Int Surg 2015;**100:**1117–1123
DOI: 10.9738/INTSURG-D-14-00222.1

Rapid Pore Cranial Drilling With External Ventricular Drainage for Treatment of Intraventricular Hemorrhage: A 36-Year Case Series

Wei Zhang[1,2], Lin Wei[3], Gang Li[1], Jinlong Sun[4], Peng Jin[5], Jun Yang[5], Daokui Wang[6], Yunan Bai[2], Xingang Li[1], Chang Fei[7], Chengwei Wang[8], Baoan Wang[9], Shumao Pan[4], Jihai Du[10], Bo Xie[11], Dongfang Xu[12], Changming Xin[13], Jihua Wang[14], Qinglin Zhang[8]

[1]*Qilu Hospital, Shandong University, Jinan, Shandong Province, China*
[2]*Weifang Yidu Central Hospital, Weifang, Shandong Province, China*
[3]*Qianfoshan Hospital, Jinan, Shandong Province, China*
[4]*Yantai Hospital of Binzhou Medical College, Yantai, Shandong Province, China*
[5]*Affiliated Hospital of Qingdao University, Qingdao, Shandong Province, China*
[6]*Weifang People's Hospital, Weifang, Shandong Province, China*
[7]*Linyi People's Hospital, Linyi, Shandong Province, China*
[8]*No.2 Hospital of Shandong University, Jinan, Shandong Province, China*
[9]*No.1 Hospital of Zibo, Zibo, Shandong Province, China*
[10]*Juxian People's Hospital, Rizhao, Shandong Province, China*
[11]*No.2 Hospital of Rongcheng, Weihai, Shandong Province, China*
[12]*Dezhou People's Hospital, Dezhou, Shandong Province, China*
[13]*Taian Central Hospital, Taian, Shandong Province, China*
[14]*No.3 Jinan Hospital, Jinan, Shandong Province, China*

Corresponding author: Xingang Li, PhD, Department of Neurosurgery, Qilu Hospital, Shandong University, 107 Wenhua West Road, Jinan, Shandong Province, China, 250012.
Tel.: 86 536 3275657; Fax: 86 536 3275657; E-mail: lixg@sdu.edu.cn
Corresponding author: Qinglin Zhang, PhD, Department of Neurosurgery, No.2 Hospital of Shandong University, 247 Beiyuan Street, Jinan, Shandong, China, 250033.
Tel.: 86 531 85875455; Fax: 86 531 85875455; E-mail: zhangqinglin@sdu.edu.cn

This study aimed to describe the technique details of rapid pore cranial drilling with external ventricular drainage and document its clinical outcomes by highlighting the advantages over the traditional and modified cranial drilling technique. Intraventricular hemorrhage is one of the most severe subtypes of hemorrhagic stroke with high mortality. The amount of blood in the ventricles is associated with severity of outcomes, and fast removal of the blood clot is the key to a good prognosis. Between 1977 and 2013, 3773 patients admitted for intraventricular hemorrhage underwent rapid pore cranial drilling drainage. The therapeutic effects and clinical outcomes were retrospectively analyzed. Of these patients, 1049 (27.8%) experienced complete remission, 1788 (47.4%) had improved condition, and 936 (24.8%) died. A total of 3229 (85.6%) patients gained immediate remission. One typical case was illustrated to demonstrate the efficacy of the rapid pore drilling technique. Rapid pore cranial drilling drainage in patients with intraventricular hemorrhage is fast, effective, and provides immediate relief in patients with severe conditions. It could be a better alternative to the conventional drilling approach for treatment of intraventricular hemorrhage. A randomized controlled trial for direct comparison between the rapid pore cranial drilling drainage and conventional drilling technique is in urgent need.

