Laser localization with soft-channel minimally invasive surgery in cerebral hemorrhage

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Abstract. The aim of the present study was to evaluate the efficacy and safety of laser localization combined with soft-channel minimally invasive surgery (MIS) for the treatment of cerebral hemorrhage, and to develop stereotactic alternatives that are cost-effective, safe and precise for underdeveloped regions. To meet this aim, 60 patients with cerebral hemorrhage were randomly assigned to the control group (n=30) or the study group (n=30). The patients in the study group were treated with laser localization combined with soft-channel MIS to remove the hematoma, whereas the control group was treated with YL-1 needle puncture to drain the intracranial hemorrhage. All patients underwent successful surgical treatment. The hematoma clearance rate was revealed to be 88.72±2.82% in the study group and 84.50±4.26% in the control group. Both groups achieved residual hematoma volume <10 ml or a hematoma clearance rate >70%, and the difference in the hematoma clearance rate was found to be statistically significant ($P<0.05$), with the study group having an improved hematoma clearanc2e rate compared with the control group. The median 7-day postoperative Glasgow Coma Scale score was 13.0 [interquartile range (IQR), 12.0, 14.0] for the study group and 12.0 (IQR, 11.0, 13.0) for the control group, indicating an improved outcome in the study group. The puncture accuracy was 100% (30/30) in the study group compared with 76.66% (23/30) in the control group ($P<0.05$). The hematoma drainage time was found to be significantly shorter in the study group (40.57±8.24 h) compared with that in the control group (56.80±14.40 h) ($P<0.05$). At the 6-month follow-up, the median modified Rankin Scale score was found to be 2.0 (IQR, 2.0, 3.0) in both groups. Neither group experienced rebleeding, hydrocephalus or cerebral infarction. No intracranial infections occurred in the treatment group, whereas three cases of intracranial infection were observed in the control group. In conclusion, the findings of the present study have shown that laser localization combined with soft-channel MIS is effective and safe in the treatment of cerebral hemorrhage.

Introduction

Spontaneous intracerebral haemorrhage (ICH) results from small arterial rupture, associated with hypertension and excessive salt intake, Inflammation, infection, and dysregulation of the brain-gut axis further exacerbate the progression of cerebral small vessel disease (1). A sudden rise in blood pressure can lead to hematoma formation, rapid progression of the disease and poor prognosis, as well as high rates of disability and mortality, The disability rate can be as high as 73%, with a mortality rate ranging from 6.5 to 19.6%, and a 30-day mortality rate reaching up to 50, resulting in a serious social and economic burden (2). In China, cerebral hemorrhage accounts for 30-55% of cases of stroke, which is higher than the 8-15% in Western populations (3,4). The pathophysiological changes that ensue after hematoma formation mainly include neurological function impairment and brain tissue injuries that are caused by the toxic effects of hematoma, which can lead to cerebral vascular permeability changes, cerebral edema and increased intracranial pressure (ICP) and, in severe cases, cerebral hernia (5). Therefore, timely hematoma removal is able to reduce the complications and improve prognosis (6). Craniotomy is the definitive intervention for completely evacuating hematomas and achieving optimal hemostatic outcomes. This surgical approach is particularly recommended for patients at high risk for brain herniation, serving as the preferred method in these critical cases (7). However, clinical trials [for example, surgical treatment of intracerebral hemorrhage (ICH) phase I and II trials] have shown that craniotomy fails to significantly improve neurological prognosis or reduce mortality (8). Preliminary results from the minimally

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Abbreviations: CTA, computed tomography angiography; GCS, Glasgow Coma Scale; mRS, modified Rankin Scale; ICH, intracerebral hemorrhage; IQR, interquartile range; MIS, minimally invasive surgery; LAS-MISUT, laser soft-channel MIS combined with urokinase thrombolysis; MISTIE, MIS with thrombolysis in ICH evacuation; HV, hematoma volume

Key words: laser localization, precise puncture, stereotactic suction, soft-channel minimally invasive surgery, spontaneous intracerebral hemorrhage

invasive surgery (MIS) with thrombolysis in ICH evacuation (MISTIE) II and III trials have suggested that MIS in combination with alteplase therapy may be advantageous in certain patients with cerebral hemorrhage, who have been revealed to have reduced mortality rates and improved prognoses (9). The results of the MISTIE II trial showed that administering MIS plus recombinant tissue-type plasminogen activator led to a favorable prognosis in patients who achieved a residual hematoma <10 ml or clot clearance >3% (10); >84% of patients achieved the treatment goals of residual hematoma <15 ml or clot clearance >70%. For patients within 24-48 h of symptom onset, with haematoma volumes <50 ml, and in the absence of contraindications, precise puncture localisation and appropriate intrahaematoma thrombolytic agents are recommended, Puncturing along the long axis of the neural fibres reduces nerve fibre damage. Choosing a puncture along the long axis of the cerebral haematoma, with side holes in the drainage tube, enhances haematoma evacuation, emphasizing the importance of optimizing patient selection and drain placement to improve hematoma evacuation efficiency and surgical success (11,12).

Currently, MIS techniques for the treatment of spontaneous ICH internationally include computed tomography (CT)-guided real-time aspiration, stereotactic-guided aspiration and endoscopic surgery (13). Traditional stereotactic surgery requires the use of a stereotactic head frame for precise positioning, with the patient's head being immobilized in the head frame, and fixation pins are inserted into the skull. However, techniques such as frameless stereotactic and image-guided navigation systems offer alternatives to traditional methods (14). Moreover, CT-guided real-time aspiration may result in the exposure of the operator to radiation, while the use of neuroendoscopic equipment, frameless navigation systems and robotic surgical instruments are expensive and difficult to obtain in primary hospitals in developing countries (15). Uneven economic and technological development in these regions makes it difficult to popularize minimally invasive ICH removal techniques. Currently, hard-channel (YL-1 type) puncture and drainage is mainly used in primary hospitals in mainland China, although the employment of this method may result in more damage being caused to normal brain tissues, inaccurate localization or the emergence of complications, such as increased incidence of intracranial infections and seizures (16).

