Accepted Manuscript

Submission Date: 2024-03-25
Accepted Date: 2025-01-20
Accepted Manuscript online: 2025-03-23

Journal of Neurological Surgery Part A: Central European Neurosurgery

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DOI: 10.1055/a-2564-1309

Please cite this article as: Hou L, Zhang J, Meng K et al. The Application Value of Personalized 3D Printing Navigation Molds in Neurosurgery. Journal of Neurological Surgery Part A: Central European Neurosurgery 2025. doi: 10.1055/a-2564-1309

Conflict of Interest: The authors declare that they have no conflict of interest.

This study was supported by JiLin Science and Technology plan project, 20210401143YY, 20220401089YY

Abstract:
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Background: Most neurosurgical procedures have the problems of high cost, large technical differences and high incidence of complication rate.Based on the clinical advantages of 3D technology in surgical procedures, it is necessary to develop an application method for personalized navigation molds that use 3D printing technology in precise and minimally invasive directions,analyze the clinical application of this technology in intracerebral hemorrhage, hydrocephalus, and brain abscess, and expand the research on the clinical application value range of this technology in neurosurgery.
Methods: According to the patient specific brain CT imaging data, reconstructed the three-dimensional structure of intracranial lesions or target structures, constructed a three-dimensional model of important brain regions, allowed doctors to accurately locate the location of intracranial lesions under conditions equivalent to direct vision, analyzed the morphology and size of lesions, and performed precise puncture positioning. Based on patient specific differences, designed the best path 3D printing navigation molds to improve the puncture accuracy of targeted intracranial lesions and truly achieved personalized medical treatment.
Results:This article focuses on 5 cases of intracerebral hematoma, 2 cases of hydrocephalus, and 2 cases of brain abscess in the neurosurgery department of the Third Bethune Hospital of JiLin University from September 2020 to January 2022. Neurosurgical puncture and drainage was performed with 3D printing navigation molds, the basic situation of the surgery was analyzed ,the lesion clearance rate was over 70% and the average puncture error was 2.86mm.All the 9 patients recovered well after surgery, and no infection or death occurred.
Conclusion: The personalized 3D printing navigation molds provided in this study is beneficial for clinical doctors to accurately locate intracranial lesions or target three-dimensional structures during surgery. It has the advantages of cheap equipment, simple operation, and accurate positioning, and is suitable for promotion in grassroots hospitals.

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The Application Value of Personalized 3D Printing Navigation Molds in Neurosurgery

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Abstract

Background: Most neurosurgical procedures have the problems of high cost, large technical differences and high incidence of complication rate.Based on the clinical advantages of 3D technology in surgical procedures, it is necessary to develop an application method for personalized navigation molds that use 3D printing technology in precise and minimally invasive directions,analyze the clinical application of this technology in intracerebral hemorrhage, hydrocephalus, and brain abscess, and expand the research on the clinical application value range of this technology in neurosurgery.

Methods: According to the patient specific brain CT imaging data, reconstructed the three-dimensional structure of intracranial lesions or target structures, constructed a three-dimensional model of important brain regions, allowed doctors to accurately locate the location of intracranial lesions under conditions equivalent to direct vision, analyzed the morphology and size of lesions, and performed precise puncture positioning. Based on patient specific differences, designed the best 3D printing navigation molds to improve the puncture accuracy of intracranial lesion targeting, analyzed the sources of deviation, and provided clinical application basis.

Results: This article focuses on 5 cases of intracerebral hematoma, 2 cases of hydrocephalus, and 2 cases of brain abscess in the neurosurgery department of the Third Bethune Hospital of JiLin University from September 2020 to January 2022. Neurosurgical puncture and drainage was performed with 3D printing navigation molds, the basic situation of the surgery was analyzed ,the lesion clearance rate was over 70% and the average puncture error was 2.86mm.All the 9 patients recovered well after surgery, and no infection or death occurred.

Conclusion: The personalized 3D printing navigation molds provided in this study is beneficial for clinical doctors to accurately locate intracranial lesions or target three-dimensional structures during surgery.The accuracy error analysis confirm the effectiveness of minimally invasive neurosurgical puncture in intracerebral hematoma, hydrocephalus and brain abscess， it has the advantages of cheap equipment, simple operation, and accurate positioning, etc., and is suitable for promotion in grassroots hospitals.