Key words: Intraventricular hemorrhage – External ventricular drainage – Rapid pore cranial drilling

Intraventricular hemorrhage (IVH) denotes a bleeding within the ventricular system of the brain. It usually results from traumatic brain injuries or hemorrhagic stroke, and the prognosis can be very poor.[1,2] Volume of IVH has been reported to be a predictor of outcome in patients with spontaneous intracerebral hemorrhage (ICH) and extension to the ventricles.[3,4] Epidemiologic data has demonstrated a strong association between the amount of blood in the ventricles and severity of outcomes including mortality, coma, and functional impairment.[4] This finding provides substantial support for the therapeutic idea of intraventricular hematoma removal, which has been validated in animal studies. The removal of blood clot from ventricles prevents hydrocephalus and inhibits inflammation mediated progressive tissue damage.[5,6] External ventricular drainage (EVD), also known as ventriculostomy, has then been developed to remove the blood or obstructed cerebrospinal fluid (CSF) from the ventricles of the brain, which thus relieves the elevated intracranial pressure (ICP) and hydrocephalus.[7] Efforts have been made to improve the drilling and drainage techniques. For example, the method of percutaneous needle trephination has been introduced and performed in case of emergency as a simple, low-risk, effective way to reduce ICP.[8,9] Similarly, Zhang *et al* first introduced a medical device named rapid pore drilling apparatus in 1975, and shortly after reported the first success using the rapid pore drilling technique to perform EVD via the frontal horn of the lateral ventricle, which saved the life of a patient with IVH and severe tonsillar hernia.[10,11] It was a fast procedure, completed within 10 minutes, and could be performed at the bedside under sterile condition. Since then, this technique has been adopted in many hospitals in Shandong Province, China. In this study, we collected and analyzed clinical data on 3773 patients who were admitted for IVH at 14 hospitals from 1977 to 2013 and received rapid pore cranial drilling with EVD. The clinical experiences, including operating procedures, duration, technical performances, and the therapeutic effect of rapid pore drilling with EVD were recorded. To our best knowledge, the present study was the biggest one that involved the largest cohort so far and summarized the clinical practice of the rapid pore cranial drilling technique over 30 years. The results indicate that the rapid pore cranial drilling technique is minimally invasive, fast, safe, and effective for treating patients with severe IVH.

Materials and Methods

Patient information

The study consisted of 3773 patients who were admitted to hospitals from 1997 to 2013 and treated

for IVH using rapid-pore cranial drilling with EVD. This study was performed in accordance with the Declaration of Helsinki (1964). Informed consent was obtained from legally authorized representatives of each patient.

Causes of bleeding included hypertensive intracerebral hemorrhage (2326 cases, 61.6%), aneurysm rupture (449 cases, 11.9%), cerebral arteriovenous malformation bleeding (206 cases, 5.5%), traumatic brain injury (269 cases, 7.1%), Moyamoya disease (59 cases, 1.6%), other (93 cases, 2.5%), and unknown reasons (371 cases, 9.8%). The main symptoms and clinical manifestations for admission were headache, vomiting, unconsciousness, convulsions, and other neurologic deficits. The Glasgow Coma Scale score before the operation was: 3 to 6 (761 cases, 20.2%), 7 to 9 (1788 cases, 47.4%), and 10 to 15 (1224 cases, 32.4%).

Surgical method

The pistol-like drilling apparatus (Fig. 1) was designed by Dr. Qinglin Zhang and Dr. Cheng Zhang, and manufactured by Xinhua Medical Instrument Factory of Shandong Province in 1964.[10] The most common puncture site was located 2 to 3 cm above the hairline and 2 to 3 cm beside the middle line, pointing to the frontal horn of the lateral ventricle. After local anesthesia of the puncture site, the scalp, skull, and dura mater were drilled directly in 1 line, and the drainage tube was inserted with a needle about 7 to 8 cm from the skin. The opening of the drainage tube was 10 to 15 cm higher than the ventricle level. Bilateral drainage was performed when the lateral ventricle was full of hematoma. The key point of the procedure was to prevent the scalp from slipping to ensure that the scalp puncture point and the skull hole were aligned.