Considering the information available at present, the treatment for ICH remains challenging and requires a balancing act, taking into consideration the cost, precision, safety and accessibility of the technique concerned. Advanced technologies, such as neuroendoscopy and frameless stereotactic systems, offer precise and minimally invasive options, although their use is limited at present by high costs, technical complexity and the difficulty of use in resource-limited settings (17,18). On the other hand, simpler methods such as hard-channel drainage, although more readily available, are associated with compromised precision and patient safety. Therefore, there is an urgent need to develop cost-effective, minimally invasive alternatives to ensure surgical accuracy and patient safety, especially in resource-limited settings. In the future the development of portable imaging technology, simplified neuroendoscopy and affordable navigation systems (19) should improve the accuracy of hematoma drainage, reduce congenital injuries and improve the long-term neurological prognosis of patients with ICH, thereby providing more cost-effective, minimally invasive treatment options for ICH in resource-limited areas.

In the current study, preliminary results with a novel laser-guided localization technique integrated with soft-channel MIS for the management of cerebral hemorrhage are presented. This new approach was evaluated in comparison with the conventional YL-1 puncture method to determine its clinical efficacy concerning hematoma evacuation, puncture precision and postoperative outcomes. The present study focused on the development of advanced stereotactic surgical techniques aimed at enhancing the accuracy and safety of minimally invasive interventions for ICH and evaluated whether laser localization combined with soft-channel MIS is effective and safe in the treatment of cerebral hemorrhage.

Materials and methods

Patients, ethics approval and consent. The present study was retrospectively registered with the China Clinical Trial Registration Center (ChiCTR) under the registration number ChiCTR2400094351, with registration completed on 20th December 2024. The present prospective, partially randomized, controlled study included 60 patients aged ≥45 years. The study group (n=30) underwent laser-guided minimally invasive surgery in combination with a soft-channel approach at the affiliated Nanchuan Hospital of Chongqing Medical University between May 2022 and October 2023. The control group (n=30) received YL-1 hard-channel puncture and aspiration for intracerebral hemorrhage. Ethics approval for the present study was obtained from the Ethics Committee of Nanchuan Hospital of Chongqing Medical University (approval no. YXYJ-2022-013; Chongqing, China), and all patients provided written informed consent prior. The study sample (n=60 patients) was randomly divided into two groups (study group and control group) using a fully randomized numerical table method. All procedures were performed by the same experienced neurosurgeon within 6-24 h following the onset of ICH. The inclusion criteria were as follows: i) The first diagnosis of the patient was CT-confirmed, single-site ICH; ii) the age of the patient was between 45-85 years; iii) the patient had a supratentorial hematoma volume (HV) of 30-65 ml with a midline shift of >5 mm; iv) the cerebellar HV was in the range of 10-30 ml with brainstem compression; v) the vital signs were stable (blood Pressure: 140-160/80-90 mmHg; heart Rate: 60-100 beats per min; respiratory Rate: 12-18 breaths per min, Oxygen Saturation: maintained above 95%, Temperature: 36.5-37.5˚C); vi) the oxygen saturation level was ≥90%, as measured by finger pulse oximetry; vii) the Glasgow Coma Scale (GCS) score (20) was ≥8 points, and viii) patients with seizures treated with sodium valproate. The exclusion criteria were as follows: i) Cerebral herniation (such as dilated pupils) was present; and ii) the patient was diagnosed with ischemic stroke leading to hemorrhage, neoplastic stroke, abnormal vascular structures (including arteriovenous malformations and aneurysms) or coagulation abnormalities, as demonstrated by routine CT angiography (CTA) on admission. However, the duration of bleeding (from stroke onset to surgery) was not used as an exclusion criterion.

Materials and equipment. For the study group, a laser localizer [second-generation laser-positioning instrument (Hunan Zhuoshi Chuangsi Technology Co., Ltd.) approved by the National Medical Products Administration, China] was employed. The program 'DuRofi CT baseline simulator' was used, whereas the disposable catheter and disposable 10- or 12-gauge cerebral drainage puncture devices were purchased from Shandong Baiduoan Medical Equipment Co., Ltd. For the control group, a YL-1 puncture needle was obtained from Beijing Wantefu Medical Devices Co., Ltd.

Unlike traditional stereotactic systems, the novel laser localizer eliminates the need for a secondary CT or MRI scan for accurate localization. It utilizes a high-precision laser-guided coordinate mapping system to minimize targeting errors. Additionally, the use of a disposable guide during both preoperative planning and intraoperative localization reduces the risk of infection by avoiding repeated manipulations. This design enhances precision and safety while streamlining the localization process.

Technical parameters and working principles

Technical parameters. Table I presents the technical parameters of the laser positioner used in the present study.

Working principles. The core principle of the laser-positioning system is based on the three-dimensional (3D) geometric axiom, which states that if two non-overlapping planes share a common point, there exists exactly one straight line passing through that point. When the longitudinal and lateral laser axes are aligned within a single plane targeting the objective, the positioning device ensures that the intersection of the two laser planes passes through both the target point and any entry point within the space (21). This principle is utilized in neurosurgical planning to achieve precise localization based on cranial CT imaging data. By passing the relevant data [anatomical landmarks (bilateral external auditory canal, lens) and hematoma centre target data on cranial CT scan films] through the 'DuRofi CT baseline simulator' (an application designed for baseline simulation), the system accurately identifies and marks the projection of intracranial targets onto the patient's surface anatomy. This enables precise preoperative localization of intracranial targets, thereby providing a crucial reference for cranial surgeries.

