A Novel Frameless Laser Stereotaxis System for Neurosurgical Interventions

Dan Tang[1], Jun liu[2], Chunwen Xiao[3], Dujie Xie[4], Xiaohong Fu[5], Shenghua Cui[6], Bo He[7], Mingchu Li[8], Lingyun Zhang[3]

■ OBJECTIVE: **The aim of the article is to introduce a novel laser-based frameless stereotactic device that can locate intracranial lesions quickly and with computed tomograph (CT)/magnetic resonance imaging (MRI) films. Preliminary experiences of application in 416 cases are also summarized.**

■ METHODS: **From August in 2020 to October in 2022, a total of 416 cases of new minimalist laser stereotactic surgery have been performed on 415 patients. Of the 415 patients, 377 had intracranial hematomas, while the remaining cases were brain tumors or brain abscesses. Postoperative CT was used to evaluate the accuracy of catheterization of 405 patients according to the MISTIE study. The duration time of locating was recorded. Rebleeding refers to the definition: Compared with preoperative CT, the relative volume of postoperative hematoma increases by >33% or absolute volume increase >12.5 mL.**

■ RESULTS: **According to postoperative CT, the accuracy of 405 stereotactic catheterization cases was good in 346 cases (85.4%) and suboptimal in 59 cases (14.6%), with no poor results. Postoperative rebleeding occurred in 4 spontaneous cerebral hemorrhage cases and 1 brain biopsy case. The average localization time of supratentorial lesions was 13.2 minutes in the supine position, 21.5 minutes in the lateral position, and 27.6 minutes in the prone position.**

■ CONCLUSIONS: **The new laser-based frameless stereotactic device is simple in principle and convenient in positioning operation of brain hematoma and abscess puncture, brain biopsy and tumor surgery, and appropriate to the precision requirements in most craniocerebral surgery.**

INTRODUCTION

High acquisition and maintenance costs have hindered many neurosurgical centers in China and other low- and middle-income countries from providing stereotactic-assisted neurosurgical care.[1] In China, more than 1 million patients suffer from hypertensive intracerebral hemorrhage per year, with more than 100,000 among them requiring minimal invasive surgeries.[2] The freehand technique for insertion of a drainage tube based on experience is often inefficiently precise. Hence, hospitals and doctors are denied a low-cost and time-efficient stereotactic platform, especially when highly sophisticated and expensive navigation systems are not available.

That is why we created a new frameless stereotactic system, the Durofi frameless stereotactic system (developed by Hunan Zhuoshichuangsi Technology Company, and approved by the National Medical Products Administrations, China), for which a physician only needs to read the computed tomography (CT)/ magnetic resonance imaging (MRI) film and use the laser plane to restore the scanning state of the CT/MRI for positioning and orientation.[3]

METHODS

The Durofi laser system consists of 2 parts: a laser locator and a recording system. The laser locator is designed according to the Cartesian coordinate system including 2 base lasers and 4 target

Key words
- Frameless
- Global neurosurgery
- Laser
- Novel stereotaxis

Abbreviations and Acronyms
CT: Computerized tomography
EAC: External auditory canals
ICH: Intracerebral hemorrhage
MRI: Magnetic Resonance Imaging

From the [1]Department of Neurosurgery, The First People's Hospital of Huaihua; Departments of [2]Neurology and [3]Neurosurgery, The Second People's Hospital of Huaihua, Huaihua, Hunan; [4]Department of Neurology, Third Xiangya Hospital, Central South University, Changsha; [5]Department of Neurosurgery, The First People's Hospital of Zunyi, ZunYi, Guizhou; [6]Department of Neurosurgery, The Second Affiliated Hospital, Hengyang Medical School, University of South China, Hengyang; [7]Emergency Department, Xiangtan Central Hospital, Xiangtan; and [8]Department of Neurosurgery, Capital Medical University, Xuanwu Hospital, China International Neuroscience Institute (China-INI), Beijing, China

*To whom correspondence should be addressed: Lingyun Zhang, M.D.
[E-mail: 58368287@qq.com]*

Supplementary digital content available online.

*Citation: World Neurosurg. (2023) 174:175-182.
https://doi.org/10.1016/j.wneu.2023.03.094*

*Journal homepage: **www.journals.elsevier.com/world-neurosurgery***

*Available online: **www.sciencedirect.com***

lasers. The base lasers are fixed on the frame to match the datum section of CT/MRI, while the 4 target lasers are divided into anteroposterior and lateral groups which could move to aim at the target according to coordinates of the target point on the corresponding CT/MRI slice (**Figure 1A**). Once the target lasers are aligned with the target, positioning is completed. At this point, rotating 2 target lasers separately through the predetermined surgical entry points completes orientation. The recording system is used to record the direction indicated by the laser locator and measure the depth of the target. It consists of 2 parts, a planner for preoperative positioning and a guider for intraoperative guidance (**Figure 1B**).