The CSF pulsation of the tube was checked regularly to ensure that the tube was unobstructed. If obstruction occurred, the tube was reopened by irrigation with normal saline, squeezing, or repositioned by adjustment of depth. The drainage volume was maintained at about 200 mL/d, holding 5 to 7 days. Urokinase was infused to the ventricles as early as possible to decompose the hematoma clot and prevent tube blockage, especially for patients with a ventricular cast. CT scans were performed regularly to monitor the status of hematoma and obstruction. The results from CT scans were used to determine the efficacy of EVD. Before extubation, the tube was elevated to 20 cm above the ventricle for 24 hours. If the patient's condition did not worsen, the drainage tube could be removed. In this study, the longest duration of intubation was 15 days.

Fig. 1 The rapid pore cranial drilling apparatus. It includes a hand drill, several chisel-type drill bits, and safety stops. When the local anesthetic lidocaine is injected subcutaneously, the skin inflates and becomes pale; then the skin, skull, and dura mater are drilled directly in one line, and the drainage tube is inserted into the ventricle with the needle through the bone hole.

Results

This study included a total of 3773 patients suffering from IVH and admitted to 14 hospitals in Shandong Province from 1977 to 2013 (Table 1). Of these patients, 2172 were male and 1601 female, with a male–female ratio of 1.36:1. Patients ranged in age from 43 days to 97 years, with a mean of 51.7 years. A total of 58.2% of patients underwent unilateral cranial drilling with EVD treatment, and 41.8% underwent bilateral treatment. The drainage tubes were held from 5 to 15 days. By the end of the treatment, 1049 patients (27.8%) experienced complete remission, 1788 (47.4%) showed improvement, and 936 (24.8%) died. Statistics indicated that the conditions such as brain stem hemorrhage, aneurysm rupture, cerebral arteriovenous malformation hemorrhage, and thalamic hemorrhage had higher mortality (>30%).

The main complications in these patients treated with rapid pore cranial drilling and EVD were intracranial infection (178, 4.7%), upper gastrointestinal bleeding (162, 4.3%), lung infection (136, 3.6%), drilling point and/or puncture tract bleeding (67,

Table 1 Distribution of patients with intraventricular hemorrhage treated in 14 hospitals of Shandong Province between 1997 and 2013

Hospital	Year of first use	Male	Female	Total	Age range (y)	Mean age (y)	Unilateral	Bilateral
Qilu Hospital	1997	641	448	1089	7–91	43.4	511	578
Affiliated Hospital of Qingdao University	1980	291	171	462	7–90	45.3	261	201
Qianfoshan Hospital	1993	147	118	265	11–97	55.0	112	153
No. 2 Hospital of Shandong University	1997	84	58	142	8–89	45.6	87	55
Linyi People's Hospital	1978	74	50	124	43 d–86	54.0	112	12
Weifang People's Hospital	1979	140	117	257	21–74	36.0	176	81
No.1 Hospital of Zibo	1992	77	51	128	20–81	63.0	88	40
Dezhou People's Hospital	1980	177	116	293	16–80	43.8	190	103
Yantai Hospital of Binzhou Medical College	1980	147	123	270	17–80	56.0	162	108
Taian Central Hospital	1990	107	125	232	27–76	53.0	135	97
Weifang Yidu Central Hospital	1993	113	89	202	1–86	53.3	149	53
No. 3 Jinan Hospital	1985	49	38	87	11–77	42.3	61	26
Juxian People's Hospital	1994	98	85	183	11–84	59.0	123	60
No. 2 Hospital of Rongcheng	1979	26	13	39	20–96	62.0	27	12
Total		2172	1601	3773	43 d–97	51.7	2194	1579

1.8%), and others (19, 0.5%). It is worth mentioning that in this study no cases needed emergent surgical operation to remove a hematoma occurring due to puncture.