Keywords: 3D printing navigation molds, neurosurgery, precise positioning, intracerebral hematoma, hydrocephalus, brain abscess

1. Introduction

Ventricular peritoneal shunt has been proved to be one of the effective methods for the treatment of hydrocephalus, but it has high requirements for the location and path of inserting soft drainage tube, if the location or path of inserting soft drainage tube is not good, postoperative complications is easy to occur. Improper positioning of the shunt (such as positioning it too close to the choroid plexus or against the ventricular wall) is a common cause of shunt obstruction[1].In order to reduce the occurrence of complications caused by shunt obstruction, it is recommended to place the head of the shunt as close as possible to the frontal angle of the lateral ventricle and avoid placing it in the choroidal plexus. The common location of intracranial hematoma is in the basal ganglia area, and the hematoma has different shapes and sizes[2]. Related researches such as STICH (Surgical Treatment for Cerebral Hemorrhage)Ⅰand Ⅱ had shown that open craniotomy did not improve neurological outcomes or reduced mortality rates compared to drug therapy alone[3]. Meanwhile, other researches such as MISTIE Ⅲ had found that under the premise of reducing the hematoma by at least 70% or reducing the residual volume of the hematoma to<15ml,patients could achieve functional improvement of the nervous system within 1 year, stereotactic thrombolysis and other noncraniotomy techniques could reduce the mortality and poor functional prognosis after cerebral hemorrhage, the effect size was approximately 0.50, however in the occurrence of severe bleeding and infection, MISTIE treatment was safe[4], indicating that minimally invasive puncture surgery has certain advantages over conventional craniotomy under specific surgical strategies.

For some neurosurgical lesions (such as intracranial hematomas), it is generally believed that minimally invasive puncture surgery has less trauma and comparable lesion clearance rate compared to craniotomy surgery, lower cost than endoscopic assisted control surgery, and less impact on individual clinical techniques. At the same time, the trauma is equivalent [5]. Some studies have shown that puncture aspiration of brain abscesses is as effective and less invasive as craniotomy clearance surgery [6]. Therefore, minimally invasive puncture surgery has become the preferred surgical method. The key to the success of puncture drainage surgery lies in the accuracy of puncture positioning. Currently, the main auxiliary positioning methods include neuro navigation, stereotaxic instrument, CT imaging data surface positioning, etc. Common complications include excessive deviation in puncture tube placement or loss of arterial blood vessels, which aggravates damage. For the surgical treatment of the above diseases, it is shown that accurate positioning guidance is indispensable for puncture surgery.At present, hospitals usually use robot assisted positioning to solve such problems. Although it is easy to operate and has high accuracy, it is expensive and difficult to popularize in grassroots hospitals.Meanwhile, traditional CT positioning requires doctors to determine the location of hematoma based on two-dimensional images, which requires doctors to have good three-dimensional anatomical thinking and precise puncture skills. For inexperienced doctors, this method may lead to inaccurate positioning and increase the risk of brain tissue damage [7]. Another stereotactic technique was first proposed by Backlund et al.[8] in 1978 to solve the problem of clearing intracranial hematomas. In recent years, computer technology has made breakthroughs in puncture accuracy, but it requires the use of large positioning frames to fix the patient's head reference point, which is time-consuming and laborious[9].Neuronavigation technology allows physicians to use virtual images to locate real surgical instruments to assist in the location of intracerebral hematoma and guidance for puncture. However, before use, the skin marker should be fixed on the patient's head and its position should not change, otherwise movement or swelling may cause positioning errors[10]. Therefore, finding a method with relatively simple technology, low price and high accuracy has become a problem that researchers have been trying to solve.

Specific studies have shown that 3D printing technology has been introduced into surgical procedures and has demonstrated good clinical outcomes.Although some previous studies have shown that minimally invasive puncture surgery can effectively treat cerebral hemorrhage, hydrocephalus, and brain abscess, there is currently no research combining minimally invasive puncture with 3D technology to treat hydrocephalus and brain abscess on the basis of comparing the accuracy, convenience, and application cost of puncture [10-11].Therefore, we urgently need to develop minimally invasive puncture methods based on 3D technology to further study and verify their accuracy and clinical effectiveness in surgeries for cerebral hemorrhage, hydrocephalus, and brain abscess.In addition, these studies will help expand the clinical application scope of minimally invasive puncture technology, especially to meet the needs of grassroots hospitals in puncture drainage surgery, and improve the prospects for clinical promotion. Through these efforts, we hope to achieve more efficient and precise surgical treatment on a larger scale, and improve the overall medical level.

2. Materials and Methods

2.1. General information

This study included 9 patients who underwent 3D printed navigation molds assisted puncture and drainage surgery at the Neurosurgery Department of The Third Bethune Hospital of JiLin University from September 2020 to January 2022. Among them, 5 patients had intracerebral hematoma, 2 patients had brain abscess, and 2 patients with hydrocephalus. The surgery was approved by the patient's family. All procedures conducted in studies involving human participants comply with the ethical standards of institutional or national research committees, and the relevant research projects were reviewed and approved by the Ethics Committee of Jilin University Sino-Japanese Friendship Hospital (also known as The Third Bethune Hospital of JiLin University) before implementation, and all patients or their families signed informed consent forms. The detailed clinical information of patients is showed in Table 1.

3D printer purchased from China GuangDong ShenZhen Aurora Innovation Technology Co., LTD. A8S model.The printing consumables were solid polylactic acid (PLA) material.

2.2.Construction of personalized 3D printing navigation molds

2.2.1. Three-dimensional reconstruction of intracranial lesions

Thin-slice computed tomography (CT) was performed on the patient to obtain CT image data, extracted images in the form of DICOM files, burned files and imported them into 3D Slicer software.The patient's skull, skin, intracranial lesions and target structures were segmented according to the original proportions, differentiated by different colors, and then reconstructed in three dimensions.

