operation. A drainage tube was placed in the lateral ventricle after the operation. For patients with bilateral EVD, if the drainage fluid was clear on the first day after the operation, one ventricular drainage tube could be removed, and the second could be removed after 2–3 days, according to the results of the CT. In one case, as shown by CT images before and after surgery, the left thalamus hemorrhaged, and the hematoma moved into the ventricle (**Figure 5**).

Observation indicators
The incision design, operation time, postoperative ICU monitoring time, ventricular drainage tube placement time, postoperative drainage tube obstruction rate, complications (intracranial infection, intracranial gas accumulation, cerebrospinal fluid leakage, secondary bleeding), 3-month mortality, and Glasgow Outcome Scale (GOS) (1: Death, 2: persistent vegetative state, 3: severe disability, 4: moderate disability, 5: low disability) were recorded and compared between the two groups. Additionally, the IVH volume, Graeb scores (Graeb score = right ventricular score + left ventricular score + 3rd ventricular score + 4th ventricular score), and GCS scores were analyzed and compared between the two groups before the operation and at 1, 3, and 5 days after the operation. The standards for patients to be transferred from ICU were: (1) Cerebral CT indicated that intraventricular hematomas were removed and no ventricular drainage tube remained. (2) Patient vital signs were stable, without ventilator-assisted ventilation. (3) No intracranial infection or cerebrospinal fluid leakage. The follow-up surveys were performed after 3 months. The 3-month mortality and GOS were collected from patient medical records upon readmission, from the outpatient clinic records, or *via* telephone interview. The GOS was the primary outcome measure.

Statistical analysis
Data are expressed as the mean ± SD or number and percentage. SPSS 13.0 statistical software (SPSS Inc., Chicago, IL, USA) was used for data analysis. The ICU monitoring time before and after treatment, ventricular drainage tube placement time, and operation time were compared using *t*-tests. The rate comparisons were performed using the chi-square test and Fisher's exact test. The IVH volume, Graeb

scores, and GCS scores before the operation and at 1, 3, and 5 days after the operation were compared using repeated-measures analysis of variance (ANOVA). A *P*-value less than 0.05 was considered statistically significant.

Results
Clinical manifestation
No significant differences were observed in the preoperative indicators between the INET and control groups (**Table 1**). The results for the intraoperative and postoperative indicator comparisons were as follows. First, the surgical approaches and the puncture points were identical in the two groups. We used a 3-cm-base small curved flap, and the drainage tube exited through a subcutaneous tunnel (**Figure 3**). Second, operation duration was longer for the INET group, while ICU monitoring and ventricular drainage-tube placement times were shorter.

Short- and medium-term outcomes
The INET group had a lower 3-month mortality and higher GOS than the control group (**Table 2**). Repeated-measures ANOVA was performed for IVH volume, Graeb score, and GCS score before the operation and at 1, 3, and 5 days afterward (**Table 3**). The results revealed a statistically significant main effect of time (IVH volume: $F = 1598.0$, $P = 0.00$; Graeb score: $F = 784.8$, $P = 0.00$; GCS score: $F = 333.6$, $P = 0.00$), and significant interactions between time and the intervention factors (IVH volume: $F = 21.1$, $P = 0.00$; Graeb score: $F = 94.8$, $P = 0.00$; GCS score: $F = 38.7$, $P = 0.00$).

Complications
A comparison of the postoperative drainage-tube obstruction rate between the two groups showed that while no patient had drainage tube occlusion in the INET group, occlusion was found in nine patients in the control group (**Table 4**). The incidence of complications suggested that the rates of secondary bleeding and intracranial infection in the INET group were lower than those in the control group ($P < 0.05$), but the rate of intracranial gas accumulation was higher in the INET group. No significant difference was observed in the incidence of cerebrospinal fluid leakage between the two groups ($P = 0.202$; **Table 4**).

Discussion
IVH is a fatal type of stroke. Even if patients survive the initial attack, the growing hematoma triggers a series of life threatening events, leading to the obstruction of cerebrospinal fluid flow, progression of neurobehavioral deficits, and possible death (Fiorella et al., 2015; Yu et al., 2015). Neuroendoscopic techniques have progressed rapidly and the use of neuroendoscopy for the treatment of ventricular hemorrhage has many advantages, especially for reducing postoperative mortality, preventing acute hydrocephalus, reducing intracranial pressure, and improving hematoma clearance. Additionally, it can improve the recovery of neurological