As an illustrative case, a 45-year-old male patient was admitted for sudden headache and left hemiparalysis for 2 hours with a primary diagnosis of IVH. The brain CT scan showed acute hydrocephalus and diffusive brain edema (Fig. 2). The ICP was about 360 mmH_2O (3.53 kPa). At the bedside, bilateral rapid pore cranial drilling was performed and EVD was initiated within 10 minutes. After discharge of 60 mL bloody CSF, the patient's respiration, blood pressure, and pulse became stable, consciousness improved, and pupil dilation returned to normal. The patient gained consciousness after drainage of 24 hours, and the drainage volume was about 150 to 200 mL/d. The CSF became clear within 4 days, and the CT scan showed no visible hydrocephalus and reduced hemorrhage in the ventricles (Fig. 3). Catheter of the right lateral ventricle was removed on the seventh day and the CT scan on the 11th day showed that the hemorrhage was partially absorbed (Fig. 4). The left drainage catheter was removed on day 14 following

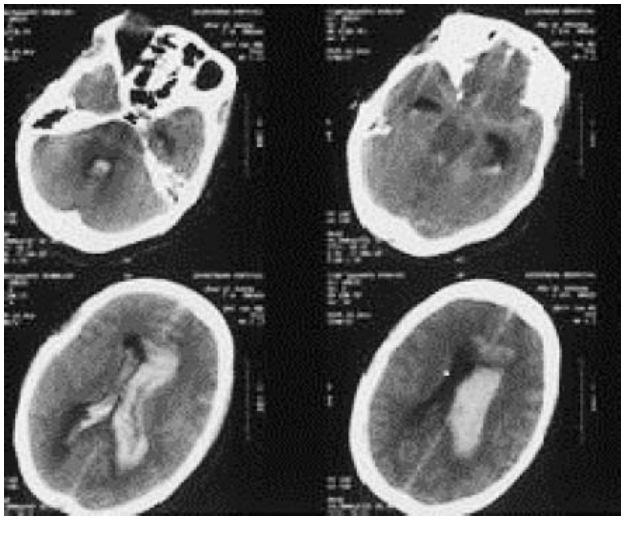

Fig. 2 CT image of brain scans of a patient with intraventricular hemorrhage. The results revealed IVH-induced acute hydrocephalus and diffusive brain edema.

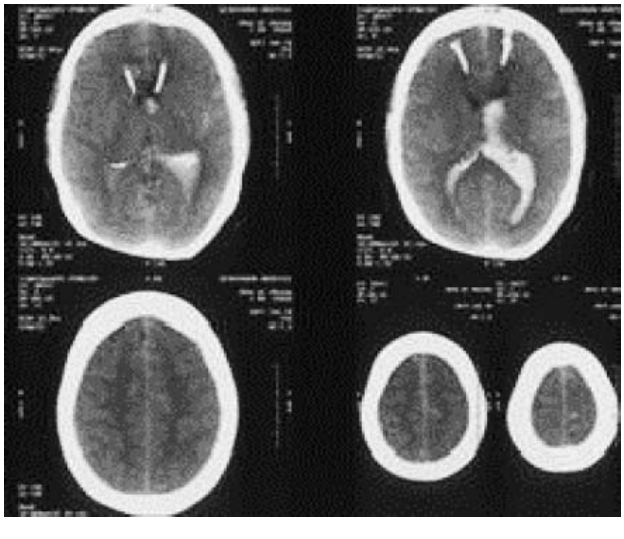

Fig. 3 CT image of brain scans of the same patient taken 4 days after external ventricular drainage performed via bilateral rapid pore cranial drilling. The results showed absence of hydrocephalus and reduced hemorrhage in the ventricles.

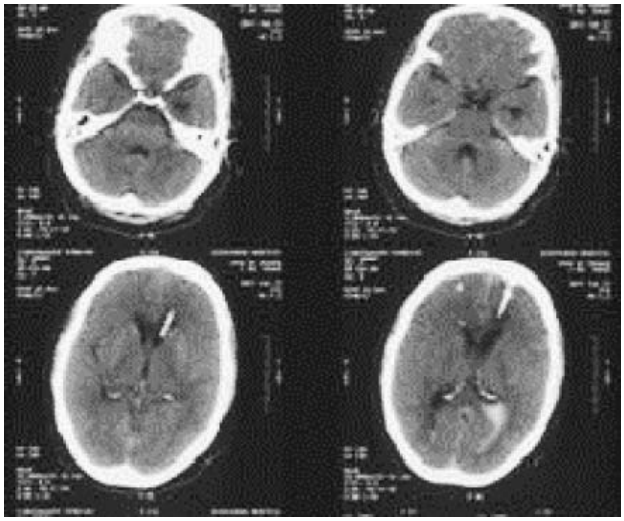

Fig. 4 CT image of brain scans of the same patient taken 11 days after rapid pore cranial drilling with external drainage. The catheter of the right lateral ventricle had been dislodged. The intraventricular hemorrhage had disappeared.

the disappearance of hemorrhage, and the patient was safely discharged after further treatment upon full recovery.