2.2.2. Design of 3D printing navigation molds

The puncture target was determined using the line connecting the entry point of the puncture channel with the direction of the puncture, as well as the lesion center (and ipsilateral frontal angle). Important blood vessels and functional areas were avoided.The guide tube radius of the navigation molds was larger than the radius of inserting soft drainage tube. The navigation molds were designed according to the angle of the puncture path and the patient's personalized craniofacial features.

2.2.3. Acquisition of 3D printing navigation molds

Using the reconstructed skin as the inner surface, the personalized navigation molds with a thickness of 3mm were expanded, and the mask was closely fitted to the patient's face, ensuring the accuracy of puncture. After combining with 1/2 guide tube, the minimal navigation molds containing fixed maxillofacial positioning structure such as orbit and , nose root, etc., was intercepted. This aim was to save printing time,and the puncture depth was determined by the measured distance in the software.

2.2.4. Printing of 3D printing navigation molds

The designed navigation molds were exported as STL file, and then exported as GCODE file after setting printing parameters in the slicing software, and then 3D printing was carried out.The printing equipment meet the following conditions: 1) layer thickness≤0.3 mm; 2) Printing accuracy≤0.1 mm; 3) Printing error (deformation rate, 3D offset) ≤5%. Moreover, the appearance of the guide plate should be perfectly matched and attached to the surgical site. After installation, there should be no warping or loosening, and the surface should be smooth without any residual support materials or powder debris.

The size of the navigation molds affected the printing time. While ensuring the accuracy of puncture positioning, it could be adjusted to only retain some fixed feature positioning marks, while closely fitting the face, minimizing the printing area and shortening the preoperative preparation time.

2.2.5. Disinfection of 3D printing navigation molds

In order to effectively prevented pollution and infection, the designed navigation molds must be disinfected before use. The PLA material selected for the navigation molds had the characteristics of being resistant to high temperature and humidity. And they were disinfected or sterilized using low-temperature plasma and ethylene oxide disinfection method to ensure the sterile operation of the surgery.

2.3. 3D printing navigation molds assisted puncture and drainage surgery

Patients with intracranial lesions were placed in a supine position. After general anesthesia took effect, the operative area was routinely disinfected. After the navigation molds were disinfected at low-temperature, it was then covered with sterile film and attached to the patient's craniofacial positioning structure. The operation was carried out according to the direction and planned depth of the guidance tube of the navigation mold. Thin-slice CT scan of the head was performed after surgery to evaluate the efficacy of the operation.

2.4. Lesion clearance rate and Puncture error

Preoperative and postoperative thin-slice CT data of the head were imported into 3D Slicer, and Volume Rendering was used for 3D reconstruction to obtain the volume size of intracranial lesions or target structures [12] and 3D images of surgically implanted soft drainage tubes.After registering the preoperative and postoperative thin-slice CT data of the head, the clearance rate was calculated according to the changes in the volume of the lesion before and after surgery. At the same time, the center point of the head end of the soft drainage tube was taken as the standard. After calibration by Line tool in 3D Slicer software, the deviation distance between the actual position of the head end of the soft drainage tube and the simulated head end position in 3D design was obtained. And the distance between the actual puncture point and the preset puncture target (preoperative planning) was the puncture error, and the average value was taken. The smaller the puncture error, the higher the positioning accuracy and the lower the risk of complications.

3. Results

3.1. Surgical outcomes

All 9 surgeries were successfully completed, and postoperative CT showed that the head of the drainage tube was within the lesion. According to the deviation distance of the soft drainage tube placement in 9 patients (in Table 2), the average positioning accuracy of the target point for intracranial ventricular puncture drainage was 2.86 mm. Compared with the requirement of traditional medical surgical assisted puncture positioning accuracy within 3mm, it was lower than the predetermined target and had high-precision positioning ability, which could meet the actual puncture accuracy needs [13]. At the same time, the average clearance rate of intracranial lesions in the patients was more than 70%, no postoperative infection occurred, and the operation effect was good.The reason for the large puncture deviation distance in patients with brain abscess was the large displacement of the head end when the soft drainage tube passed through the abscess enveloped. The reason for the low brain abscess clearance rate was considered to be the poor compliance of the abscess envelope and the small volume change after abscess extraction. The deviation of the ventricular end of the shunt tube was more likely to be caused by the drift of the ventricular end of the shunt tube in the cerebrospinal fluid, but it conformed to the predetermined target.

3.2. Representative cases

3.2. 1. A case of intracerebral hemorrhage

The patient was intracerebral hemorrhage (Fig.1). Vascular lesions were excluded by preoperative CTA, and the transtemporal surgical path was designed according to the morphology and location of intracerebral hematoma. Before surgery, we reconstructed the patient's skull (gray part), hematoma (red part) and planned 3D printed navigation molds (green part). And the surgical path was designed (yellow part, Fig1.C-D).The printing navigation molds was placed at the head positioning surgical position of the patient (Fig 1.E). After the soft drainage tube was inserted according to the navigation molds during the operation, 11ml of unorganized hematoma was smoothly extracted (Fig 1.F), and the postoperative head CT of the patient showed a good placement of the soft drainage tube (Fig 1.B).