function, reduce the rate of ventricular peritoneal shunts, and improve the prognosis of IVH patients (Komatsu et al., 2010; Chen et al., 2011; Basaldella et al., 2012; Johnson et al., 2017). However, the currently used neuroendoscopic sheath is constructed from metal and cannot be used for visualized punctures. Opaque metal sheaths lead to narrow visual fields during surgery, which increases the risks associated with operation in the narrow ventricular space. The diameter of the commonly used transparent sheath is large and not suitable for intraventricular puncture (Wang et al., 2015; Sun et al., 2017). Some smaller diameter transparent sheaths can be used for intraventricular puncture, but this design cannot be used for complete intra-neuroendoscopic operations. This procedure is termed a neuroendoscopy control technique (Nishihara et al., 2005). In this technique, endoscopy only functions as an illumination system; all operational procedures are implemented outside the endoscope. In contrast, here the neuroendoscope provided a working channel and two flushing-drainage channels in addition to lighting. Further, all our operations were performed in the endoscopic working channel. We designed a new transparent sheath for the large-channel neuroendoscope, and using this, we achieved a visualized puncture and access to a broader field of vision during the operation. We call the new method, INET (Du et al., 2017). The finer and more minimally invasive puncture channel, the more secure full-scale visualization operation, and more efficient hematoma removal are the outstanding advantages of the new technique.

Comparison of the INET and EVD + UT methods in the treatment of severe IVH

This study was a non-randomized concurrent control trial, and patients were grouped according to their or their family's willingness to accept a treatment. To control the grouping bias, we have taken a series of measures. For example, the inclusion and exclusion criteria were strict and no significant differences were observed in the preoperative baseline indicators between the INET and control groups. The current study was mainly for severe IVH cases (Graeb score > 5 points), and we knew that the strict restrictions might limit the promotion of the new technique. However, to confirm the findings for this new technique, we will cover various types of IVH in the follow-up studies. Additionally, the clinicians providing treatment suggestions were not investigators in the current study.

EVD is a simple and widely used method for reducing intraventricular pressure that can effectively avoid the occurrence of acute obstructive hydrocephalus. However, the incidence of postoperative drainage-tube obstruction with EVD is high, and hematoma-removal efficiency is low (Hughes et al., 2015). Urokinase injection through the drainage tube can dissolve the thrombosis and increase the intraventricular hematoma drainage efficiency, but the risk of thrombolysis may be underestimated (Naff et al., 2011). In the current study, patients with unilateral ventricle hemorrhage underwent unilateral EVD, and others underwent bilateral EVD. All drainage devices were part of the Medtronic in vitro drainage and monitoring system (Product standard number: YZB/USA 6560-2012). The urokinase intraventricular thrombolysis method was conducted as follows. Urokinase (10,000 U) was administered twice a day. The brain CT results were reviewed to determine whether the ventricular drainage tube should be removed, and the tube placement time was no more than 14 days. The patients were typically discharged from the ICU after their drainage tubes were removed, at 1 to 2 days. Intrathecal injection through the lumbar pool drainage tube was used when intracranial infection was found through daily examination of the cerebrospinal fluid. Our results found that although operation time (86.8 ± 15.2 minutes *vs.* 39.7 ± 9.2 minutes; *P* < 0.01) was significantly longer in the INET group than in the control group, the ICU monitoring time (5.0 ± 0.8 days *vs.* 16.2 ± 5.3 days; *P* < 0.01) and ventricular drainage-tube placement time (2.9 ± 0.7 days *vs.* 12.6 ± 5.8 days; *P* < 0.01) were significantly shorter in the INET group than in the control group. The ventricular drainage tube was usually removed from patients in the INET group within 3 days, and their residence time in the ICU was less than 1 week. Because hematomas in the third and lateral ventricles were removed during the INET operation, no postoperative drainage-tube obstruction occurred. However, nine cases of drainage-tube obstruction occurred in the control group, which accounted for 30% of the patients. If we had not added UT therapy, the ratio would have been even higher. The diameter of the transparent sheath was 7 mm for the INET operation, and the operation time was longer for this group, which was also prone to postoperative cerebrospinal fluid leakage. However, due to the 3-cm-base small curved-flap design, the incidence of cerebrospinal fluid leakage in the INET group did not increase, and no difference was observed between the INET and control groups (INET: 11.4%; control: 23.3%; *P* = 0.202). Leakage of cerebrospinal fluid usually occurred after extubation, and was stopped using a full-thickness scalp suture and raising the head to 45 degrees. When intracranial infection was found by routine examination of cerebrospinal fluid after the operation, it was usually resolved by intrathecal injection of vancomycin (10 mg) every 12 hours for 3–5 days. The incidence of intracranial infection in the control group was significantly higher than that in the INET group (26.7% *vs.* 5.7%; *P* = 0.02), which was primarily because of the prolonged placement of the ventricular drainage tube, repeated intraventricular injection of urokinase, and longer ICU stays and rehabilitation times. The incidence of intracranial gas accumulation was significantly higher in the INET group than in the control group (82.9% *vs.* 20%; *P* = 0.00). Intracranial gas accumulation primarily occurred in the bilateral forehead subdural and intraventricular spaces, and it usually disappeared within 2–3 days. Postoperative intraventricular injection of water dramatically improved intraventricular gas accumulation. Bilateral forehead subdural gas accumulation occurred because of the volume contraction of brain tis-