Discussion

It has been reported that 40% of patients with spontaneous intracerebral hemorrhage (ICH) have extension of the hemorrhage into the ventricles early or late in the sequence.[4,12,13] The 30-day mortality rate for patients with IVH is nearly 5 times higher than those with ICH alone.[14] We think there are several reasons for the high mortality rate and disability rate of IVH: first, a vicious cycle of acute increased ICP inducing fatal brain hernia[15]; second, potential triggering of cerebral vasospasm by vasoactive agents arising from or released by the hemorrhage, such as serotonin, prostaglandins, catecholamines, angiotensin, oxyhemoglobin, endothelin, calcium ion, protein kinase C, thromboxane A2 (TxA2), substance P, histamine, hypothalamus exudate, biogenic amines and peptides, fatty peroxides, and free radicals[16,17]; third, secondary brain edema; and fourth, acute obstructive hydrocephalus.[4] Whether these pathologic processes, especially the rapid increase of ICP and tissue inflammation, can be blocked or relieved is the key to successful treatment of severe IVH. Rapid pore cranial drilling is a quick and effective practice to gain the patients immediate relief from elevated ICP, stop the malignant pathologic development of brain hernia, and facilitate further treatment. Significant impact has been made in patients with very severe IVH who were in deep coma (Glasgow Coma Scale score $\leq$6) and/or showed unstable vital signs. More than 20% of the patients in our study belonged to this group, and most of them experienced quick remission through the immediate use of rapid pore cranial drilling drainage. A very similar procedure, percutaneous needle trephination, was introduced in the early 1980s, and demonstrated clinical efficacy.[18] Although the principle of the procedure is the same as ours, the drilling technique is different and takes approximately 20 minutes to complete the procedure, which is significantly longer than ours (5 minutes for unilateral drainage). Despite these differences, the complication rates, including the rate of intracranial infection, are both low and comparable between the 2 procedures.[8,9]

The rapid pore cranial drilling technique has multiple advantages over the traditional methods including the Dandy's approach. A comparison of procedures shows that the rapid pore drilling is superior to Dandy's drilling in terms of complexity of operating procedures and requirements, number of trained personnel required, operation duration and cranial injury (Table 2). Rapid pore drilling allows the initiation of unilateral EVD within 5 minutes, which greatly reduces the lethal risk of brain herniation from prolonged ICH and IVH. The scalp incision and diameter of bone hole are very small compared to that from conventional drilling (5 mm versus 40 mm and 5 mm versus 12–14 mm, respectively), which minimizes the damage to the hypothalamus and reduces the stress response from invasive surgery. The prognosis is greatly improved and better outcome is achieved. The statistic data have shown that the case fatality rate for conservative treatment of severe IVH was 78%, and it was 58% for EVD performed by conventional drilling technique.[1] In our study, the mortality rate of 3773 cases with rapid pore drilling was only 24.8%, and the mortality rate for patients with severe conditions such as aneurysm rupture and cerebral arteriovenous hemorrhage was slightly higher (>30%), yet still significantly lower than the historical comparator. However, this comparison was made from indirect observational studies using historic data. The analysis did not adjust for the differences in medical conditions of the patients, age and sex composition of the group, surgical protocols, and definition for infection. Therefore, a well-controlled study is required for direct comparison of the rapid

Table 2 Comparison of traditional Dandy's drilling and rapid pore drilling techniques for treating intraventricular hemorrhage

