Effectiveness of endoscopic surgery for supratentorial hypertensive intracerebral hemorrhage: a comparison with craniotomy

*Xinghua Xu, MD, Xiaolei Chen, MD, Fangye Li, MD, Xuan Zheng, MD, Qun Wang, MD, Guochen Sun, MD, Jun Zhang, MD, and Bainan Xu, MD

Department of Neurosurgery, Chinese PLA General Hospital, Beijing, China

OBJECTIVE The goal of this study was to investigate the effectiveness and practicality of endoscopic surgery for treatment of supratentorial hypertensive intracerebral hemorrhage (HICH) compared with traditional craniotomy.

METHODS The authors retrospectively analyzed 151 consecutive patients who were operated on for treatment of supratentorial HICH between January 2009 and June 2014 in the Department of Neurosurgery at Chinese PLA General Hospital. Patients were separated into an endoscopy group (82 cases) and a craniotomy group (69 cases), depending on the surgery they received. The hematoma evacuation rate was calculated using 3D Slicer software to measure the hematoma volume. Comparisons of operative time, intraoperative blood loss, Glasgow Coma Scale score 1 week after surgery, hospitalization time, and modified Rankin Scale score 6 months after surgery were also made between these groups.

RESULTS There was no statistically significant difference in preoperative data between the endoscopy group and the craniotomy group ($p > 0.05$). The hematoma evacuation rate was $90.5\% \pm 6.5\%$ in the endoscopy group and $82.3\% \pm 8.6\%$ in the craniotomy group, which was statistically significant ($p < 0.01$). The operative time was 1.6 ± 0.7 hours in the endoscopy group and 5.2 ± 1.8 hours in the craniotomy group ($p < 0.01$). The intraoperative blood loss was 91.4 ± 93.1 ml in the endoscopy group and 605.6 ± 602.3 ml in the craniotomy group ($p < 0.01$). The 1-week postoperative Glasgow Coma Scale score was 11.5 ± 2.9 in the endoscopy group and 8.3 ± 3.8 in the craniotomy group ($p < 0.01$). The hospital stay was 11.6 ± 6.9 days in the endoscopy group and 13.2 ± 7.9 days in the craniotomy group ($p < 0.05$). The mean modified Rankin Scale score 6 months after surgery was 3.2 ± 1.5 in the endoscopy group and 4.1 ± 1.9 in the craniotomy group ($p < 0.01$). Patients had better recovery in the endoscopy group than in the craniotomy group. Data are expressed as the mean $\pm$ SD.

CONCLUSIONS Compared with traditional craniotomy, endoscopic surgery was more effective, less invasive, and may have improved the prognoses of patients with supratentorial HICH. Endoscopic surgery is a promising method for treatment of supratentorial HICH. With the development of endoscope technology, endoscopic evacuation will become more widely used in the clinic. Prospective randomized controlled trials are needed.

<https://thejns.org/doi/abs/10.3171/2016.10.JNS161589>

KEY WORDS endoscopic surgery; hypertensive intracerebral hemorrhage; craniotomy, vascular disorders

SPONTANEOUS intracerebral hemorrhages (ICHs) are responsible for 10%–30% of all strokes yet are one of the leading causes of stroke-related mortality and morbidity.¹⁰ Hypertensive ICH (HICH) is the most common type of ICH, accounting for approximately 70% of all ICHs.¹⁴ HICH is a common neurological emergency characterized by high fatality and disability rates. The me-

dian 30-day mortality rate after HICH is approximately 40%.^{21,25} Many survivors remain severely disabled and therefore pose a huge burden on society and families.⁷

Surgical hematoma evacuation and conservative therapy are the main treatments for ICH. Theoretically, surgical removal can facilitate the survival of a penumbra of functionally impaired but potentially viable surrounding tissue,

ABBREVIATIONS GCS = Glasgow Coma Scale; HICH = hypertensive intracerebral hemorrhage; ICH = intracerebral hemorrhage; mRS = modified Rankin Scale; STICH = Surgical Trial in Intracerebral Haemorrhage.