Data collection and analysis. The study group consisted of 21 male and 9 female patients with a mean age of 64.80±10.56 years and a mean supratentorial HV of 41.32±10.91 ml, mean cerebellar HV of 16.78 ml. There were 6 cases of supratentorial HV (20.00%), 23 cases of basal ganglia and thalamus HV (76.66%), 11 cases of ventricular system effusion (36.66%) and 1 case (3.33%) of cerebellar HV. Occurrence of ventricular system effusion in 11 cases (36.66%) was associated with hemorrhage in the basal ganglia and thalamus regions.

The control group comprised of 19 male and 11 female patients with a mean age of 64.30±9.77 years, a mean supratentorial HV of 45.99±3.40 ml and a mean cerebellar HV of 17.53±4.50 ml. There were 4 cases of lobar HV (13.33%), 23 cases of basal ganglia and thalamus HV (76.66%), 3 cases of cerebellar HV (10.00%) and 8 cases of ventricular HV (26.66%). After the haematoma stabilised (6 h post-haemorrhage), all patients underwent repeat CT scans to assess any

Table I. Specific technical parameters of the laser positioner.

Technical parameter	Value/classification
Model no.	DRF-M-01
Marking range	200x250x90 mm
Scale resolution	1 mm
Maximum laser power	Red laser, 635±5 nm; green laser, 520±5 nm
Number of lasers	6
Laser type	130 degree one-line laser line width of 1 mm
Laser safety classification	Class 2M
Laser safety requirements	Avoid using optical instruments to observe the laser
Temperature	-25˚ to +40˚C
Relative humidity	≤90%
Atmospheric pressure	500-1,060 hPa
Operating conditions	Normal ambient temperature, 5-40˚C; relative humidity, 30-75%; atmospheric pressure, 700-1,060 hPa
Power supply	3.7 V, 70 mAh; charge/discharge 1C; with protection board
Dimensions, length x width x height	510x255x450 mm
Weight	11 kg
Other security requirements	
Type of protection against electric shock	Internal power supply type
Degree of protection against electric shock	Type B application section
Degree of protection against incoming fluids	Not applicable
Degree of safety when used in the presence of flammable anesthetic gases mixed with air or flammable anesthetic gases mixed with oxygen or nitrous oxide	AP/APG type
Mode of operation	Continuous
Rated voltage and frequency of the equipment	DC3.7V
Application section for protection against defibrillation discharge effects	No
Signal input and signal output section	No
Installation of equipment	Non-permanent
Electromagnetic compatibility	Group 1 Class B

changes in haematoma volume prior to surgery. Preoperative CT angiography (CTA) was performed to exclude aneurysms or arteriovenous malformations. Postoperative CT scans were conducted to confirm the position of the drainage catheter and evaluate residual haematoma. Before catheter removal, follow-up CT was performed to determine whether removal was indicated. A final CT scan was carried out on the first day after catheter removal to document residual haematoma volume. The efficacy and safety of the new stereotactic aspiration were subsequently evaluated. Both the stable volume and the final HV were calculated on the basis of the CT data. Hematoma volume was calculated using the ABC/2 formula (22). Subsequently, the mean of the two evaluated volumes was calculated; if the difference was >2 ml, a third radiologist adjudicated on the results.

The following data were collected and analyzed: The GCS score both on admission and on day 1 after extubation, the preoperative HV, time from onset to surgery, (from the start of bleeding to the start of surgery), the surgery time, the drainage time, the percentage of hematoma cleared, the GCS score on day 7 postoperatively, the GCS score at discharge and the modified Rankin Scale (mRS) score (23) at 6 months post-discharge. The mRS scores, surgery-associated complications (hemorrhage, hydrocephalus, intracranial gas and scalp necrosis) and postoperative systemic complications (pneumonia, seizures, electrolyte disorders, renal insufficiency, gastrointestinal symptoms and cardiac failure) were collected and analyzed. In addition, the patients were monitored for infection, intracranial gas accumulation and scalp necrosis. The percentage thrombus clearance was used to assess hematoma clearance, and this was defined as the reduction in bleeding divided by the preoperative HV. Favorable and unfavorable outcomes were defined as mRS scores of 0-2 and 3-5, respectively.

Surgical treatment options

Study group. After appropriate preoperative preparations (Blood tests, CT scans, hair removal), the attending physician selected the midpoint of the external auditory canal for the bilateral lens, the window value of the lens, the midpoint of the external auditory canal and the level at which the target point was located using the 'DuRofi CT baseline simulator' applet. The external auditory canal on the affected side was selected as the zero point, and the CT scanning baseline plane as well as the target point level through the zero point were then acquired. Four points of the baseline plane on the patient's body surface (target point) were then marked. The baseline plane was then matched to the frame of the Durofi laser, and the laser was subsequently moved to the target level. Based on the coordinates of the target point at that level, the laser at the target level was moved to align with the target point. The laser was then rotated through the puncture point, and the intersection of the two laser planes in space represented the direction of the puncture. The direction was recorded and the depth was determined, using a 'Du Rofi' disposable guide plate. The body surface of the disposable guide plate was marked to indicate the puncture point, and the positioning device was moved away to end the positioning. The preoperative positioning information was reproduced using a sterile guide plate to guide the surgical direction. A 3-cm incision was made into the scalp, the skull was drilled into at a depth of 0.5 cm, and a 0.2-0.3-cm incision was made into the dura mater following hemostasis of the bone margins. To minimize the risk of malposition during the operation, the puncture entry point was chosen on the forehead, 3 cm from the midline. The catheter was subsequently inserted through a subcutaneous tunnel (5 cm in length), reducing the risk of infection and ensuring secure fixation. The cortex was then electrocauterized to test the resistance of the drainage tubes, ensure a smooth puncture, and minimize additional injury. Under the guidance of the introducer, a 10- or 12-gauge cerebral drainage puncture device was guided to the depth of the target point, and then moved forward by 0.5 cm to ensure that the lateral hole of the drain was centered on the target point. The drainage tube was then connected to the 10-ml syringe, and slow aspiration was performed under negative pressure as the drainage tube rotated. If resistance was encountered, the force of negative pressure suction was reduced. Suctioning was stopped when resistance was first encountered or when hematoma suction had reached one-third of the total volume, and the drainage tube was retained to facilitate the subsequent injection of urokinase and the drainage of dissolved clots. Urokinase (30 thousand units to dissolve blood clots.) was injected into the hematoma cavity from the heparin cap attached to the drainage tube 2-3 times a day; the tube was clamped for 2 h, reopened for 2-4 h, and this procedure was repeated. Clearance of the hematoma usually lasts 2-3 days and up to 5 days. The drains are removed after the hematoma is cleared (more than 75%). In addition, blood pressure, dehydration, hemostasis, and potential infections were monitored, with provision of enteral or parenteral nutrition, prevention of deep vein thrombosis, and necessary rehabilitation. Finally, cranial closure was performed.