	Traditional Dandy's drilling	Rapid pore drilling and drainage
Procedures	• Local anesthesia • Scalp incision • Hemostasis with scalp clip • Electrocoagulation hemostasis • Retraction with mastoid retractor • Drilling the skull • Rinsing • Clearing the residual internal lamina • Hemostasis with bone wax • Electrocoagulation of the dura mater • Incision of the dura mater • Cortical electrocoagulation • Insertion of drainage tube to the ventricle • Suturing the subcutaneous tissue and galea aponeurotica (3 pins) • Suturing the scalp (4 pins) • Fixing the drainage tube • Connecting to the drainage device • Pasting the dressing	• Local anesthesia of puncture point • Piercing the scalp and then drilling the skull, dura mater to the cortex successively in one process (without pause) • Inserting the ventricle drainage catheter • Suture l pin to fix • Connection • Pasting the dressing
Cranial injury	• Scalp incision: $\geq$ 40 mm • Diameter of bone hole: 12–14 mm	• Scalp incision: 5 mm • Diameter of bone hole: 5 mm
Time (min)	60	5
Personnel required	2 doctors and 1 nurse	1 doctor

pore cranial drilling with the conventional drilling technique and modified procedures such as percutaneous needle trephination.

Ventricular drainage combined with fibrinolytics has been proved to improve the outcome of IVH.[19–21] In our study, fibrinolysis with urokinase was used to accelerate clot dissolution and keep the drainage tube unobstructed. In addition, lumbar puncture or lumbar catheter drainage can be used in patients in stable condition to promote the circulation of CSF and clearance of bloody CSF, thereby reducing hydrocephalus, arachnoid adhesions, cerebral ischemia, cerebral infarction and other delayed complications.[22]

Intracranial infection is the major complication of external ventricular drainage and the risk of infection increases with the duration of drainage, which greatly limits its use in patients who need longer drainage. A recent study reported the use of long subcutaneous tunneling of external ventricular drainage, which uses an externalized distal catheter to increase the distance between the drainage exit site and the puncture hole on the skull in order to reduce the risk of infection.[23] Unfortunately, our rapid pore cranial drilling is not suitable to adopt this adaptation. However, other preventative measures can be taken to minimize the chance of infection, such as the use of antibiotic-impregnated catheters, strict sterile techniques, and standardized perioperative management protocols.

One limitation of this study is that it uses historic data as controls. Since our results provide very strong evidence demonstrating the effectiveness of rapid pore cranial drilling in increasing the success rate and decreasing the mortality, it is urgent to conduct a prospective controlled trial.

Acknowledgments

The authors declare that they have no competing interests. Additionally, this study reported the percentage of patients who experienced complete, improved remission or died after the rapid pore cranial drilling combined with external ventricular drainage. The cause of ventricular bleeding before treatment was recorded and percentage of each cause analyzed. Main complications during the treatment were examined and percentage of each complication was calculated. No other statistical analysis was performed in this study. This study was supported by grants from the Shandong Provincial Technology Development Plan Financial Aid Project (no. 2008GG10002059) and the Shandong University 985 Project Phase III Neurosurgery Construction Program. Wei Zhang and Lin Wei contributed equally to this manuscript.