3.2.2. A case of hydrocephalus

The patient was hydrocephalus (Fig.2). Preoperative head CT (Fig 2.A) showed obvious dilatation of bilateral lateral ventricles in the patient. Before the surgery, the skull (gray part), ventricular system (blue part), and planned navigation mold (yellow part) containing nasal roots, eyebrow arches, and parietal nodules were reconstructed based on DICOM data from the patient's thin-slice head CT (Fig 2.C-D). The surgical path was shown in red (Fig 2.D). The designed navigation molds was 3D printed (Fig 2.E-F) for intraoperative assistance, and the postoperative head CT of the patient showed a good placement of the soft drainage tube (Fig 2.B).

3.2.3. A case of brain abscess

The patient was brain abscess (Fig.3). Preoperative head CT showed a circular low-density shadow of the left basal ganglia (Fig 3.A).The surgical plan reconstructed the brain abscess (yellow part,Fig 3.C), the surgical path was designed (red part, Fig 3.C) and planned 3D printing navigation molds (green part,Fig 3.D). The 3D printing navigational molds applied during the operation (Fig 3.E-F). Postoperative head CT showed a good position of the soft drainage tube (Fig 3.B).

4. Discussion

With the advancement of technology, cutting-edge tools such as specialized anatomical models and clinical applications are increasingly being used in the clinical work of neurosurgery [14]. Normal pressure hydrocephalus (NPH) is one of the important diseases that affect the physical and mental health of the elderly, mainly manifested as a clinical triad of gait disorders, cognitive impairment, and bladder dysfunction[15]. NPH can be successfully treated by cerebrospinal fluid shunt surgery, and the timing of surgery has a great impact on the patient's condition and prognosis. The main surgical methods include ventriculoperitoneal shunt and lumbocisternitoneal shunt,etc., due to its advanced technology, easy learning, and precise results, ventriculoperitoneal shunt has become the most important surgical technique among them [16]. Shunt tube obstruction is a common complication of ventriculoperitoneal shunt surgery. A recent study showed that the most common cause of shunt tube complications was obstruction within 1 month after implantation and choroidal plexus invasion within 3-6 months, which might be related to improper placement of ventricular shunt tubes [17]. Obstruction of the shunt tube system can be caused by factors such as choroidal plexus wrapping [18], through 3D printing navigation technology, a facial positioning mold with guide holes can be designed based on the patient's facial features. By accurately positioning the puncture angle and position, repeated puncture and passing through the choroid plexus can be prevented, and reduce the risk of brain tissue damage, and the risk of fragmentation of brain tissue and blockage of the official cavity caused by clots [19]. More importantly, compared to traditional methods, this 3D printing navigation molds have higher puncture positioning accuracy. Surgical treatment of hypertensive intracerebral hemorrhage is mainly craniotomy or minimally invasive surgery to remove the hematoma [20]. Traditional craniotomy can effectively stop bleeding by rapidly compressing the hematoma on the brain tissue, however it is an invasive procedure that does not preserve the healthy brain tissue surrounding the hematoma and can lead to more serious damage. Minimally invasive surgery utilizes stereotactic positioning of soft drainage tubes and endoscopes, which have the advantages of minimal trauma, precise results, and fast recovery time [21]. Due to the different bleeding sites of patients, especially deep intracerebral hematoma, it is necessary to find out how to choose the best placement location and puncture angle to improve the clearance rate of hematoma lesions and reduce the rate of hematoma rebleeding. Puncture and drainage of brain abscess can reserve the abscess specimen for culture, which can guide antibacterial treatment and has the advantages of micro-invasive [11]. Therefore, there should be certain standards for the accuracy of stereotactic puncture of abscesses, especially for brain abscesses located in deep functional areas such as the basal ganglia and thalamus, which are mostly small in size and polycystic. In addition to antibacterial treatment and symptom measures, stereotactic puncture drainage can identify pathogens and reduce the size of abscesses, and the trauma is small, which can easily avoid intraoperative traction damage to the corticospinal tract, resulting in poor prognosis for patients, and even inability to take care of themselves. Postoperative bleeding in brain abscess can be attributed to inflammation and lack of tissue support for neovascularization in the brain abscess wall, leading to hypoxic injury, especially in cases where blind methods such as manual puncture and aspiration are used [22-23].By using 3D modeling software and raw medical digital imaging data, precise analysis of each patient's lesion can be achieved through 3D navigation molds, and personalized surgical plans can be formulated to promote rapid reduction of abscesses and reduce recurrence, especially for recurrent brain abscesses. For previous puncture lesions, due to the excellent stereotactic accuracy of the method, the initial trajectory can be reused without the need for new skull perforation, effectively preventing the risk of infection in key areas such as venous sinus, functional area, and frontal sinus.