Control group. YL-1 disposable puncture needle was used to remove the hematoma. Based on the preoperative CT scanning results, a body marking was attached to the affected temporal scalp, located on the largest slice of the hematoma, i.e., this marking was used as the puncture point after routine disinfection was performed on the scalp. While the patient was under local anesthesia (lidocaine 100 mg), The distance between the puncture point and the hematoma was measured by using CT software and YL-1 puncture needle in the electric drill was driven directly into the center of the hematoma. The extraction of the core of the needle, blockage of the puncture opening, connection of the lateral tube to the drainage tube, suction method and subsequent urokinase protocol were all performed identically to that described for the study group.

Case presentation from the study group. An initial CT scan showed a right basal ganglia hemorrhage of 35 ml (Fig. 1Aa), and a 3D reconstruction of the hematoma was also performed (Fig. 1). A follow-up CT scan performed 6 h postoperatively revealed a notable reduction in the volume and density of the hematoma (Fig. 1B and b). Another CT scan performed at 48 h postoperatively (prior to the removal of the catheter from the hematoma cavity) revealed that the hematoma had largely resolved (Fig. 1C and c).

Statistical analysis. Statistical analyses were performed using SPSS version 25.0 (IBM Corp.) or Excel 2019 (Microsoft), and GraphPad Prism 10.0 software (Dotmatics) was used for visual representation of the data. Continuous variables are presented

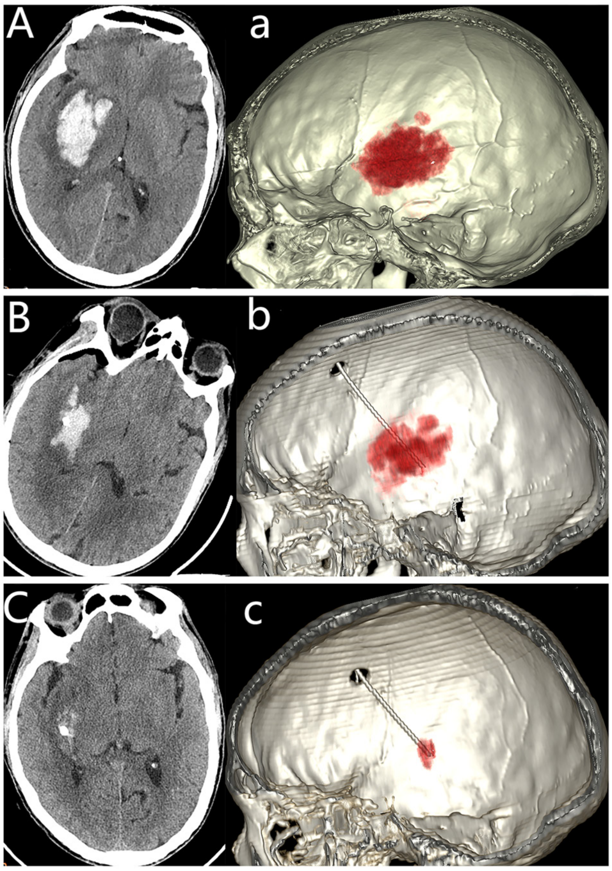

Figure 1. Case presentation. (A) Preoperative CT scan showing a hematoma in the right basal ganglia, with a volume of 35 ml. (a) A three-dimensional CT reconstruction image of the hematoma location. A follow-up CT scan performed 6 h postoperatively revealed a notable reduction in the volume and density of the hematoma (B and b). Another CT scan performed at 48 h postoperatively (prior to the removal of the catheter from the hematoma cavity) revealed that the hematoma had largely resolved (C and c).

as the mean ± standard deviation (SD) or the median plus interquartile range (IQR) depending on the distribution of the data. The normality of data was assessed using the Shapiro-Wilk test. For comparisons between continuous variables, the independent samples Student's t-test was used for normally distributed data and the Mann-Whitney U-test for non-normally distributed data. For the analysis of paired data (comparisons between preoperative and postoperative study and control groups), mixed ANOVA followed by Bonferroni post hoc test was used for data conforming to the normal distribution, while the Mann-Whitney U test followed by Bonferroni's correction and the Friedman test followed by Dunn's post hoc test and Bonferroni's correction were used for data not conforming to the normal distribution. Categorical variables are presented as frequencies and percentages, and differences between groups were analyzed using the χ^2 test or Fisher's exact test as appropriate. P<0.05 was considered to indicate a statistically significance difference.