SUBMITTED June 15, 2016. **ACCEPTED** October 31, 2016.

INCLUDE WHEN CITING Published online April 7, 2017; DOI: 10.3171/2016.10.JNS161589.

* Drs. X. Xu and Chen contributed equally to this work.

FIG. 1. Volume measurement of hematoma with 3D Slicer. **A:** A preoperative CT scan confirmed a right basal ganglia hemorrhage. **B:** 3D reconstruction and volume measurement of hematoma with 3D Slicer. **C:** A postoperative CT scan showed that most of the hematoma had been evacuated. Figure is available in color online only.

by decreasing secondary brain edema resulting from the breakdown of blood and other neurotoxic chemicals.^{12,22} Hematoma removal also directly addresses the problem of local mass effect that leads to brain tissue damage.²⁸ Nevertheless, the effectiveness of craniotomy for the treatment of ICH remains controversial, despite having been repeatedly evaluated during the past 4 decades.^{1,26,34} With the development of neuroendoscopic techniques, endoscopic hematoma evacuation is proving to be effective and may have some advantages compared with craniotomy.^{1,17,18,30} Endoscopic hematoma evacuation may be theoretically attractive and may be advocated as the primary treatment of choice; however, its effectiveness remains unclear.^{8,32} We conducted a comparative study of endoscopic hematoma evacuation using a newly developed endoscope introducer versus traditional craniotomy evacuation of hematoma.

The volume of hematoma has been validated as an important independent predictor for prognosis of ICH.^{20,33} The Tada (ABC/2) formula has been widely used for bedside estimation of hematoma volume in almost all clinical studies. However, the ABC/2 formula has a certain range of error, especially in cases of irregular or large hematomas.²⁹ Therefore, 3D Slicer, a precise and freely available platform, was applied for the measurement of hematoma volume in this study.

Methods

Patient Selection

The study group (endoscopy group) consisted of 82 consecutive adult patients with supratentorial HICH treated between June 2011 and June 2014. The endoscopy group was matched to a historical control group (craniotomy group), a series of 69 consecutive patients treated by craniotomy at the Chinese PLA General Hospital between January 2009 and June 2012. The preoperative and postoperative treatments, including blood pressure management, were identical for all 151 patients. The inclusion criteria were spontaneous supratentorial HICH confirmed on brain CT scans with hematoma volume > 20 mL, admission to hospital within 48 hours of ictus, and adult-age patients with a Glasgow Coma Scale (GCS) score $\geq$ 5. Some patients underwent CT angiography to exclude underlying structural vascular disease. The exclusion criteria were hemorrhage caused by tumor, trauma, coagulopathy,

aneurysm, arteriovenous malformation, hemorrhage after infarction, and use of antiplatelet or anticoagulant drugs over a long period of time. Inclusion and exclusion criteria were the same for both groups. The study was approved by the Chinese PLA General Hospital medical ethics committee.

Calculation of Hematoma Volume

In all patients, a brain CT scan was obtained before and 24 hours after surgery. CT image data sets were acquired in the DICOM format. The data were transferred to a personal computer (Intel Core i5 CPU, 2 $\times$ 2.5 GHz, 4 GB RAM) and then assessed with 3D Slicer. Hematomas were automatically identified pixel by pixel in each slice after setting the threshold range at 50–100 Hounsfield units. Then, a 3D model was constructed and the hematoma volume was calculated by the accumulating volume of the pixels (Fig. 1). The hematoma evacuation rate was defined as follows: (preoperative volume – postoperative volume)/ (preoperative volume) $\times$ 100%.