Core Principles

The principle of this localization method is based on the second axiom of solid geometry: If 2 planes have a common point, then they have only 1 common line passing through that point. In this device, once the anteroposterior and lateral laser axes are aimed at the target in 1 plane, the intersection line of the 2 laser planes passes through the target point and any entry point in space (**Video 1**).

Video

Video available at www.sciencedirect.com

First Step

Datum Confirmed Phase. We developed an application for convenience that can use the CT/MRI slice distance numerical value to calculate the CT/MRI scan plane based on the relative height difference of anatomical markers. The value of these markers, including the bilateral pupils/bilateral external auditory canals (EACs)/target point, were put into the app with the result of a datum and a target section. Four points of the chosen datum section are marked on the patient's face. (**Figure 2**; **Video 2**).

Second Step

Location Phase. After the patient's head is maintained in a neutral position under the laser locator, the basal laser plane of the laser locator was used to match the marked points of the datum section on the face of the patient by adjusting the laser frame. Once the datum section matched, we move the target laser plane to match the patient's target section according to the 2-plane distance between the datum and target CT/MRI film. We then move anteroposterior and lateral lasers on the external frame to aim at the target, respectively, in the rectangular coordinates set up by the CT/MRI.

Once the entry point on the skin has been selected, the anteroposterior and lateral lasers are rotated to pass through the entry point. The intersection line of the plane of the anteroposterior and lateral laser in space is the entry trajectory. The entry trajectory is recorded with the planner, and the target depth is measured with the laser. The skin surface contact points of the 3 legs of the planner and parameters such as the angular leg length of the planner are recorded (**Figure 3**; **Video 3**).

Operation Phase. All localization devices are maintained with routine disinfection, and the entry trajector is guided by a sterilized guider that copies coordinates of the planner. The key point to prevent distortion is under the guidance of the adjusted guider, and the surgical trajectory with the guidance of the guider (**Figure 4**; **Video 4**).

Clinical Application. From August 2020 to October 2022, a total of 416 cases of new laser stereotactic surgery were carried out on 415 patients with intracranial lesions (average age 43 [range 16–86] years, M/F = 240/175) in 60 hospitals in China. Informed consent was obtained from the patients or their families. All patients who participated had either undergone brain CT or MRI

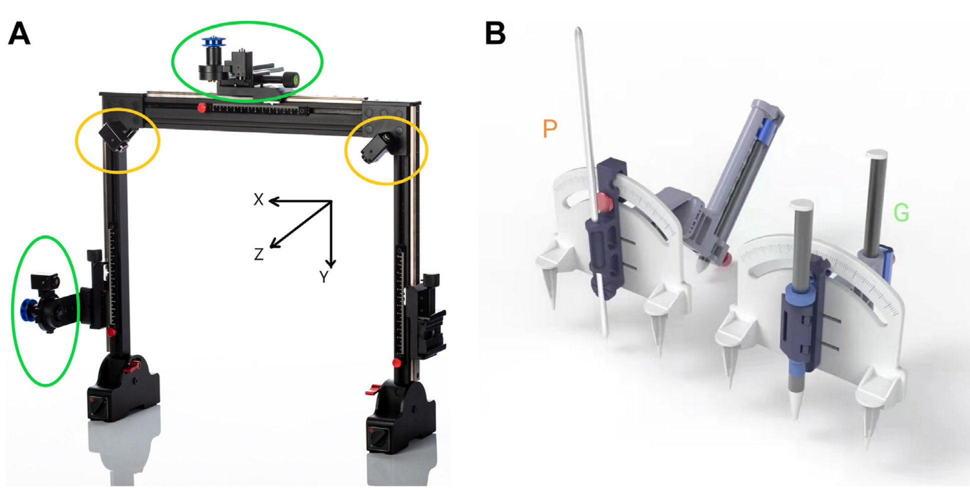

Figure 1. Laser locator system. (**A**) Laser locator: The laser plane in the *yellow circles* is designed for matching the datum section of CT/MRI scan, the laser plane in the *green circles* is designed for matching target section. (**B**) Planner and guider. P, the planner for recording trajectory and measuring depth; G, the guider for surgery guiding.