Results

Demographic and baseline characteristics. No statistical differences were identified in terms of sex, age, the hematoma location, or Surgical operation time between the study group and the control group (P>0.05; Table II). The distribution of hematoma locations (supratentorial lobe, basal ganglia and thalamus, cerebellum, and ventricles) did not reveal significant differences between the groups (P>0.05). All patients underwent successful surgical treatment. In the study group, the time from onset of the symptoms to surgery was 13.20±6.25 h, the Control group was 10.17±5.29, no statistically significant between the two groups (P>0.05 Table II). The operation time was 32.20±4.69 min in the study group and 32.40±5.04 min in the control group, although no statistically significant difference in the operation time was identified between the two groups (P>0.05).

Hematoma and neurological outcomes. An analysis was conducted to evaluate the differences in HV between the two groups at preoperative and postoperative (extubation) time points. The results indicated no significant differences in HV between the two groups preoperatively (P>0.05; Fig. 2 and Table II). However, both the study and control group exhibited a substantial reduction in hematoma residuals postoperatively. Notably, the study group demonstrated lower HV compared with the control group, which reached statistical significance (P<0.001; Fig. 2 and Table III). Furthermore, within-group analyses revealed significant reductions in HV postoperatively compared with the preoperative time point for both the control and study groups (P<0.05; Fig. 2).

Glasgow coma scale (GCS) scores. The GCS scores were assessed preoperatively, at 7 days postoperatively and at discharge (Fig. 3). The results demonstrated no significant differences in the GCS scores between the two groups preoperatively (P>0.05; Table II). However, at both the 7-day postoperative and discharge time points, the study group exhibited significantly higher GCS scores compared with the control group (P<0.05; Table III).

The results of within-group comparisons indicated that the GCS scores at 7 days postoperatively were significantly higher compared with those preoperatively in both the control and study groups (P<0.05; Fig. 3 and Table III). Additionally, the GCS scores at discharge were significantly higher compared with those at both the preoperative and 7-day postoperative assessments (P<0.05; Fig. 3 and Table III).

Surgical and postoperative outcomes. The puncture localization and accuracy rate was 100% (30/30 patients) in the study group and 76.67% (23/30 patients) in the control group. The difference between the puncture accuracy rates of the two groups was found to be statistically significant (P<0.05), indicating a significant improvement in the study group compared with the control group (Fig. 4 and Table III). Postoperatively, the drainage tube was left in place for 40.57±8.24 h in the study group and 56.80±14.40 h in the control group. The difference in drain retention time between the two groups was also found to be statistically significant (P<0.001), and this was significantly shorter in the study group compared with the control group (Table III). In addition, the residual hematoma in the study group was 4.45±1.01 ml, with a clot clearance rate of 88.72±2.82%, whereas in the control group the residual hematoma was 6.25±1.37 ml, and the clot clearance rate reached 84.50±4.26% (Table III). The difference in hematoma clearance rate between the two groups was statistically significant (P<0.001), with the study group exhibiting a significantly improved hematoma clearance rate compared with the control group. These findings indicated that all patients in both groups

Table II. Clinical characteristics of patients.

Characteristic	Study group	Control group	P-value
Sex			0.786
Male	21	19	
Female	9	11	
Age, years	64.80±10.56	64.30±9.77	0.850
Preoperative GCS score	10.0 (9.0, 12.0)	9.0 (8.0, 11.0)	0.164
Preoperative HV, ml	40.85±10.11	43.14±13.55	0.460
Hematoma location, n (%)			
Supratentorial lobe of the brain			0.317
No	24 (80.00)	26 (86.67)	
Yes	6 (20.00)	4 (13.33)	
Basal ganglia and thalamus			1.000
No	7 (23.33)	7 (23.33)	
Yes	23 (76.67)	23 (76.67)	
Cerebellum			0.157
No	29 (96.67)	27 (90.00)	
Yes	1 (3.33)	3 (10.00)	
Ventricles			0.096
No	19 (63.33)	22 (73.33)	
Yes	11 (36.67)	8 (26.67)	
Time from onset to surgery, h	13.20±6.25	10.17±5.29	0.047

GCS, Glasgow Coma Scale; HV, hematoma volume.

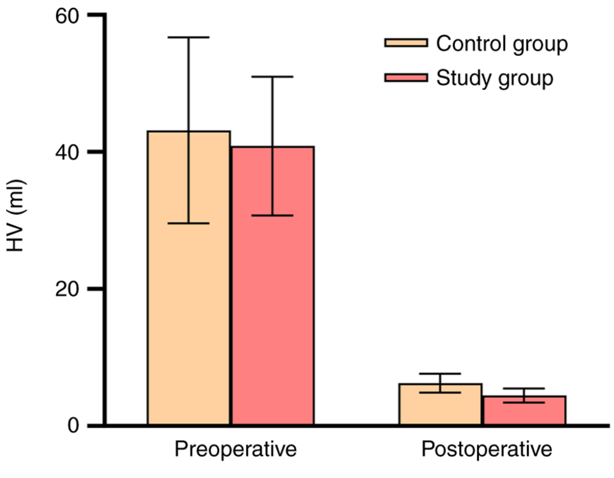

Figure 2. Comparison of preoperative and postoperative HVs between the two groups. HV was significantly reduced postoperatively in both groups compared with the preoperative time point. There were significant reductions in HV postoperatively compared with the preoperative time point for both the control and study groups. HV, hematoma volume.

achieved the goals of <10 ml of residual blood and >70% hematoma clearance. All patients regained consciousness at discharge, and the median GCS score was 15.0 (IQR, 15.0, 15.0) in the study group and 15.0 (IQR, 14.0, 15.0) in the control group (Table III). At the end of the 6-month follow-up period, no patient had died or was bedridden, and the majority of patients had a favorable neurological prognosis (mRS score <3). In terms of comparing the groups, 63.33% (19/30) of the patients in the study group had an improved prognosis compared with 56.67% (17/30) of the patients in the control group), and the median mRS score was 2.0 (IQR, 2.0, 3.0) in both groups (P=0.869; Table III).