Surgical Technique

The surgical procedure was performed while the patient was under general anesthesia. For the endoscopy group, a 3-cm skin incision was made according to the position of the hematoma on CT scan. We used a bur hole over the coronal suture for anterior basal ganglia hemorrhages that were not elongated but rather were more spherical. A parietooccipital bur hole was created to treat posterior basal ganglia and thalamic hemorrhages. In cases involving superficial lobar hemorrhages, we commonly use a bur hole directly over the hematoma where the lesion is closest to the surface.³ The dura mater was coagulated and incised in a cruciate fashion. We used our self-developed endoscopic puncture and working channel system (patent number 201210066281.1, Beijing Jin Cheng Medical Technology Co.) to create the operating space for the neuroendoscope. After the puncturing needle was positioned in the predetermined center of the hematoma, the needle core was removed and suction was applied with a 10-mL syringe to reduce intracranial pressure and to determine whether the puncture lever was in place. Next, a transparent sheath was introduced to an expected depth along the puncturing needle (Fig. 2). Through the transparent sheath,

FIG. 2. Schematic diagrams of the hematoma puncture process in the endoscopy group. **A:** Hematoma puncture with a blunt puncturing needle. **B:** Suction of the hematoma with a syringe. **C and D:** Placement of the transparent endoscopic sheath along the puncturing needle. Copyright Xiaolei Chen. Published with permission. Figure is available in color online only.

a neuroendoscope (diameter 3.6 mm, 0°, Karl Storz) was inserted and a metal suction catheter was used to evacuate the hematoma (Fig. 3). For the craniotomy group, a traditional craniotomy was performed to evacuate the hematoma. After opening the dura, the neurosurgeon accessed the hematoma cavity via a transcortical approach using microscopic assistance and removed the hematoma. All patients received the best medical treatment after surgery. A postoperative CT scan was obtained in every patient 24 hours after surgery to evaluate for any residual hematoma.

Statistical Analysis

All statistical analyses were performed with SPSS statistics version 21 (IBM Corp.). After confirmation of distribution, data are expressed as the mean $\pm$ SD. An unpaired t-test, rank-sum test, or χ^2 test was used for comparison between groups, as appropriate. A p value < 0.05 was considered statistically significant.

Results

Baseline Information

A total of 151 consecutive patients were enrolled in this

study: 82 in the endoscopy group and 69 in the historical control group (craniotomy group). Baseline characteristics are summarized in Table 1. The average age of patients was 52.9 years in the endoscopy group and 53.8 years in the craniotomy group ($p > 0.05$). The mean admission GCS score was 7.9 for the endoscopy group and 7.8 for the craniotomy group ($p > 0.05$). The mean time from ictus to surgery was 15.6 hours in the endoscopy group and 13.7 hours in the craniotomy group ($p > 0.05$). In the endoscopy group, the mean hematoma volume was 55.2 ml, whereas in the craniotomy group, it was 55.9 ml ($p > 0.05$). Most hematomas were located at the basal ganglia in both the endoscopy group (65 of 82) and the craniotomy group (52 of 69) ($p > 0.05$). There were no statistically significant differences between these groups with respect to the average age of patients, sex ratio, GCS score at admission, time to surgery, preoperative hematoma volume, and hematoma location.

Clinical Results

The general clinical results are presented in Table 2. The hematoma evacuation rate of the endoscopy group was significantly higher than that of the craniotomy group

FIG. 3. Endoscopic surgery. **A:** A newly developed endoscopic sheath. **B:** An analog incision and puncture direction. **C:** A small bone window craniotomy. **D:** The dura mater is coagulated and incised. **E:** Hematoma puncture. **F:** Hematoma evacuation under the endoscope. Figure is available in color online only.