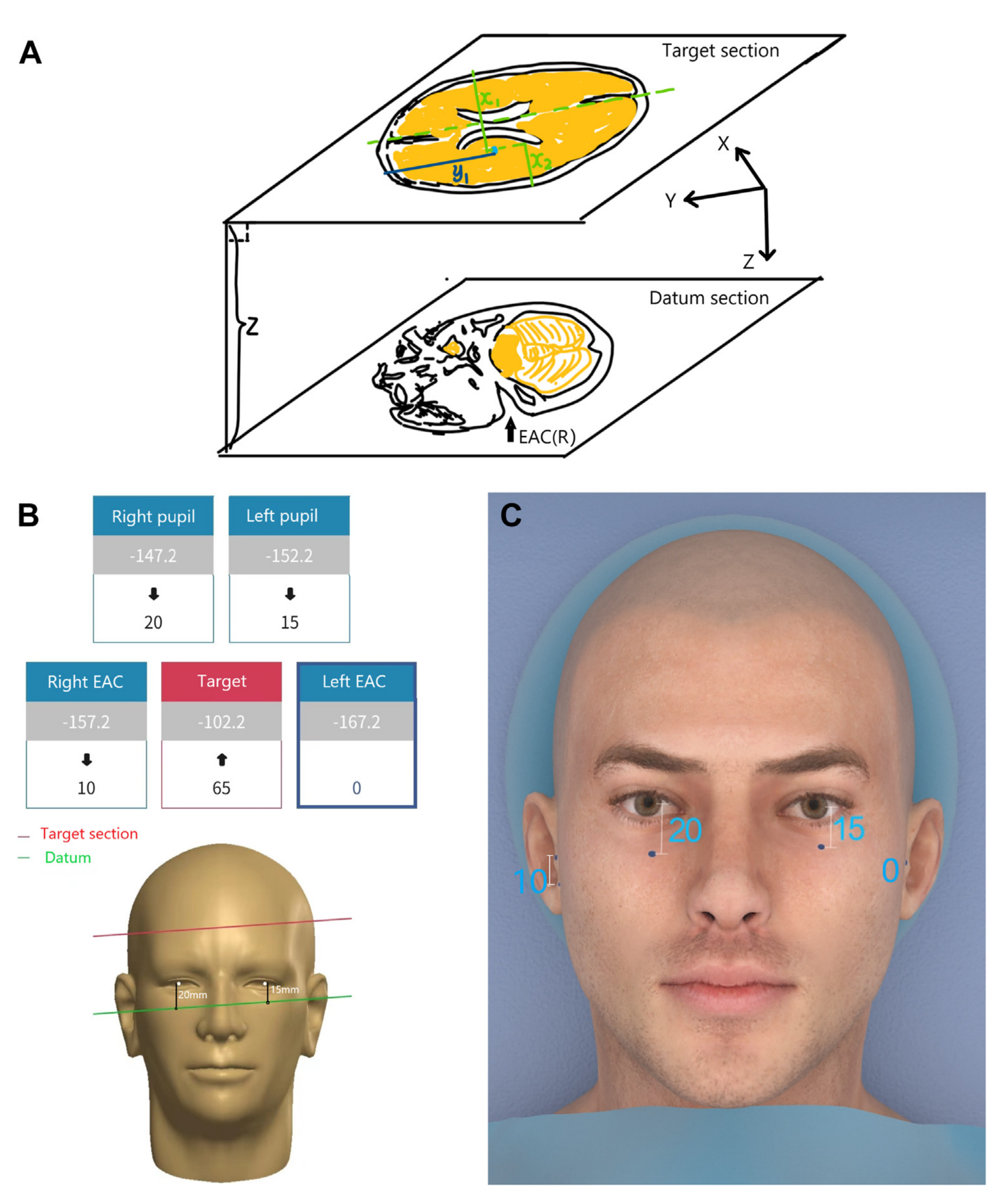

Figure 2. The datum and target section and the application. (**A**) Datum and target section in the rectangular coordinate system of CT/MRI. (**B**) Datum of right EAC and the target section which is calculated and presented by the app we developed. (**C**) Four points of the chosen datum section are marked on the face.

angiography in order to exclude the presence of other neurovascular lesions.