sue when using negative pressure to remove the hematoma in the ventricle. One method used to improve this situation consisted of using cotton sheets to prevent gas from entering the dura from the bone hole. The incidence of secondary bleeding was significantly lower in the INET group than in the control group (0% *vs.* 16.7%; *P* = 0.04), and the main cause of bleeding was intraventricular thrombolysis. Rapid removal of ventricular hematoma and restoration of normal cerebrospinal fluid circulation was the core treatment for severe IVH (Starnoni et al., 2017). These results indicated that the IVH volume and Graeb scores for both groups decreased with time, while the GCS score increased. INET therapy removed the intraventricular hematoma faster than the control therapy, and GCS scores were significantly improved in the INET group within 5 days after the operation. Efficient removal of hematoma is also a key factor in shortening ICU monitoring time and ventricular drainage-tube placement time, reducing the incidence of intracranial infection and secondary intracranial bleeding. All of these can reduce the damage to the brain tissue and improve rehabilitation of brain function, which is ultimately reflected in the reduction in mid-term mortality and improvement of neurological function.

INET effect on postoperative rehabilitation of neurological function

Primary and secondary brain damage occurs in the pathological processes of IVH. The primary damage usually occurs within minutes to hours and is mainly caused by mechanical disruption due to the mass effect of hematoma. The cytotoxicity of blood, excitotoxicity, oxidative stress, and inflammation together result in secondary brain damage, which can cause severe disability or death (Keep et al., 2012). After hemorrhage, the blood components, including thrombin and iron, have a major role in brain injury and their effect may combine to exacerbate IVH-induced injury, as found in intracranial hemorrhage (Nakamura et al., 2005). Therefore, it is critical to find an effective surgical treatment that can remove hematomas quickly and provide neuroprotection to patients suffering from IVH. In this study, our new technique has achieved this goal and neural trauma was less than what we saw with the current standard method. The results at the 3-month follow-up indicate that mortality was lower and that GOS score was higher in the INET group than in the control group. These better medium-term outcomes were largely due to the safe and efficient processing of the new technique.

Limitations

This study was a non-randomized concurrent control trial. Although some methods were taken to reduce bias, such as strictly controlling the selection criteria and balanced treatment of mixed factors using statistical methods, we still could not guarantee that all bias was removed. The surgeons were trained to do the operation before the study, but some differences in surgical techniques were still unavoidable. The

patients' compliance with treatment and the condition of their post-discharge rehabilitation treatment also have some impact on the prognosis.

Conclusion

The INET operation for severe intraventricular hematoma evacuation is a safe and efficient new surgical option. This technique is minimally invasive and may be helpful for providing good outcomes for selected patients. It can quickly remove ventricular hematomas, and using postoperative urokinase intraventricular thrombolytic therapy is no longer necessary. Hematomas in the bilateral ventricles and the third ventricle can be removed during one session, and the postoperative drainage-tube congestion problem can be avoided. INET surgery can resolve the core issues of treatment for patients with severe IVH. This approach shortened the patient treatment time and obviously improved the patient prognosis. The INET operation process is visualized, flexible, and convenient, and it is readily accepted by patients. Therefore, it is suitable for technical promotion. A more accurate assessment of the clinical efficacy of the INET requires the support of multi-center follow-up randomized controlled-trial studies with large sample sizes and long durations.

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Open peer review reports:

Reviewer 1: Marvin Antonio, Escuela Superrior de Medicina IPN, Mexico.

Comments to authors: The work is technically good and the presentation is right. Also, the authors included some limitations. However, the link with neurorepair, neuroregeneration or neuroprotection processes is very weak. The work is interesting, and it is among those fields with increased attractiveness. However, I suggest the enrichment of references approaching this topic.

Reviewer 2: Attilio Marino, Center for Micro-BioRobotics@SSSA, 56025 Pontedera, Italy.

Comments to authors: See Additional file 1.

Additional files:

Additional video 1: Remove lateral ventricle hematoma.

Additional file 1: Open peer review report 2.

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