Complications and adverse events. Among the patients in the study group, 24 cases of headache, 21 cases of hemiplegia, 9 cases of aphasia, 8 cases of intracranial Pneumatosis and 2 cases of Seizures were reported, while no cases of mild scalp necrosis were reported. In intracranial pneumatosis, a total of 6 cases of mild intracranial pneumatosis and 2 cases of moderate pneumatosis were located either around the hematoma or below the frontal dura mate. In comparison, among the patients in the control group, 25 cases of headache, 24 cases of hemiplegia, 11 cases of aphasia, 10 cases of intracranial Pneumatosis, 3 cases of Seizures and 1 case of mild scalp necrosis were reported. Neither group experienced rebleeding, hydrocephalus, or cerebral infarction. No intracranial infections occurred in the treatment group, whereas three cases of intracranial infection were observed in the control group. Patients with seizures who were treated with sodium valproate experienced relief of their symptoms.

Discussion

ICH exerts physical pressure on surrounding structures, impeding neural signaling and leading to neurological deficits. Cytotoxic metabolites, the inflammatory response and

Table III. Comparison of postoperative characteristics between the two groups.

Characteristic	Study group	Control group	P-value
HV at extubation	4.45±1.01[a]	6.26±1.38[a]	<0.001
Positioning and puncture accuracy, n (%)			0.011
No	0 (0.00)	7 (23.33)	
Yes	30 (100.00)	23 (76.67)	
Operating time, min	32.20±4.69	32.40±5.04	0.874
Drainage tube retention time, h	40.57±8.24	56.80±14.40	<0.001
Hematoma clearance, %	88.72±2.82	84.50±4.26	<0.001
Rebleeding rate, n (%)			0.326
No	29 (96.67)	28 (93.33)	
Yes	1 (3.33)	2 (6.67)	
GCS score at 7 days postoperatively	13.0 (12.0, 14.0)[a]	12.0 (11.0, 13.0)[a]	0.017
GCS score at discharge	15.0 (15.0, 15.0)[a,b]	15.0 (14.0, 15.0)[a,b]	0.015
mRS score at 6 months	2.0 (2.0, 3.0)	2.0 (2.0, 3.0)	0.869
Postoperative complications, n (%)			
Intracranial infection			0.083
No	30 (100.00)	27 (90.00)	
Yes	0 (0.00)	3 (10.00)	
Intracranial pneumatosis			0.489
No	22 (73.33)	20 (66.67)	
Yes	8 (26.67)	10 (33.33)	
Scalp infection/necrosis			0.326
No	30 (100.00)	29 (96.67)	
Yes	0 (0.00)	1 (3.33)	
Seizures			0.326
No	28 (93.33)	27 (90.00)	
Yes	2 (6.67)	3 (10.00)	

[a]P<0.05 vs. preoperative group. [b]P<0.05 vs. the corresponding group at 7 days postoperatively. GCS, Glasgow Coma Scale; mRS, modified Rankin Scale; HV, hematoma volume.

blood-brain barrier disruption resulting from ICH have all been shown to trigger secondary brain injury (24). Early intervention and hematoma removal are therefore essential to limit secondary damage and improve prognosis (25). Reducing ICP, improving cerebral perfusion, removing toxic metabolites and preventing brain herniation are key to treatment (26,27). Traditional soft-channel hematoma puncture and drainage are associated with the risk of making errors and repeated puncture (28,29), whereas stereotactic drainage can be accurately localized, although it requires a second CT scan to be performed, is complicated to operate and the supporting equipment is expensive, which makes it difficult to be implemented in primary hospitals (30,31). Craniotomy allows rapid hematoma removal and hemostasis, although this procedure is prone to intraoperative hemorrhage and brain tissue injury, also affecting postoperative recovery due to high trauma. Compared with craniotomy, neuroendoscopic hematoma debridement is a simpler, shorter and more straightforward approach; however, this technique is limited by two-dimensional imaging, high operator-training requirements, the difficulty in dealing with potentially massive hemorrhage and high costs, which limits its applicability in less developed regions (32,33). YL-1 hard-channel aspiration is mostly used in primary hospitals in China, and although it is an effective method, it carries the risks of brain tissue damage, rebleeding, inaccurate localization, infection and epilepsy (34,35). Despite the promise provided by precision soft-channel technology in neurosurgery, its application in resource-limited areas is constrained by the shortage of resources, facilities and personnel. These areas usually lack both precise instruments for surgical localization and the necessary infrastructure and monitoring systems (36). Therefore, there is a need to develop stereotactic alternatives that are cost-effective, safe and precise.