There were 402 cases of deep lesions, including lesion in deep lobe, basal ganglia, thalamus, brainstem, and cerebellum. Superficial lesions were found in 14 cases. The types of surgery included puncture and drainage of 312 cases of deep brain hematoma, 63 cases of brain stem hematoma, 12 cases of brain abscess, 20 cases of brain biopsy, 4 cases of lesion location for surgical plan, 3 cases of guidance for microscopic surgery, and 2 cases of stereotactic endoscope surgery (Figure 5). Each key step of positioning should be validated, such as whether the lasers match the corresponding CT/MRI section, and if the 2 measurements for each coordinate match each other under the laser (Figure 6). Because lesions were more prominent on MRI, most brain biopsies are localized using MRI films. However, the accuracy was affected by the thickness of the MRI film, with most layer differences greater than 5 mm. In order to ensure the positioning accuracy, the diameter of the brain biopsy lesions were greater than 1.5 cm.

We use the accuracy of catheter placement to evaluate the effect of surgical positioning that was done in 405 cases according to the CT/MRI examination before and after the operation. We refer to

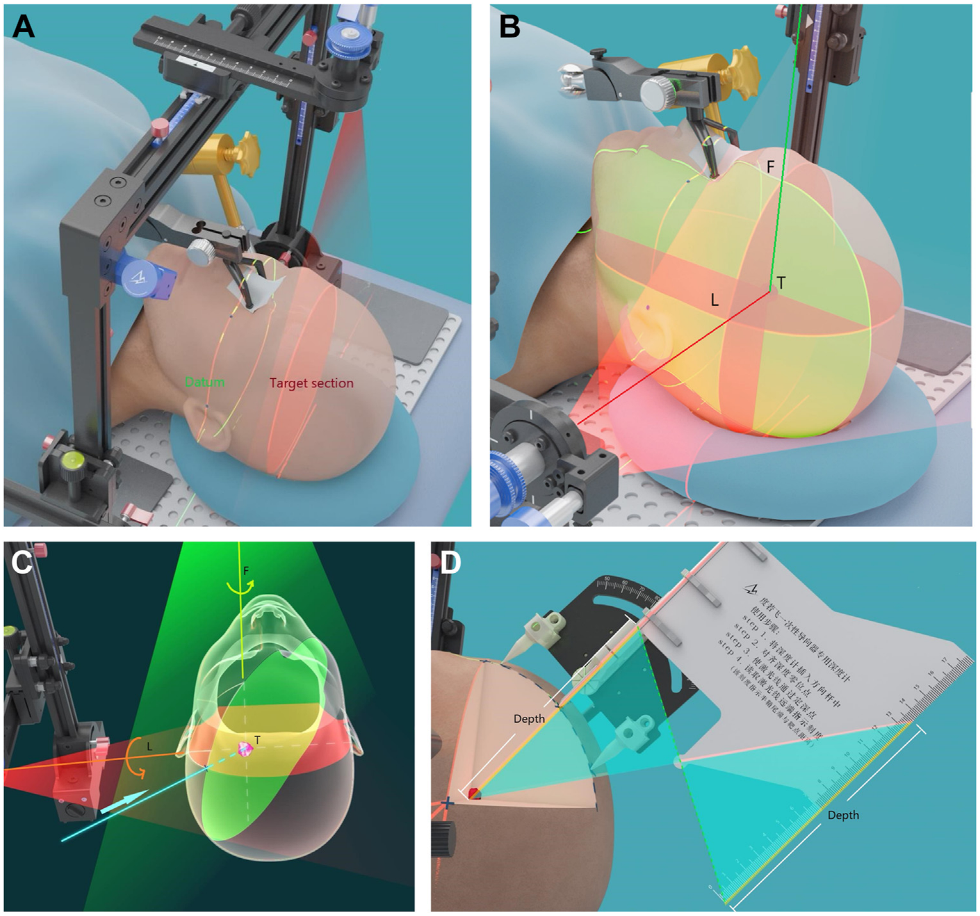

Figure 3. The process of laser stereotaxis system. (**A**) The lasers match the datum and the target section of CT/MRI. (**B**) The rotation axis of anteroposterior and lateral lasers are aimed at the target. (**C**) Target orientation, the intersection line of the 2 laser planes at the puncture point was the trajectory (*blue arrow*). (**D**) The planner records the trajectory and measures the depth in combination with the laser.

the MISTIE study for evaluating accuracy.[4] A good catheter position should be placed two-thirds of the way along the longest axis of the lesion and in the middle of the width of the lesion. If the catheter was in the lesion but not in the middle two-thirds, it was considered as suboptimal, and if the lesion was not touched, it was considered poor (Figure 7).

RESULTS

Satisfactory localization was achieved in all operations. No postoperative infection was noted. In this group, catheterization was used in 405 cases, with good position in 346 cases (85.4%) and suboptimal position in 59 cases (14.6%). There were 5 postoperative rebleeding cases after surgery. Four of them were intracerebral hemorrhage patients with poor blood pressure management, and 1 biopsy case with abundant blood supply lesion.