(90.5% vs 82.3%; $p < 0.01$) (Fig. 4). The operative time was 1.6 hours in the endoscopy group and 5.2 hours in the craniotomy group ($p < 0.01$). The intraoperative blood loss of the endoscopy group was far less than that of the craniotomy group (91.4 vs 605.6 ml; $p < 0.01$). The mean GCS score 1 week after surgery was 11.5 in the endoscopy group and 8.3 in the craniotomy group ($p < 0.01$). The mean length of hospital stay was shorter in the endoscopy group than in the craniotomy group (11.6 vs 13.2 days; $p < 0.05$). Two patients in the endoscopy group had rebleeding and 6 patients in the craniotomy group had rebleeding ($p > 0.05$). The hospital mortality rate was 7.3% in the endoscopy group and 14.5% in the craniotomy group; the difference was not statistically significant ($p > 0.05$).

Patients were followed up by telephone at 6 months after surgery. Four (4.9%) patients in the endoscopy group and 5 (7.2%) patients in the craniotomy group were lost to follow-up. The rate of patients who were lost to follow-up was within the permissible range. Of the patients who were

followed up in the endoscopy group, 5 had no symptoms, 12 had no significant disability, 13 had a slight disability, 17 had moderate disability, 8 had moderately severe disability, 8 had severe disability, and 15 had died. Of the patients who were followed up in the craniotomy group, 2 had no symptoms, 2 had no significant disability, 7 had a slight disability, 10 had moderate disability, 16 had moderately severe disability, 9 had severe disability, and 18 had died. The mean modified Rankin Scale (mRS) score of patients was 3.2 in the endoscopy group and 4.1 in the craniotomy group; the difference was statistically significant ($p < 0.01$; Fig. 5). The endoscopy group had better neurological recovery compared with the craniotomy group.

Discussion

HICH is a common neurological disease characterized by poor prognosis and outcomes. Only approximately 20% of patients with HICH can live on their own post-hemorrhage.³ The management of HICH is still contro-

TABLE 1. General characteristics of all patients

Variable	Patient Group		p Value
	Endoscopy, n = 82	Craniotomy, n = 69	
Average age, yrs*	52.9 ± 12.3	53.8 ± 13.5	0.152
Male, no. (%)	58 (70.7)	46 (66.7)	0.526
GCS score at admission*	7.9 ± 2.2	7.8 ± 3.1	0.892
Time to surgery, hrs*	15.6 ± 14.9	13.7 ± 11.6	0.381
Mean preop hematoma vol, ml*	55.2 ± 28.4	55.9 ± 27.6	0.973
Hematoma location, no. (%)			0.696
Basal ganglia	65 (79.3)	52 (75.4)	
Subcortex	17 (20.7)	17 (24.6)	

* Values are expressed as the mean ± SD.

TABLE 2. Comparison of general clinical results between the endoscopy and craniotomy groups

Variable	Patient Group		p Value
	Endoscopy, n = 82	Craniotomy, n = 69	
Clearance rate, %*	90.5 ± 6.5	82.3 ± 8.6	0.001
Op time, hrs*	1.6 ± 0.7	5.2 ± 1.8	0.001
Intraop blood loss, ml*	91.4 ± 93.1	605.6 ± 602.3	0.001
Postop GCS score at 1 wk*	11.5 ± 2.9	8.3 ± 3.8	0.001
Hospital stay, days*	11.6 ± 6.9	13.2 ± 7.9	0.035
Hospital mortality, no. (%)	6 (7.3)	10 (14.5)	0.161
mRS score 6 mos postop*	3.2 ± 1.5	4.1 ± 1.9	0.004

* Values are expressed as the mean ± SD.

FIG. 4. Comparison of the hematoma evacuation rates between the endoscopy and craniotomy groups. Endoscopic surgery has a much higher hematoma evacuation rate than craniotomy.

versial, and the role of surgery in the treatment of HICH has not been fully established.⁸ Surgical evacuation of the intracerebral hematoma is based on the idea of reducing mass effect and thereby decreasing intracranial pressure, improving regional blood flow, and restricting the release of toxic breakdown products released by the clot.⁹ Possible negative side effects include the additional trauma caused by the procedure itself and a possibly increased risk of rebleeding by removing the tamponade of the hematoma.