The application of 3D printing navigation technology in medicine is increasingly integrated, and this technology has great potential due to its flexibility, diversity and creativity. Based on the research of David H et al. [24],3D printed anatomical models and surgical guidelines have been shown to reduce surgical time and operating room costs by shortening surgical time afterward, based on their financial analysis showing the value and financial cost-saving feasibility of 3D printing in terms of preoperative planning and saving intraoperative time. In this research work, full consideration was given to the issue of the medical environment in grassroots hospitals, which lack experienced doctors and accumulated surgical experience, as well as expensive medical equipment, only conventional intracranial imaging examination equipment.Considering that routine preoperative preparation requires assessment of the patient's condition, anesthesia, and determination of intracranial lesion localization, there are deficiencies in clinical practice such as insufficient preoperative preparation, long lesion localization time, poor cooperation between medical and nursing teams, and unsmooth surgical connection [9].Especially in the aspect of preoperative evaluation of lesion localization, due to the special presentation form of two-dimensional view of CT image data, the lack of Angle and spatial data puts forward higher requirements for doctors' three-dimensional anatomical understanding ability, and they must be proficient in puncture technology.

For grassroots medical institutions, there are certain challenges when using this technology, such as possibly reducing positioning accuracy and prolonging preoperative preparation time.With the use of 3D printing navigation technology, clinicians can formulate and implement preoperative preparation procedures. After intracranial hemorrhage patients are admitted to hospital, clinical signs, imaging, laboratory and other examinations are carried out, and preoperative surgical evaluation is carried out in combination with 3D Slicer software, which can realize rapid hematoma segmentation and accurate positioning. The time of calculating target positioning by traditional methods was saved, the preoperative preparation process was optimized, and the operation time was greatly shortened.At the same time, for the preparation of 3D printing navigation molds, we choose polylactic acid material according to actual needs, which has good biodegradability.The polylactic acid powder can form customized and precise geometric shapes required for thermoforming and compression molds.Based on its performance characteristics, the printing process of polylactic acid powder is safe and non-toxic. If applied to casting, there is no smoke or toxic gas generated during the process, making it more low-carbon and environmentally friendly. In addition, the melting temperature of polylactic acid powder is lower, which helps to reduce energy consumption, and the cost of printing with polylactic acid is lower. The cost of printing with a puncture guide plate is controlled within 50yuan[25]. As a high molecular weight material with good biocompatibility and biodegradability, polylactic acid powder material can highlight its advantages in medical applications.In recent years, the use of 3D printing navigation technology for minimally invasive soft drainage tube placement in the treatment of cerebral hemorrhage has achieved success [26]. As part of the study, 9 patients with different conditions received treated. In order to ensure that the soft drainage tube accurately reaches the target point, the 3D printing navigation molds are used to guide the placement of the soft drainage tube. Although it is easy to achieve accurate positioning in large tertiary hospitals with high-end equipment such as neural navigation and neurosurgical robots, taking into account the actual medical situation in China, the promotion of 3D printing navigation molds are of great significance for grassroots hospitals in underdeveloped areas. However, the technology also faces challenges. Due to the increased demand for this technology, clinical practitioners must not only be skilled users of modeling-related software, but also be able to perform modeling and printing work quickly, even if it can be completed quickly, it is inconvenient to the clinic due to the need to jump multiple systems during use. We believe that the software processing platform based on medical image, involving CT/MRA image import, automatic segmentation, 3D reconstruction results display, automatic access to puncture and drainage surgical path, 3D navigation molds automatic printing and other functions, will soon appear.Through the integrated operable interface, it can improve the efficient application of grassroots clinical and shorten the operation time.

In this paper, we expand the application of 3D printing navigation technology in the treatment of hydrocephalus and brain abscess, and explore the accuracy of the application of navigation molds in neurosurgery. However, the application of 3D printing technology in neurosurgery is not only in these neurosurgery operations, but also in the application of 3D printing navigation technology in the literature, such as balloon compression of trigeminal neuralgia and the treatment of various tumors and other diseases [27-28]. In addition, the combination of neuroendoscopes with other devices can further broaden the scope of application of 3D printing navigation technology in neurosurgery.

This study is a single center retrospective study. Although it covers surgical procedures for several neurological diseases, the results may be biased due to the small sample size. It is recommended to apply the technology for multi center validation after its promotion. 3D printing navigation technology enables surgeons to achieve highly personalized treatment while reducing technical requirements. However, it requires doctors to learn additional 3D modeling and data application related technologies, which increases additional learning costs.

5. Conclusions

In this paper, 3D printing navigation molds designed based on individual patient differences was used as an auxiliary surgical instrument for minimally invasive puncture drainage, and 5 cases of intracerebral hematoma, 2 cases of hydrocephalus and 2 cases of brain abscess were taken as research objects to discuss the feasibility and clinical application of personalized 3D printing navigation molds in improving puncture targeting accuracy. The results showed that 9 patients with 3D printing navigation molds assisted minimally invasive puncture drainage recovered well after surgery, and no infections or deaths occurred, verifying the effectiveness of the new technology. To a certain extent, 3D printing navigation molds reduce the dependence of traditional surgery on the experience of puncture positioning. The preoperative three-dimensional and visual simulation provided by 3D printing navigation molds can help neurosurgeons to plan the puncture path more reasonably, which has broad application potential in the field of neurosurgery, especially for promotion and implementation in grassroots hospitals.