The duration of locating from the placement of the laser frame to the completion of the positioning was recorded according to 3 positions of the patients. The mean time spent in 3 positions was as follows: 11 minutes in supine position, 16 minutes in lateral position, and 21 minutes in prone position (Figure 8).

DISCUSSION

Precise positioning is the foundation of neurosurgery. Tomography imaging technology, represented by CT and MRI, has made micro lesions “visible”. Both frame and frameless stereotactic devices share the similar technical idea of forming image-space in a computer based on high-quality DICOM data of CT scan subsequently as to complete the positioning and orientation of any intracranial target and then match the physical space with the image-space through the frame fixed on skull (frame) or space camera (frameless).[5]

High-quality scan data means close coordination with the radiology department, which is not easy for emergency surgery at night. A relatively complex combination of software and hardware and human—computer interaction means a high learning curve

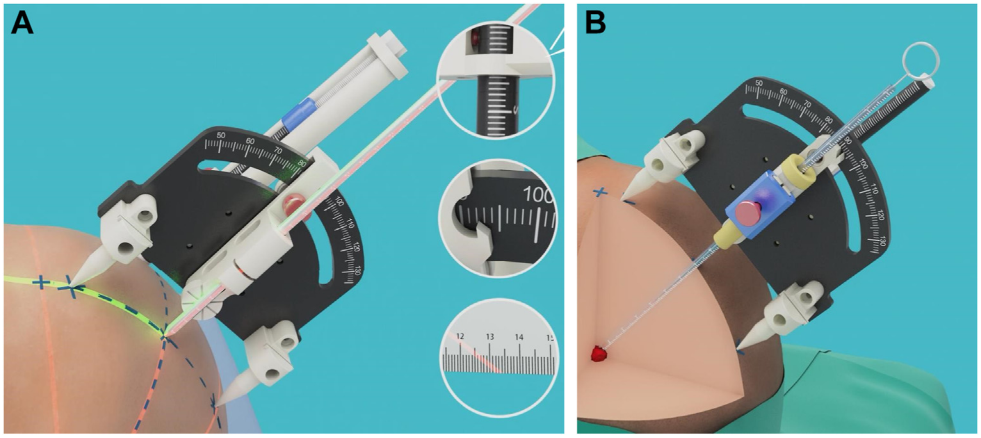

Figure 4. The process of guider guided operation. (**A**) Parameters of the planner are recorded and marked on the scalp. (**B**) The guider replicates the planner and guides the surgical trajectory.

and less skillful users. This may explain part of the phenomenon that, even though being available for decades, these frame and frameless stereotactic devices are far from ubiquitous in global neurosurgery.[6]

Global neurosurgery is the clinical and public heath practice of neurosurgery with the primary purpose of ensuring timely, safe, and affordable neurosurgery care to all who need it.[7,8] However, the lack of widespread application of precise positioning technology severely hinders the progress of global neurosurgery.[9-11] As demonstrated by the 44 essential surgical procedures in the Disease Control Priorities published by the World Bank, burr hole drainage of intracranial hematoma is the only neurosurgical procedure.[12] The cost-effective improvement of surgical precision will undoubtedly expand the usability of neurosurgery. Therefore, there is an urgent need to develop a simple, rapid, and accurate standardized localization device more readably adoptable for the global population.[13]

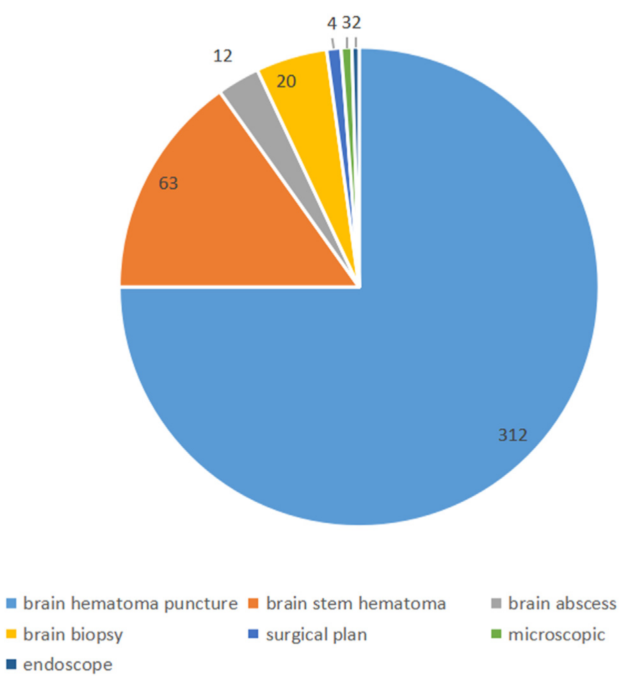

Figure 5. Operation types.