The present study investigated a novel approach of stereotactic aspiration in patients with ICH using laser-guided localization in combination with soft-channel MIS. The laser soft-channel MIS combined with urokinase thrombolysis (LAS-MISTIE) trial (37) concluded that a higher proportion of patients with a residual HV of <10 ml had improved clinical outcomes in the experimental group compared with the hard-channel group. Specifically, ~73.3% of patients with a residual HV of <10 ml had favorable clinical outcomes. In the present study, all patients in the study group had a residual

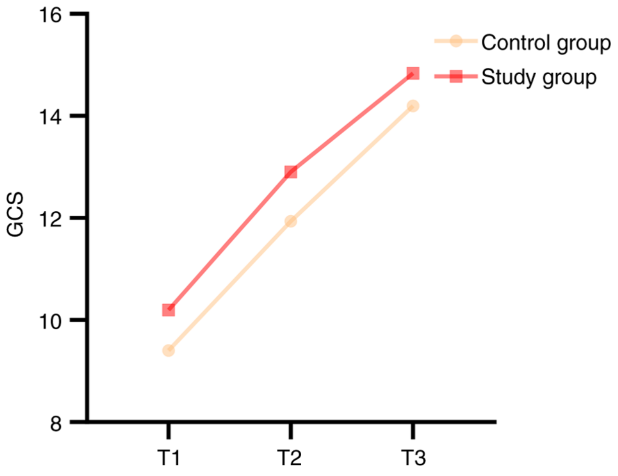

Figure 3. Comparison of GCS scores among different groups and times. The results demonstrated no significant differences in the GCS scores between the two groups preoperatively at both the 7-day postoperative and discharge time points, the study group exhibited significantly higher GCS score compared with the control group. T1, before surgery; T2, 7th postoperative day; T3 time of discharge; GCS, Glasgow Coma Scale.

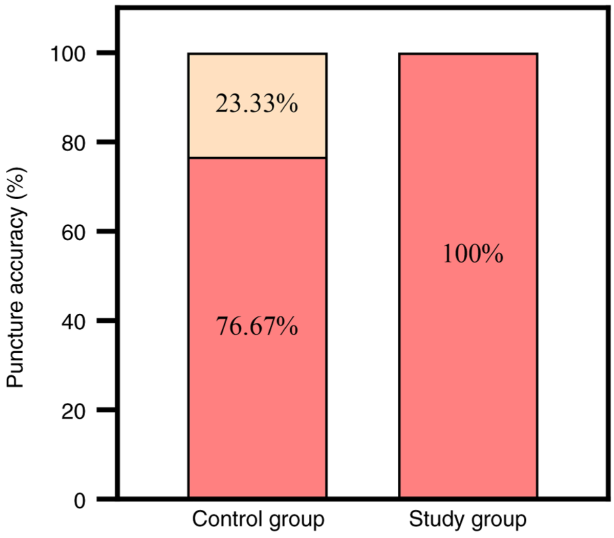

Figure 4. Accuracy of the localization of hematomas and puncture points. The puncture localization and accuracy were higher in the study group compared with that in the control group.

HV of <10 ml, and 63.33% had an mRS score <3 at the end of the study.

In the study group, the time from onset of the symptoms to surgery was 13.20±6.25 h, which is consistent with emergency surgery. The puncture accuracy was higher in the experimental group compared with the control group. In addition, drainage tube retention time in the study group was shorter than in the control group, Theoretically, shorter drain retention times may reduce the risk of intracranial infection. The design of the laser-guided puncture path was simply achieved. Through combining basic CT scanning parameters with the optics of laser technology, the method allows for flexible selection of puncture points and directions, avoiding critical brain areas and blood vessels. The puncture path is aligned with the long axis of the brain's nerve fibers, and the use of soft-channel material effectively reduces additional damage to normal brain tissue. The procedure is suited for treatment of small hematomas in functional areas, the deep brain and posterior cranial fossa (38).

The anatomic location and size of the hematoma are key factors in determining the success of surgical removal. MISTIE offers potential advantages over medical treatment in the management of supratentorial hemorrhage, including a reduction in HV and peripheral edema, with minimal damage to healthy brain tissue. This approach may subsequently reduce mortality (39). Hemorrhage in deep brain structures, such as the basal ganglia, thalamus and internal capsule, is associated with high morbidity and poor functional prognosis. Postoperative neurological deficits are a major concern, necessitating individualized therapeutic strategies and early intervention (40).

The present study demonstrated that early removal of the basal ganglia and internal capsule hematoma protects motor function, whereas thalamic hemorrhage often results in sensory and cognitive deficits (41). This underscores the need for careful balancing of risks and benefits due to the complexity of the neural networks involved. Treatment of lobar hemorrhage requires the preservation of cortical function for optimal postoperative recovery, with procedures tailored to specific functional areas (42). For frontal lobe hematomas, particularly those near the motor cortex, LAS-MISUT facilitates the precise preservation of motor pathways, enhancing functional outcomes. However, larger hematomas may limit the feasibility of minimally invasive methods. In the temporal lobe, LAS-MISUT minimizes cognitive and sensory deficits, especially near structures such as the hippocampus, but may be less effective for deeper lesions. In cases of occipital hemorrhage, the purpose of LAS MISUT is to reduce the risk of damage to the visual pathways (43-45).

For intraventricular hemorrhage (IVH), which often leads to hydrocephalus and is exacerbated by inflammatory responses to blood degradation products, external ventricular drainage (EVD) remains the primary treatment, particularly in cases with cast-like hematoma or elevated ICP (46). While MISTIE techniques, such as endoscopic or stereotactic hematoma removal, offer precision, they may not fully substitute for EVD in cases of persistent cerebrospinal fluid flow obstruction (47). In patients with moderate-to-large IVH and Severe ventricular cast haematoma EVD placement alone has been associated with improved survival, although prognosis remains poor for those with concomitant thalamic hemorrhage (48).

Regarding posterior cranial fossa hematomas, spontaneous cerebellar hemorrhages are associated with hydrocephalus, brainstem compression and posterior fossa herniation. To reduce mortality, urgent surgical removal of the hematoma is recommended over conservative treatment, especially if the hematoma is >3 cm, or if hydrocephalus or brainstem involvement is present (49). For larger hematomas, suboccipital craniotomy is recommended, whereas for smaller hematomas (≤3 cm), the MISTIE technique may be considered to prevent neurological deterioration (47). Hemorrhages near the brainstem or fourth ventricle may require more aggressive surgical intervention, while hemorrhages located more laterally are more amenable to MISTIE (50). The comparison between endoscopic or stereotactic aspiration and conventional suboccipital craniectomy requires further study.