Funding Statement

This work was supported by JiLin Science and Technology plan project (20210401143YY，20220401089YY).

Data availability statement

The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

Ethics statement

The study was approved by the Ethics Committee of Jilin University Sino-Japanese Friendship Hospital (also known as The Third Bethune Hospital of JiLin University). The participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

Author contributions

Xin Feng: study concept and design, critical revision of manuscript for intellectual content. Ke Meng

: acquisition of data and clinical diagnosis and analysis. LiJie Hou: collect and analysis data, and write manuscripts. Jian Zhang and Yunpeng Xue: acquisition and interpretation of data.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Figure 1. Patient with intracerebral hemorrhage. A: preoperative CT of the patient; B: postoperative follow-up CT of the patient; C-D: 3D printing navigation molds designed and hematoma-craniofacial reconstruction diagram; E: 3D printing navigation molds and surgical location diagram for patients with cerebral hematoma; F: About 11ml hematoma was extracted after intraoperative soft drainage tube insertion.

Figure 2. Patient with hydrocephalus. A: preoperative CT; B:postoperative follow-up CT of the patient; C-D: ventricle-occipital Angle puncture designed and navigation molds designed; E-F:3D printing navigation molds for hydrocephalus patients.

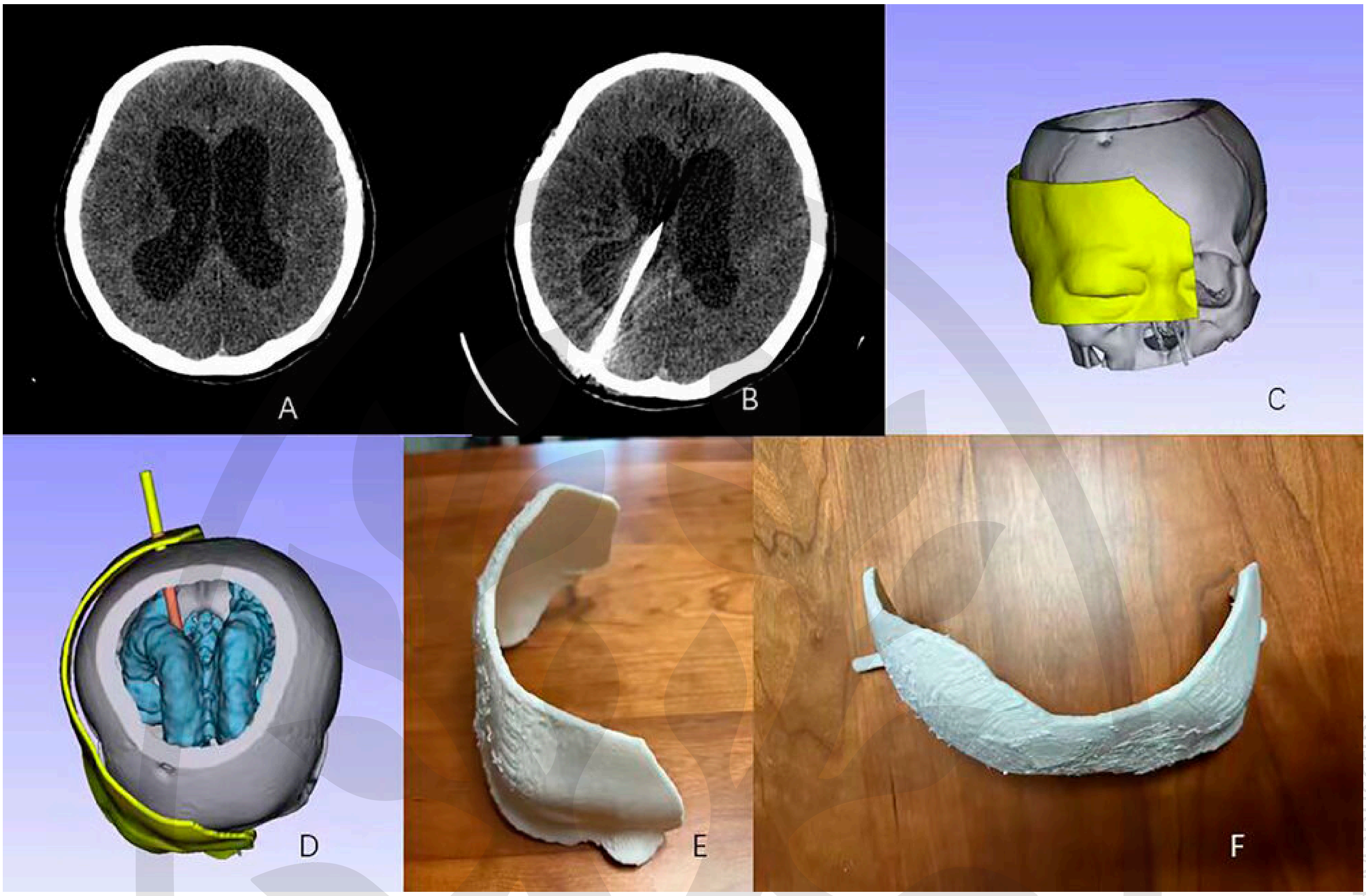
Figure 3. Patient with brain abscess. A: preoperative CT; B: postoperative CT; C: abscess puncture path designed, the Volume Rendering module in 3D Slicer was used for rendering, which aims to see the puncture path and reconstructed hematoma from the top; D: navigation molds designed; E: 3D printing navigation molds for patients with brain abscess; F: On the inside view of the 3D printing navigation molds for patients with brain abscess, while ensuring the strength of the 3D printing navigation mold, a 0.3mm precision printing was adopted to save time. The supporting materials were all set on the outer surface of the molds, and the inside was smooth, which would not cause damage to the patient's skin surface.