Thus far, multiple clinical trials have failed to find a consistent clinical benefit of hemorrhage evacuation.^{26,34} Results of the Surgical Trial in Intracerebral Haemorrhage (STICH) trial indicated that patients with spontaneous supratentorial ICH in neurosurgical units showed no overall benefit from early surgery when compared with initial conservative treatment.¹³ However, in this trial, operative intervention occurred in approximately one-quarter of patients in the initial conservative treatment group, and these crossovers from conservative treatment to surgery make interpretation of the results complicated. The STICH II trial, a study based on the results of a subgroup analysis from the STICH trial, confirmed that early surgery did not increase the rate of death or disability at 6 months and might have had a small but clinically relevant survival advantage for patients with spontaneous superficial ICH without intraventricular hemorrhage. Moreover, almost all of the patients in STICH II who underwent surgery had craniotomy. Minimal-access techniques such as endoscopic surgery might be more beneficial, and studies that compare endoscopic procedures with conventional surgery are lacking.

Endoscopic surgery is a relatively new method for treatment of HICH.¹ In endoscopic evacuation, a small bur hole is created, and an endoscope 5–8 mm in diameter is inserted through normal brain tissue into the hematoma. Suction and irrigation are applied to remove the hematoma. The brain is then visualized via the endoscope to determine the site of bleeding and to assess the amount of hematoma. As shown by our results, endoscopic surgery has some advantages compared with craniotomy, such as minimal invasiveness, high evacuation rate, shorter op-

FIG. 5. Comparison of mRS scores at 6 months after surgery. Patients in the endoscopy group had a lower mRS score, indicating that endoscopic surgery results in better functional recovery.

erative time, and better follow-up outcomes. Results of our study showed that the hematoma evacuation rate in the endoscopy group was much higher than that in the craniotomy group (90.5% vs 82.3%; $p < 0.01$), similar to results reported in the literature.^{6,15,16,18,30,31} The current literature on endoscopic evacuation of ICH is summarized in Table 3.

In our study, we used an independently developed 10-mm transparent endoscope sheath to create a minimally invasive surgical channel to the hematoma. This new application has several benefits. First, transparency of the introducer helped us to better distinguish the hematoma cavity from the brain parenchyma. Additionally, the puncture process was accomplished in 2 steps. As a result, we could easily confirm whether the puncture direction was satisfactory and avoid brain hernia induced by increased intracranial pressure. Finally, it was easy to verify whether all of the hematoma had been evacuated with use of a transparent introducer. Our results indicate that endoscopic surgery is safe and feasible. The improved mRS score at 6 months after surgery indicates that early endoscopic hematoma evacuation may improve the prognosis of patients with HICH.

Accurate measurement of hematoma volume is clinically important because it has been widely used in correlation with treatment strategy, functional outcome, and mortality. Precise assessment of hematoma volume is also critical for clinical trials, in which change in hematoma volume may be a surrogate end point.²⁴ In almost all previous studies, hematoma volumes have been estimated using the ABC/2 formula. However, the ABC/2 formula has a certain range of estimation error, which could be up to nearly 40% for some specific hematomas.²⁹ This error rate is unacceptable for research purposes. Therefore, we used a precise and freely available software, 3D Slicer, to measure the volume of hematomas. Using this method can make results from different clinical trials easier to compare, which is important for the standardization of research.