The biggest advantage of the Durofi laser positioning system is that it uses laser to directly map the Cartesian coordinate system contained in the CT/MRI film to the patient's head for direct and rapid positioning and orientation. The initial CT/MRI scan of a patient has already established a standard Cartesian coordinate system for their head. By matching the CT scan section with a laser plane outside the body, any target in the head can be located laterally and anteriorly. Thereafter, direction from any point on the non-target plane to the target can be determined by rotating the lateral and anterior laser base on the plane intersection principle.

The method described here differs from current stereotactic frames in several ways. For example, it is frameless, does not require patients to be transferred for imaging prior to the operation, and does not require disinfection of the frame before operation. The use of basic 3-dimensional geometric tools instead of complex computer analysis and expensive equipment platforms simplifies localization of intracranial targets in a cost-effective manner that is easily taught and readily available in resource-limited environments.

The error in surgical positioning accuracy mainly comes from 3 places: mechanical error, registration error, and operation error. In this study, mechanical error depends on the accuracy of the positioner laser, which is less than 0.5 mm, and the degree of

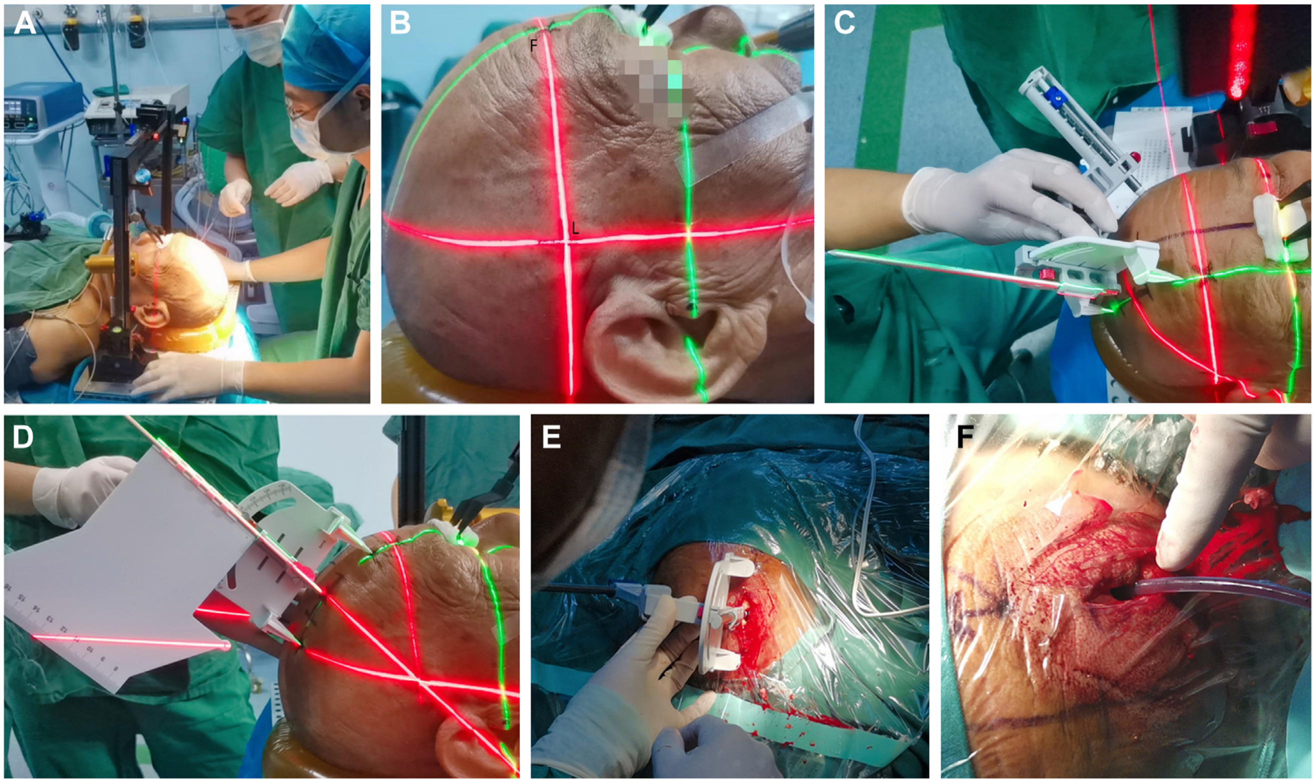

Figure 6. The process of intracerebral hemorrhage puncture. (**A**) Lasers in frame matches the datum and the target section. (**B**) Axis of lasers aimed at the target. (**C**) Planner records the trajectory. (**D**) Depth is measured. (**E**) Guider guides the surgery. (**F**) Drainage tube fixed into an appropriate length after a small amount of hematoma is removed.

matching between the guider and the drainage tube. A drainage tube with a high degree of matching and good directivity should be selected.