Table 1. Clinical data.

Case No.	Gender	Age	Diagnosis	Coma	PreoperativeLesion volume(ml)
1	M	33	Intracerebral hematoma	N	26.5
2	M	61	Intracerebral hematoma	N	39.8
3	M	53	Intracerebral hematoma	N	32.89
4	M	59	Intracerebral hematoma	Y	36.54
5	F	80	Intracerebral hematoma	N	27.37
6	F	59	Hydrocephalus	N	-
7	F	16	Hydrocephalus	N	-
8	M	61	Brain abscess	N	13.85
9	F	34	Brain abscess	N	38.76

Table 2. Lesion clearance rate and Puncture deviation data.

Case No.	Preoperative lesion volume（ml）	Postoperative lesion volume(ml）	Lesion clearance rate	Deviation distance（mm）
1	26.5	6.62	75%	1.43
2	39.8	11.16	72%	3.17
3	32.89	9.13	72%	4.65
4	36.54	8.77	76%	1.70
5	27.37	7.65	72%	2.46
6	-	-	-	3.36
7	-	-	-	1.55
8	13.85	7.65	45%	3.58
9	38.76	7.23	81%	3.85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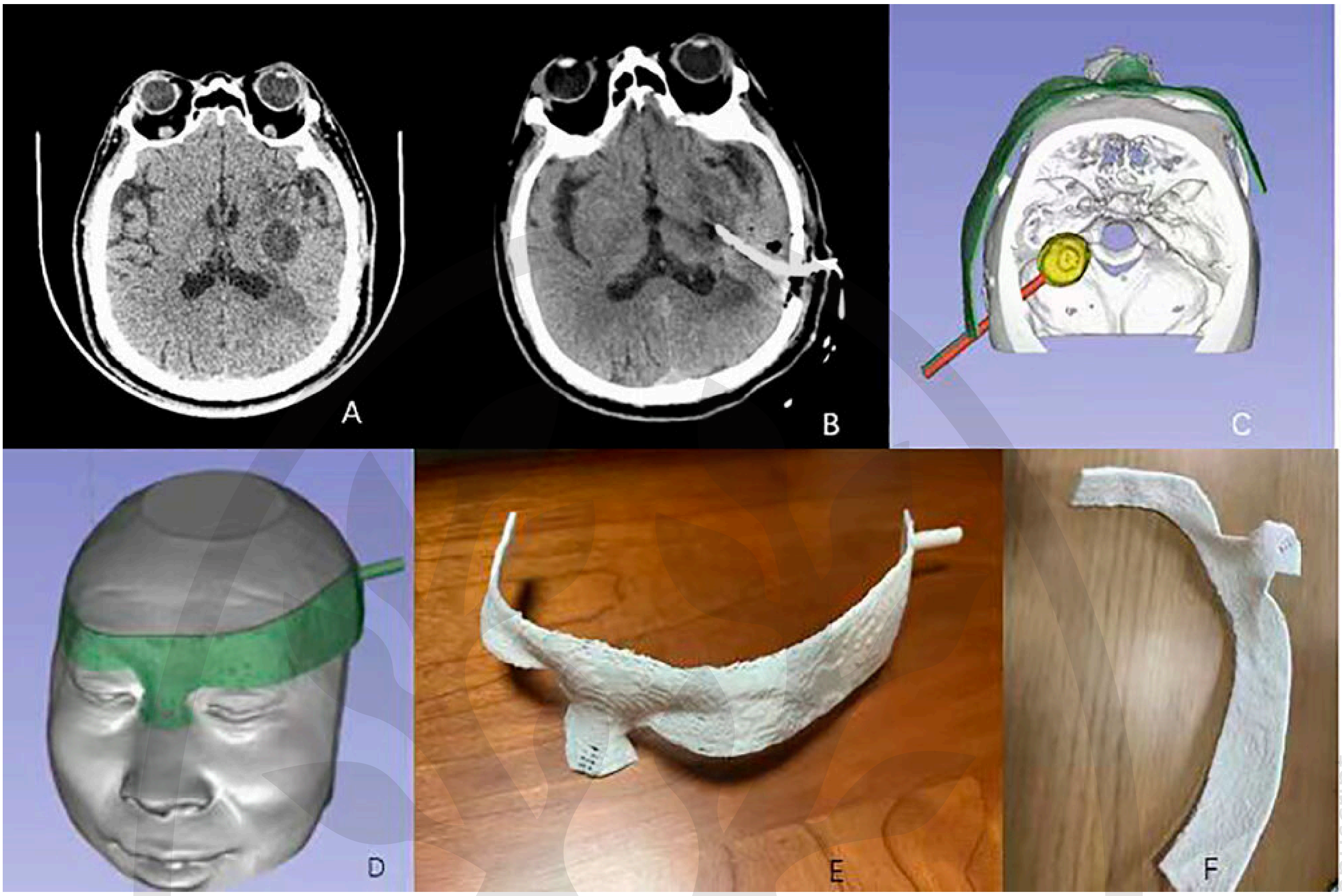
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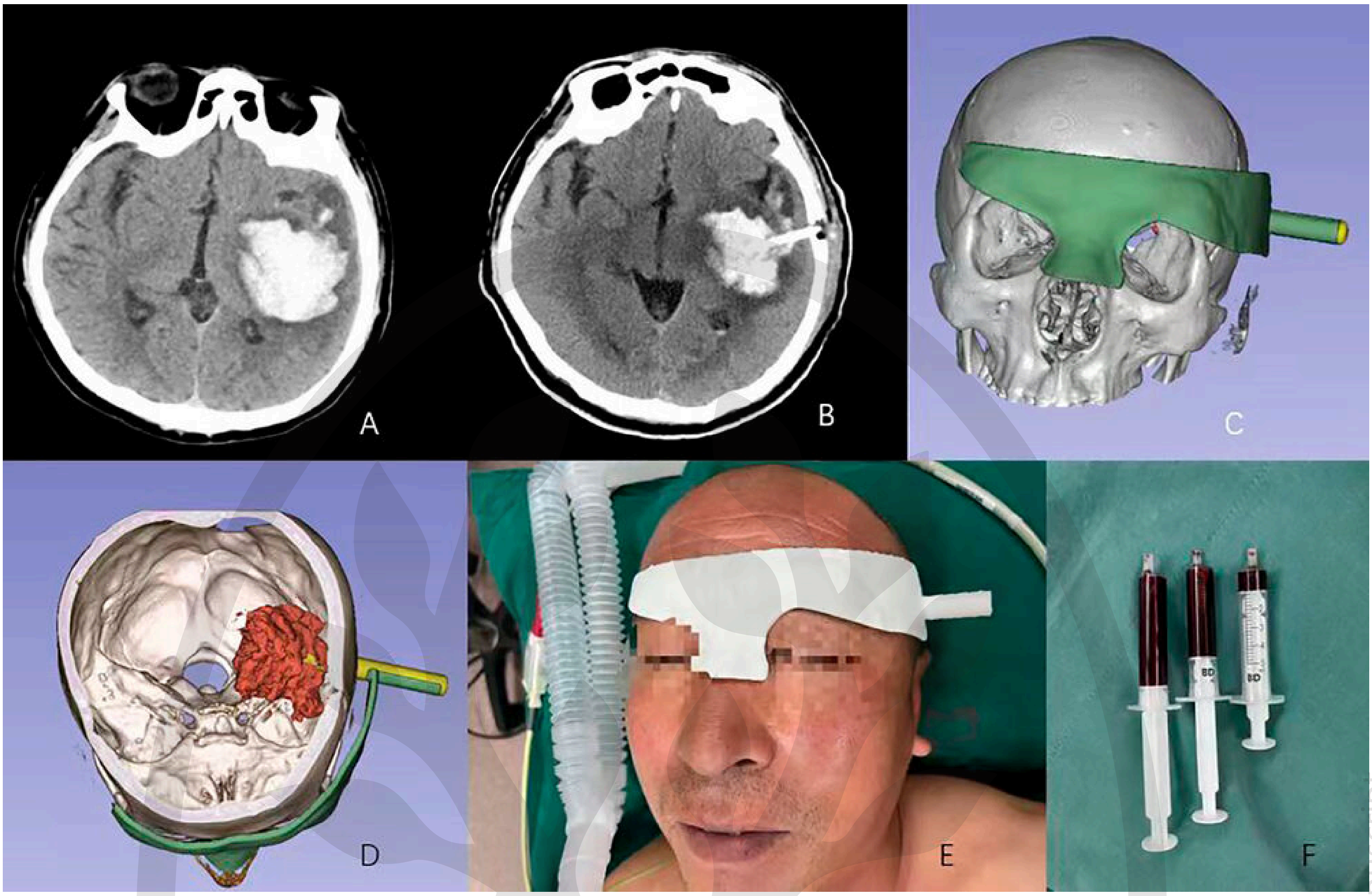
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