However, it should be noted that our study has limitations. First, data were collected retrospectively, and there might have been selection bias. Second, the patients in our

TABLE 3. Summary of the literature on endoscopic evacuation of ICH

Authors & Year	Study Design	Group	No. of Pts	Hemorrhage Location	Outcome
Auer et al., 1989	Prospective	Endo vs medi	100	Supratentorial only	Endo had a lower mortality rate & improved outcomes
Cho et al., 2006	Prospective	Endo vs stereo vs crani	90	Basal ganglia	Endo had improved outcome & was more cost-effective
Nishihara et al., 2007	Case-control	Endo vs stereo	47	Any	Endo resulted in better outcomes, reduced op time, & shorter ICU stay
Chen et al., 2007	Case series	Endo only	7	Thalamus	Endo improved the efficiency of thalamic hematoma evacuation & prevented shunt-dependent hydrocephalus
Nagasaka et al., 2011	Retrospective	Endo vs crani	43	Putamen, thalamus, or cerebellum	Endo resulted in a higher success rate, greater GCS score improvement, & a lower mortality rate
Kuo et al., 2011	Retrospective	Endo only	68	Supratentorial only	Endo had a good evacuation rate (mean 93%) w/ low morbidity & mortality rates
Basaldella et al., 2012	Retrospective	Endo + EVD vs EVD alone	96	Unspecified	Endoscopy + EVD did not significantly affect outcomes at 1 yr
Wang et al., 2015	Retrospective	Endo vs crani	21	Supratentorial only	Endo reduced ICU stay, but had no effect on 6-mo outcomes
Sun et al., 2016	Retrospective	Endo only	25	Supratentorial only	Augmented reality helped endoscopic surgery to achieve satisfactory hematoma removal

crani = craniotomy; endo = endoscopic evacuation; EVD = external ventricular drainage; medi = medical treatment; pts = patients; stereo = stereotactic evacuation.

study had larger hematoma volumes compared with patients in previous studies.

Conclusions

Our results showed that endoscopic surgery significantly increased the hematoma evacuation rate and improved mRS scores at 6 months after surgery in patients with HICH. Our findings indicate that endoscopic surgery is safe, feasible, and may improve the prognosis and quality of life of patients with HICH. Multicenter, prospective, randomized, controlled clinical trials are warranted to validate our results.

Acknowledgments

This study was funded by the Science Technological Innovation Nursery Fund of PLA General Hospital (16KMM14) and the National Natural Science Foundation of China (81271515).

References

1. Auer LM, Deinsberger W, Niederkorn K, Gell G, Kleinert R, Schneider G, et al: Endoscopic surgery versus medical treatment for spontaneous intracerebral hematoma: a randomized study. *J Neurosurg* **70**:530–535, 1989
2. Basaldella L, Marton E, Fiorindi A, Scarpa B, Badreddine H, Longatti P: External ventricular drainage alone versus endoscopic surgery for severe intraventricular hemorrhage: a comparative retrospective analysis on outcome and shunt dependency. *Neurosurg Focus* **32**(4):E4, 2012
3. Broderick J, Connolly S, Feldmann E, Hanley D, Kase C, Krieger D, et al: Guidelines for the management of spontaneous intracerebral hemorrhage in adults: 2007 update: a guideline from the American Heart Association/American Stroke Association Stroke Council, High Blood Pressure Research Council, and the Quality of Care and Outcomes in Research Interdisciplinary Working Group. *Stroke* **38**:2001–2023, 2007
4. Chen CC, Lin HL, Cho DY: Endoscopic surgery for thalamic hemorrhage: a technical note. *Surg Neurol* **68**:438–442, 2007
5. Cho DY, Chen CC, Chang CS, Lee WY, Tso M: Endoscopic surgery for spontaneous basal ganglia hemorrhage: comparing endoscopic surgery, stereotactic aspiration, and craniotomy in noncomatose patients. *Surg Neurol* **65**:547–556, 2006
6. Dye JA, Dusick JR, Lee DJ, Gonzalez NR, Martin NA: Frontal bur hole through an eyebrow incision for image-guided endoscopic evacuation of spontaneous intracerebral hemorrhage. *J Neurosurg* **117**:767–773, 2012
7. Feigin VL, Forouzanfar MH, Krishnamurthi R, Mensah GA, Connor M, Bennett DA, et al: Global and regional burden of stroke during 1990–2010: findings from the Global Burden of Disease Study 2010. *Lancet* **383**:245–254, 2014
8. Hemphill JC III, Greenberg SM, Anderson CS, Becker K, Bendok BR, Cushman M, et al: Guidelines for the management of spontaneous intracerebral hemorrhage: A Guideline for Healthcare Professionals from the American Heart Association/American Stroke Association. *Stroke* **46**:2032–2060, 2015
9. Jüttler E, Steiner T: Treatment and prevention of spontaneous intracerebral hemorrhage: comparison of EUSI and AHA/ASA recommendations. *Expert Rev Neurother* **7**:1401–1416, 2007
10. Keep RF, Hua Y, Xi G: Intracerebral haemorrhage: mechanisms of injury and therapeutic targets. *Lancet Neurol* **11**:720–731, 2012
11. Kuo LT, Chen CM, Li CH, Tsai JC, Chiu HC, Liu LC, et al: Early endoscope-assisted hematoma evacuation in patients with supratentorial intracerebral hemorrhage: case selection, surgical technique, and long-term results. *Neurosurg Focus* **30**(4):E9, 2011
12. Mendelow AD: Mechanisms of ischemic brain damage with intracerebral hemorrhage. *Stroke* **24** (12 Suppl):II115–II119, 1993
13. Mendelow AD, Gregson BA, Fernandes HM, Murray GD,