Registration errors mainly arise from the accuracy of registration points and target point coordinates. Although choosing the EAC and eyeball as the registration points is convenient for clinical use, it can cause certain errors. The thickness of CT/MRI scanning and target coordinate measurement can also affect the accuracy.

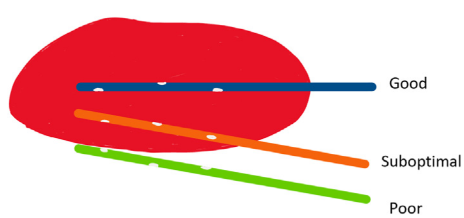

Figure 7. Catheter placement is graded as good (346 cases, 85.4%), suboptimal (59 cases, 14.6%), or poor (0 cases).

Operation error mainly arises from the movement of the guider on the scalp and whether the puncture path remains unobstructed. We recommend this positioning system for locating lesions with a diameter greater than 1.5 cm, especially lesions in the basal ganglia area that are close to the center of the head.

Because this is a retrospective study, there was no control group. Further improvements and research are essential for widespread implementation.

CONCLUSIONS

The new laser stereotaxis system described in this article simplifies the positioning process by selecting the orientation and appropriate depth through a CT/MRI coordinate system laser plane. This new stereotactic technique is conducive to the rapid popularization of precision neurosurgery, and is worthy of further research.

CRediT AUTHORSHIP CONTRIBUTION STATEMENT

Dan Tang: Investigation, Resources, Methodology, Writing – original draft. **Jun liu:** Writing – original draft, Validation. **Chunwen Xiao:** Writing – review & editing, Supervision. **Dujie Xie:** Writing – review & editing, Supervision. **Xiaohong Fu:**