References

1. Nieuwkamp DJ, de Gans K, Rinkel GJ, Algra A. Treatment and outcome of severe intraventricular extension in patients with subarachnoid or intracerebral hemorrhage: a systematic review of the literature. *J Neurol* 2000;**247**(2):117–121
2. Woo D, Broderick JP. Spontaneous intracerebral hemorrhage: epidemiology and clinical presentation. *Neurosurg Clin N Am* 2002;**13**(3):265–279
3. Diringer MN, Edwards DF, Zazulia AR. Hydrocephalus: a previously unrecognized predictor of poor outcome from supratentorial intracerebral hemorrhage. *Stroke* 1998;**29**(7): 1352–1357
4. Hanley DF. Intraventricular hemorrhage: severity factor and treatment target in spontaneous intracerebral hemorrhage. *Stroke* 2009;**40**(4):1533–1538
5. Mayfrank L, Kissler J, Raoofi R, Delsing P, Weis J, Kuker W *et al*. Ventricular dilatation in experimental intraventricular hemorrhage in pigs. Characterization of cerebrospinal fluid dynamics and the effects of fibrinolytic treatment. *Stroke* 1997; **28**(1):141–148
6. Qureshi AI, Wilson DA, Traystman RJ. Treatment of transtentorial herniation unresponsive to hyperventilation using hypertonic saline in dogs: effect on cerebral blood flow and metabolism. *J Neurosurg Anesthesiol* 2002;**14**(1):22–30
7. Hinson HE, Hanley DF, Ziai WC. Management of intraventricular hemorrhage. *Curr Neurol Neurosci Rep* 2010;**10**(2):73–82
8. Meyer B, Schaller K, Rohde V, Hassler W. Percutaneous needle trephination. Experience in 200 cases. *Acta Neurochir (Wien)* 1994;**127**(3–4):232–235
9. Zentner J, Duffner F, Behrens E. Percutaneous needle trephination for external CSF drainage: experience with 226 punctures. *Neurosurg Rev* 1995;**18**(1):31–34
10. Zhang C, Zhang Q. Animal experiment and clinical application of cranial pore drilling. *CMJ* 1975;**55**(1):641–643
11. Zhang C, Zhang Q, Zhang Y. External ventricular drainage in the treatment of intraventricular hemorrhage. *Journal of Apoplexy and Nervous Diseases* 1984;**1**(1):201–203
12. Sjoblom L, Hardemark HG, Lindgren A, Norrving B, Fahlen M, Samuelsson M *et al*. Management and prognostic features of intracerebral hemorrhage during anticoagulant therapy: a Swedish multicenter study. *Stroke* 2001;**32**(11):2567–2574
13. Leira R, Davalos A, Silva Y, Gil-Peralta A, Tejada J, Garcia M *et al*. Early neurologic deterioration in intracerebral hemorrhage: predictors and associated factors. *Neurology* 2004;**63**(3):461–467
14. Tuhrim S, Horowitz DR, Sacher M, Godbold JH. Volume of ventricular blood is an important determinant of outcome in supratentorial intracerebral hemorrhage. *Crit Care Med* 1999; **27**(3):617–621
15. Scott TR, Kronsten VT, Hughes RD, Shawcross DL. Pathophysiology of cerebral oedema in acute liver failure. *World J Gastroenterol* 2013;**19**(48):9240–9255
16. Sasaki T, Kikkawa Y. Proposed mechanism of cerebral vasospasm: our hypothesis and current topics. *Acta Neurochir Suppl* 2013;**115**:53–56
17. Baggott CD, Aagaard-Kienitz B. Cerebral vasospasm. *Neurosurg Clin N Am* 2014;**25**(3): 497–528
18. Moringlane JR, von Wild K, Samii M. Clinical value of percutaneous needle trephination (PNT). *Acta Neurochir (Wien)* 1980;**54**(3–4):181–189
19. Rainov NG, Burkert WL. Urokinase infusion for severe intraventricular haemorrhage. *Acta Neurochir (Wien)* 1995; **134**(1–2):55–59
20. Ziai WC, Triantaphyllopoulou A, Razumovsky AY, Hanley DF. Treatment of sympathomimetic induced intraventricular hemorrhage with intraventricular urokinase. *J Stroke Cerebrovasc Dis* 2003;**12**(6):276–279
21. Martinez-Lage JF, Almagro MJ, Ruiz-Espejo A, Leon MC, Garcia-Martinez S, Moralo S. Keeping CSF valve function with urokinase in children with intra-ventricular haemorrhage and CSF shunts. *Childs Nerv Syst* 2009;**25**(8):981–986
22. Huttner HB, Schwab S, Bardutzky J. Lumbar drainage for communicating hydrocephalus after ICH with ventricular hemorrhage. *Neurocrit Care* 2006;**5**(3):193–196
23. Collins CD, Hartley JC, Chakraborty A, Thompson DN. Long subcutaneous tunnelling reduces infection rates in paediatric external ventricular drains. *Childs Nerv Syst* 2014;**30**(10):1671–1678