- Teasdale GM, Hope DT, et al: Early surgery versus initial conservative treatment in patients with spontaneous supratentorial intracerebral haematomas in the International Surgical Trial in Intracerebral Haemorrhage (STICH): a randomised trial. **Lancet** **365**:387–397, 2005
14. Meretoja A, Strbian D, Putaala J, Curtze S, Haapaniemi E, Mustanoja S, et al: SMASH-U: a proposal for etiologic classification of intracerebral hemorrhage. **Stroke** **43**:2592–2597, 2012
 15. Miller CM, Vespa P, Saver JL, Kidwell CS, Carmichael ST, Alger J, et al: Image-guided endoscopic evacuation of spontaneous intracerebral hemorrhage. **Surg Neurol** **69**:441–446, 2008
 16. Nagasaka T, Tsugeno M, Ikeda H, Okamoto T, Inao S, Wakabayashi T: Early recovery and better evacuation rate in neuroendoscopic surgery for spontaneous intracerebral hemorrhage using a multifunctional cannula: preliminary study in comparison with craniotomy. **J Stroke Cerebrovasc Dis** **20**:208–213, 2011
 17. Nagasaka T, Tsugeno M, Ikeda H, Okamoto T, Takagawa Y, Inao S, et al: Balanced irrigation-suction technique with a multifunctional suction cannula and its application for intraoperative hemorrhage in endoscopic evacuation of intracerebral hematomas: technical note. **Neurosurgery** **65**:E826–E827, 2009
 18. Nakano T, Ohkuma H, Ebina K, Suzuki S: Neuroendoscopic surgery for intracerebral haemorrhage—comparison with traditional therapies. **Minim Invasive Neurosurg** **46**:278–283, 2003
 19. Nishihara T, Morita A, Teraoka A, Kirino T: Endoscopy-guided removal of spontaneous intracerebral hemorrhage: comparison with computer tomography-guided stereotactic evacuation. **Childs Nerv Syst** **23**:677–683, 2007
 20. Ruiz-Sandoval JL, Chiquete E, Romero-Vargas S, Padilla-Martínez JJ, González-Cornejo S: Grading scale for prediction of outcome in primary intracerebral hemorrhages. **Stroke** **38**:1641–1644, 2007
 21. Sacco S, Marini C, Toni D, Olivieri L, Carolei A: Incidence and 10-year survival of intracerebral hemorrhage in a population-based registry. **Stroke** **40**:394–399, 2009
 22. Siddique MS, Fernandes HM, Arene NU, Wooldridge TD, Fenwick JD, Mendelow AD: Changes in cerebral blood flow as measured by HMPAO SPECT in patients following spontaneous intracerebral haemorrhage. **Acta Neurochir Suppl** **76**:517–520, 2000
 23. Sun GC, Chen XL, Hou YZ, Yu XG, Ma XD, Liu G, et al: Image-guided endoscopic surgery for spontaneous supratentorial intracerebral hematoma. **J Neurosurg** [epub ahead of print September 16, 2016. DOI: 10.3171/2016.7.JNS16932]