Brainstem hemorrhages pose significant challenges due to their control over vital functions. Hematomas >1.5 cm with severe neurological deficits (Respiratory depression, circulatory instability, profound impairment of consciousness, and pupil abnormalities) may benefit from early surgical intervention, but only when the benefits clearly outweigh the risks (51). MISTIE techniques, such as LAS-MISUT, offer a potential alternative for moderate-sized hemorrhages (≤1.5 cm) or in patients with contraindications to conventional surgery. Multidisciplinary management remains essential.

In addition, the age, comorbidities and initial bleeding of the patient are key prognostic factors (52). Elderly patients may exhibit decreased hematoma clearance and postoperative recovery rates due to poor neuroplasticity, and also present a weaker ability to recover following brain injury. Furthermore, a larger initial hemorrhage volume increases the difficulty of clearance, especially when the hematoma extends to multiple brain regions or important structures; therefore, individualized treatment plans for high-risk patients are needed to improve surgical success and long-term prognosis.

Future research should stratify patients by ICH subtype to better evaluate the efficacy of MISTIE across different hemorrhage types. There is a need for more robust clinical trial data comparing MIS technologies in ICH, as surgeon expertise, complete hematoma evacuation and reduced rebleeding risks may offer advantages over individual techniques. Ongoing randomized controlled trials will provide valuable insights into these considerations.

From a pathophysiological perspective, minimizing collateral damage to surrounding tissues is essential for reducing secondary inflammatory responses, edema and subsequent neuronal injury (53). The soft-channel MIS approach offers notable advantages, allowing atraumatic access to the hematoma with minimal pressure on the adjacent brain tissue. By contrast, conventional techniques, such as YL-1 puncture, may cause greater tissue disruption and higher rates of iatrogenic injury. The present study demonstrated that the integration of laser guidance with soft-channel technology enhances targeting precision, promoting more complete hematoma evacuation, reducing residual clot volume and preventing sustained ICP elevation, thereby lowering the risk of secondary ischemic injury, cerebral infarction and hydrocephalus. This approach also accelerates hematoma clearance and improves neurological recovery, as evidenced by the improved GCS scores in patients. One of the primary objectives of future research is to mitigate post-ICH brain injury by addressing key pathological mechanisms, including inflammation, oxidative stress and excitotoxicity, which are key drivers of neuronal damage following ICH) (54). Additionally, advancements in minimally invasive techniques, such as laser-guided soft-channel surgery, represent a promising avenue for enhancing clinical outcomes and warrant further investigation. Further studies are required, however, to assess long-term outcomes and broader clinical applicability.

In the present study, the major complication associated with surgery was intracranial pneumatosis. A total of 6 cases of mild intracranial pneumatosis and 2 cases of moderate pneumatosis were located either around the hematoma or below the frontal dura mater. In none of the cases, however, did intracranial pneumatosis result in consequential complications, such as increased ICP or nerve fiber damage. A total of 2 cases of seizure patients treated with sodium valproate were observed, which were resolved following treatment with the extended-release tablets of sodium valproate. No cases of postoperative rebleeding, hydrocephalus, cerebral infarction or intracranial infection were reported.

To minimize damage to nerve fibers and shorten the drainage time, the following measures were taken: i) Precise positioning and stereotactic application using CT data to design a path through the frontal lobe to bypass the vessel; ii) gentle suctioning to minimize excessive ICP fluctuations; iii) planned puncture along the long axis of the hematoma using a porous soft-access channel to facilitate post-thrombolytic drainage; and iv) use of a soft-access channel, rather than a rigid needle, to perform stereotactic aspiration. Previously, the use of a rigid needle required drilling through the skull with direct entry into the hematoma cavity, necessitating penetration of the scalp, skull and dura mater. Furthermore, the high-speed rotation of the rigid metal needle caused significant additional damage. In addition, the lack of a 3D view of the hematoma and preoperative surface localization often resulted in inaccurate targeting, which could impede hematoma clearance and increase the risk of intracranial infection and rebleeding, ultimately compromising surgical outcomes (55).

In conclusion, the present study presented a MIS technique for the stereotactic treatment of ICH. The results obtained suggested that the LAS-MISUT technique used is a safe and effective treatment for ICH, as demonstrated in a cohort-controlled clinical trial. This method ensures precise puncture, significantly improves hematoma clearance and yields a favorable prognosis. In addition, its low cost makes it suitable for patients with ICH in underdeveloped countries. However, the generalizability of the results is limited by the single-center study design and small sample size, and further studies with larger clinical samples are required to address these limitations.

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Availability of data and materials

The data generated in the present study may be requested from the corresponding author.

Authors' contributions

AC conceived the study, the design of the methodology and writing, reviewing and editing the manuscript. JS was responsible for the conception of the study, the formal analysis of the data, reviewing and editing the manuscript. JP and TL performed the software analyses and data curation. LC and QW performed CT images. AC, JS, LC, WQ and TL confirm the authenticity of all the raw data. All authors read and approved the final manuscript.

Ethics approval and consent to participate

Ethics approval for the present study was obtained from the Ethics Committee of Nanchuan Hospital of Chongqing Medical University (approval no. YXYJ-2022-013; Chongqing, China), and written informed consent was obtained from all patients before the study began.

Patient consent for publication

Written informed consent for publication was obtained from all participants involved in the present study. The consent process adhered to ethics guidelines and institutional protocols to ensure that patients were fully informed about the nature, scope and potential implications of the publication of their clinical data. All patient information was anonymized to protect privacy and confidentiality, in accordance with the principles of The Declaration of Helsinki.

Competing interests

The authors declare that they have no competing interests.

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