Spon-taneous 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 median 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,
Hematoma removal also directly addresses the problem of local mass effect that leads to brain tissue damage. Nevertheless, the effectiveness of craniotomy for the treatment of ICH remains controversial, despite having been repeatedly evaluated during the past 4 decades. With the development of neuroendoscopic techniques, endoscopic hematoma evacuation is proving to be effective and may have some advantages compared with craniotomy. Endoscopic hematoma evacuation may be theoretically attractive and may be advocated as the primary treatment of choice; however, its effectiveness remains unclear. 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. 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. 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 ≥ 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 × 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 × 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. The dura mater was coagulated and incised in a cruciate fashion. We used our self-developed endoscopic puncture and working channel system (patient 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,
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 ± SD. An unpaired t-test, rank-sum test, or \( \chi^2 \) 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.
The operative time was 1.6 hours in the endoscopy group and 5.2 hours in the craniotomy group ($p < 0.01$). The mean clearances rate was 90.5% in the endoscopy group and 82.3% in the craniotomy group ($p < 0.01$). The 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 posthemorrhage. The management of HICH is still contro-

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**TABLE 1. General characteristics of all patients**

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

* Values are expressed as the mean ± SD.

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

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

* Values are expressed as the mean ± SD.
versal, and the role of surgery in the treatment of HICH has not been fully established. 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. 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. 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. 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 made 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. In endoscopic evacuation, a small burr 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 operative 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. 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. 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. 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
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.

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13. Mendelow AD, Gregson BA, Fernandes HM, Murray GD,
Endoscopic surgery for hypertensive intracerebral hemorrhage


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, Zhang, 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.

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