 24. Tao H, Ramadas G, Carrozzella J, Khatri P, Broderick J, Spilker J, et al: Parenchymal hematoma and total lesion volume in combined IV/IA revascularization stroke therapy. **J Neurointerv Surg** **4**:256–260, 2012
 25. van Asch CJJ, Luitse MJA, Rinkel GJE, van der Tweel I, Algra A, Klijn CJM: Incidence, case fatality, and functional outcome of intracerebral haemorrhage over time, according to age, sex, and ethnic origin: a systematic review and meta-analysis. **Lancet Neurol** **9**:167–176, 2010
 26. Vespa PM, Martin N, Zuccarello M, Awad I, Hanley DF: Surgical trials in intracerebral hemorrhage. **Stroke** **44** (6 Suppl 1):S79–S82, 2013
 27. Wang WH, Hung YC, Hsu SP, Lin CF, Chen HH, Shih YH, et al: Endoscopic hematoma evacuation in patients with spontaneous supratentorial intracerebral hemorrhage. **J Chin Med Assoc** **78**:101–107, 2015
 28. Xi G, Keep RF, Hoff JT: Mechanisms of brain injury after intracerebral haemorrhage. **Lancet Neurol** **5**:53–63, 2006
 29. Xu X, Chen X, Zhang J, Zheng Y, Sun G, Yu X, et al: Comparison of the Tada formula with software slicer: precise and low-cost method for volume assessment of intracerebral hematoma. **Stroke** **45**:3433–3435, 2014
 30. Yamamoto T, Nakao Y, Mori K, Maeda M: Endoscopic hematoma evacuation for hypertensive cerebellar hemorrhage. **Minim Invasive Neurosurg** **49**:173–178, 2006
 31. Zhang HZ, Li YP, Yan ZC, Wang XD, She L, Wang XD, et al: Endoscopic evacuation of basal ganglia hemorrhage via keyhole approach using an adjustable cannula in comparison with craniotomy. **BioMed Res Int** **2014**:898762, 2014
 32. Zhou X, Chen J, Li Q, Ren G, Yao G, Liu M, et al: Minimally invasive surgery for spontaneous supratentorial intracerebral hemorrhage: a meta-analysis of randomized controlled trials. **Stroke** **43**:2923–2930, 2012
 33. Zurasky JA, Aiyagari V, Zazulia AR, Shackelford A, Dinger MN: Early mortality following spontaneous intracerebral hemorrhage. **Neurology** **64**:725–727, 2005
 34. Zuccarello M, Brott T, Derex L, Kothari R, Sauerbeck L, Tew J, et al: Early surgical treatment for supratentorial intracerebral hemorrhage: a randomized feasibility study. **Stroke** **30**:1833–1839, 1999

Disclosures

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author Contributions

Conception and design: B Xu, X Xu, Chen. Acquisition of data: X Xu, Li, Zheng, Wang. Analysis and interpretation of data: X Xu, Chen, Sun. Drafting the article: X Xu. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: B Xu. Statistical analysis: X Xu, Chen, Zhang. Study supervision: B Xu.

Correspondence

Bainan Xu, Department of Neurosurgery, Chinese PLA General Hospital, Fuxing Rd. 28, Beijing 100853, China. email: xubn301@163.com.