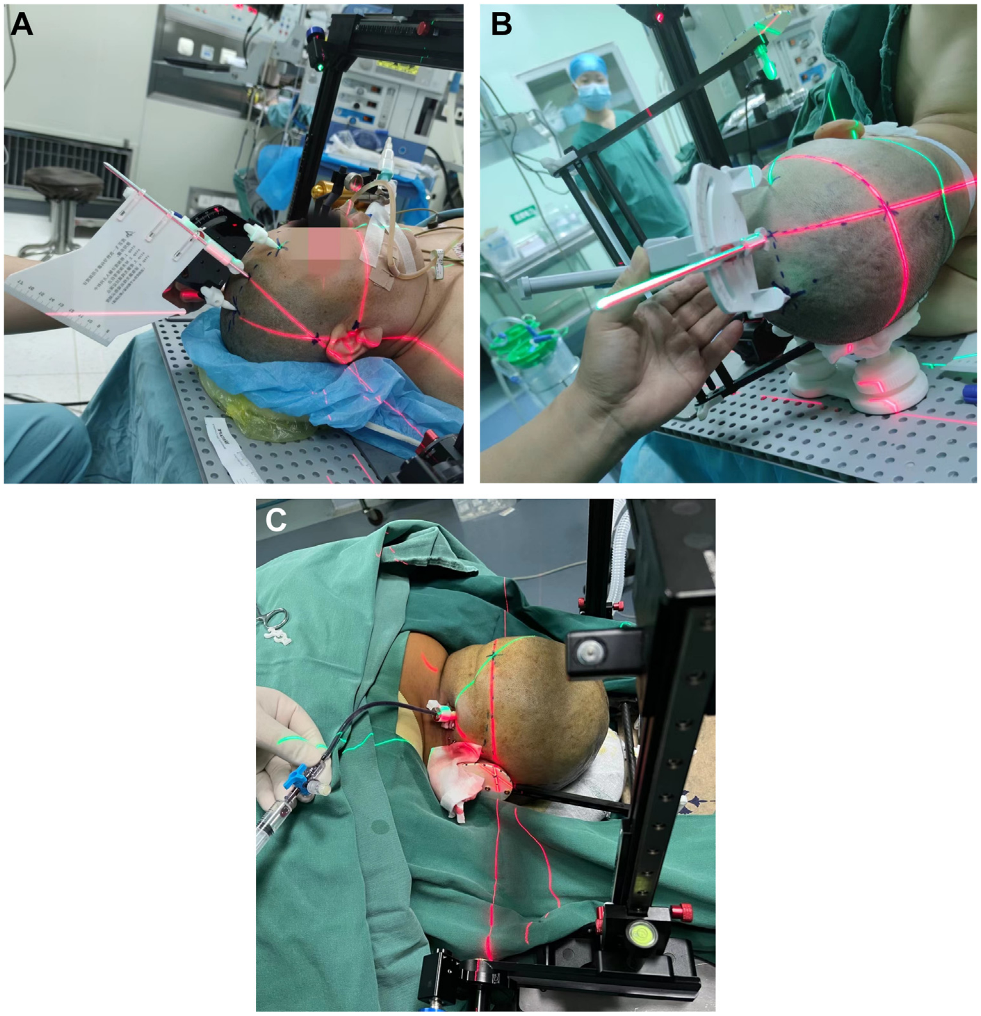

Figure 8. Three positions of location and time spent on average. (**A**) Supine took 11 minutes; (**B**) lateral took 16 minutes; and (**C**) prone took 21 minutes.

Writing — review & editing, Supervision. **Shenghua Cui:** Writing — review & editing, Supervision. **Bo He:** Writing — review & editing, Supervision. **Mingchu Li:** Writing — review & editing, Supervision. **Lingyun Zhang:** Conceptualization, Investigation, Project administration, Validation, Visualization, Writing — original draft.

REFERENCES

1. Eftekhar B. A Smartphone app to assist scalp localization of Superficial supratentorial lesions-technical Note. *World Neurosurg*. 2016;85:359-363.

2. Zhang JH. Robot-assisted surgery: an emerging minimally invasive surgery method for intracerebral hemorrhage. *Brain Hemorrhages*. 2022;3:1-2.

3. Tang D, Soto JM, Zhang L. A novel laser-based stereotactic localization device for intracranial mass resection. *Brain Hemorrhages*. 2021;9:106-110.

4. Hanley DF, Thompson RE, Rosenblum M, et al. Efficacy and safety of minimally invasive surgery with thrombolysis in intracerebral haemorrhage evacuation (MISTIE III): a randomised, controlled, open-label, blinded endpoint phase 3 trial,Hanley DF et al. *Lancet*. 2019;393:1021-1032.

5. Alexandra J. *Golby .Image-guided Neurosurgery*. 1st ed. Waltham, MA: Elsevier; 2015.

6. Fu C, Wang N, Chen H, Chen Q. A novel simple puncture positioning and guidance system for intracerebral hematoma. *World Neurosurg*. 2019; 131:562-569.

7. Ravindra VM, Kraus KL, Riva-Cambrin JK, et al. The need for cost-effective neurosurgical Innovation–A global surgery Initiative. *World Neurosurg*. 2015;84:1458-1461.

8. Rosseau G, Johnson WD, Park KB, et al. Global neurosurgery: continued momentum at the 72nd World Health Assembly. *J Neurosurg*. 2020;132: 1256-1260.

9. Park KB, Johnson WD, Dempsey RJ. Global neurosurgery: the unmet need. *World Neurosurg*. 2016;88:32-35.

10. Dwarakanath S, Suri A, Sharma BS, et al. Neuronavigation in a developing country: a pilot study of efficacy and limitations in intracranial surgery. *Neurol India*. 2007;55:111-116.

11. Wu JS, Lu JF, Gong X, Mao Y, Zhou LF. Neuronavigation surgery in China: reality and prospects. *Chin Med J (Engl)*. 2012;125:4497-4503.

12. Mock CN, Donkor P, Gawande A, et al. DCP3 essential surgery author group. essential surgery: key messages from disease control priorities, 3rd edition. *Lancet*. 2015;385:2209-2219.

13. Yang Z, Hong B, Jia Z, et al. Treatment of supratentorial spontaneous intracerebral hemorrhage using image-guided minimally invasive surgery: initial experiences of a flat detector CT-based puncture planning and navigation system in the angiographic suite. *AJNR Am J Neuroradiol*. 2014;35:2170-2175.

Conflict of interest statement: The authors declare that the article content was composed in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Received 1 March 2023; accepted 22 March 2023

Citation: World Neurosurg. (2023) 174:175-182.
https://doi.org/10.1016/j.wneu.2023.03.094

Journal homepage: ***www.journals.elsevier.com/world-neurosurgery***

Available online: ***www.sciencedirect.com***