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Application of computer-aided image reconstruction and image guide in parasagittal meningioma resection

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Abstract

Background: In recent years, smaller-sized (diameter < 2.5 cm) meningiomas are diagnosed due to increased cranial imaging. Symptomatic meningiomas need to be removed surgically. Therefore, it is extremely important to locate the lesion exactly to tailor the craniotomy especially if the neuro-navigation system is not available. Many hospitals located in the underdeveloped countries cannot afford the high costs of neuro-navigation equipment. Hence, it is relevant to discover low-cost associated and effective methods for lesion localization for surgery.

Methods: The use of localization markers in advance can help to acquire preoperative CT images of the patients to create and calculate a three-dimensional (3D) virtual graph using a computer. With the 3D graph, spatial distance of the tumor from the markers is calculated and the tumor location projected on the scalp by the Triangle Pythagorean theorem. This enables precise localization of intracranial microlesions preoperatively.

Results: The location of the tumor was consistent with that of the pre-operative virtual image, and the craniotomy was exact. The patient was discharged 3 days later without any neurological deficits.

Conclusions: This method is simple and reliable, inexpensive, and accurate in the location of small-sized lesions, which can partially compensate for the lack of neuro-navigation and is suitable for widespread application in hospitals in developing countries.

Keywords: Graphical reconstruction, Neuronavigation, Meningioma, Image guide

Introduction

Meningiomas are common intracranial tumors with a lower incidence rate compared to gliomas, ranking second in intracranial tumors. The most common growth area of meningiomas is parafalx or parasagittal sinus, accounting for 19.5–45% of intracranial meningiomas [1]. With the popularization of computed tomography (CT) and magnetic resonance (MR), more small meningiomas (less than 2.5 cm in diameter) are diagnosed, and some patients require invasive surgical treatment. The localization and surgical resection of parasagittal meningioma are still challenging. Especially when tumor size is small, it is difficult to locate the tumor accurately to limit the area of craniotomy to a needed minimum. Neuronavigation displays a helpful tool of precisely defining the surgical area, but many hospitals, especially in developing countries, are not equipped with it. This work introduces a method of CT image reconstruction using open source software for preoperative tumor localization in order to define growth area of a meningioma and plan the craniotomy accurately.

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Methods

This article provides a protocol for exact localization of small parasagittal meningioma in a representative case without neuronavigation.

Case description

We found a small parasagittal meningioma in a routine health check in a 58-year-old female patient. In the following 1 year, she suffered a severe "mental–physical" illness including insomnia, body weight and hair loss, after consulting a psychologist, the patient herself demanded surgical treatment. Medical examination showed no neurological deficits and her general health condition was good. Preoperative MRI showed a parasagittal meningioma (Fig. 1) with a diameter of 2 cm.

Preoperative preparation, tumor location, and operation process

One day before the operation, mark the median sagittal line after skin preparation of the head. According to the previous MR scan, place two electrodes as markers on approximate positions in the front and back of the tumor. A thin-layer CT scan of the head was performed to obtain the Digital Imaging and Communications in Medicine (DICOM) files (Fig. 2A). After this, import the data into the computer and run the 3D-slicer software, and reconstruct the 3D model of the tumor and electrode slices by using the Editor Tool. The spatial relationship of the three points (Marker A, Marker B, and Tumor C) can be observed on the screen (Fig. 3.1). Then run the Volume Reading Tool to get the whole head model and select CT-Fat sequence to make the model transparent. The relationship between tumor, markers, and structures around can be observed (Fig. 2B). Close the volume reading tool, and use the ruler tool to measure the distance among the three models (Fig. 3.2), rotate different angles to ensure that the three lines are on the same plate (Fig. 3.3), and obtain a triangle ABC. Use the model tool again, close the three-dimensional models of tumor and marker, leaving only line segments (Fig. 3.4). Once again, confirm that these three lines are in the same plate and each two line segments intersect at one point. Suppose that the projection point of the tumor on the 2 marker line (AB) segment is D. According to the triangle Pythagorean theorem, the lengths of AD and BD can be calculated (Fig. 4). Therefore, the precise projection point of the tumor on the body surface can be calculated. It should be pointed out that due to the radian of the scalp, there is a certain error in measuring directly with a tape measure. It is more accurate to use a pencil compass to measure the distance between two points. However, due to the close distance between point A and point B, the length of arc AB and line AB are approximately the same. In this case, the margin of error is 0.5 mm between direct measurement with a tape measure and measurement with a pencil compass. For a tumor with a diameter of 2 cm, this error can be ignored. Therefore, it is feasible to measure directly with a soft ruler.

In the operating room, mark the position of the tumor for operation according to the results of the calculation (Fig. 5). Perform the scalp incision centered on the tumor. Make two burr holes on the sagittal sinus,

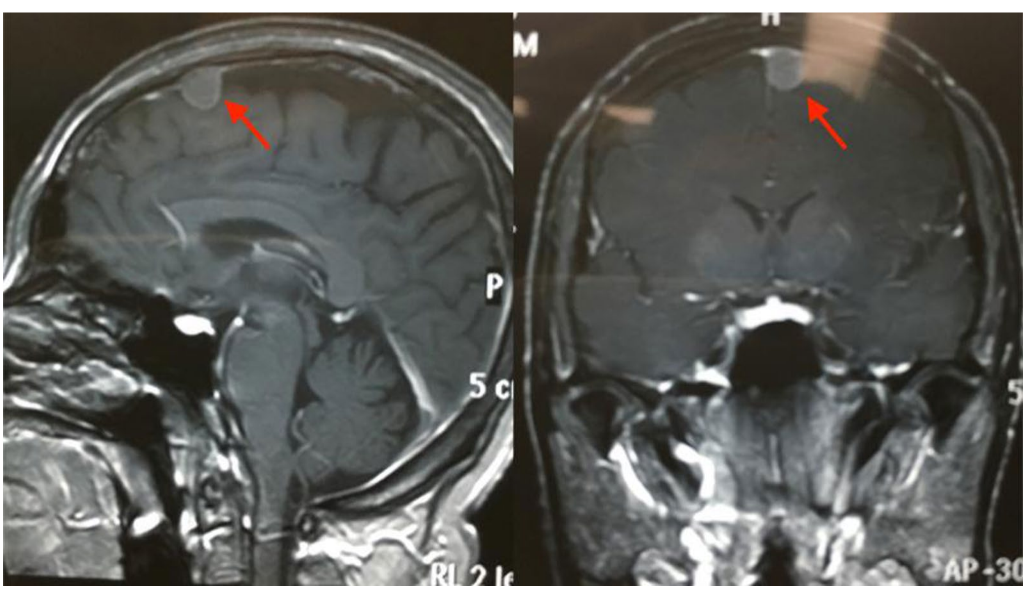

Fig. 1 After admission, MRI showed that the tumor has invaded the sagittal sinus (as the red arrows point to)

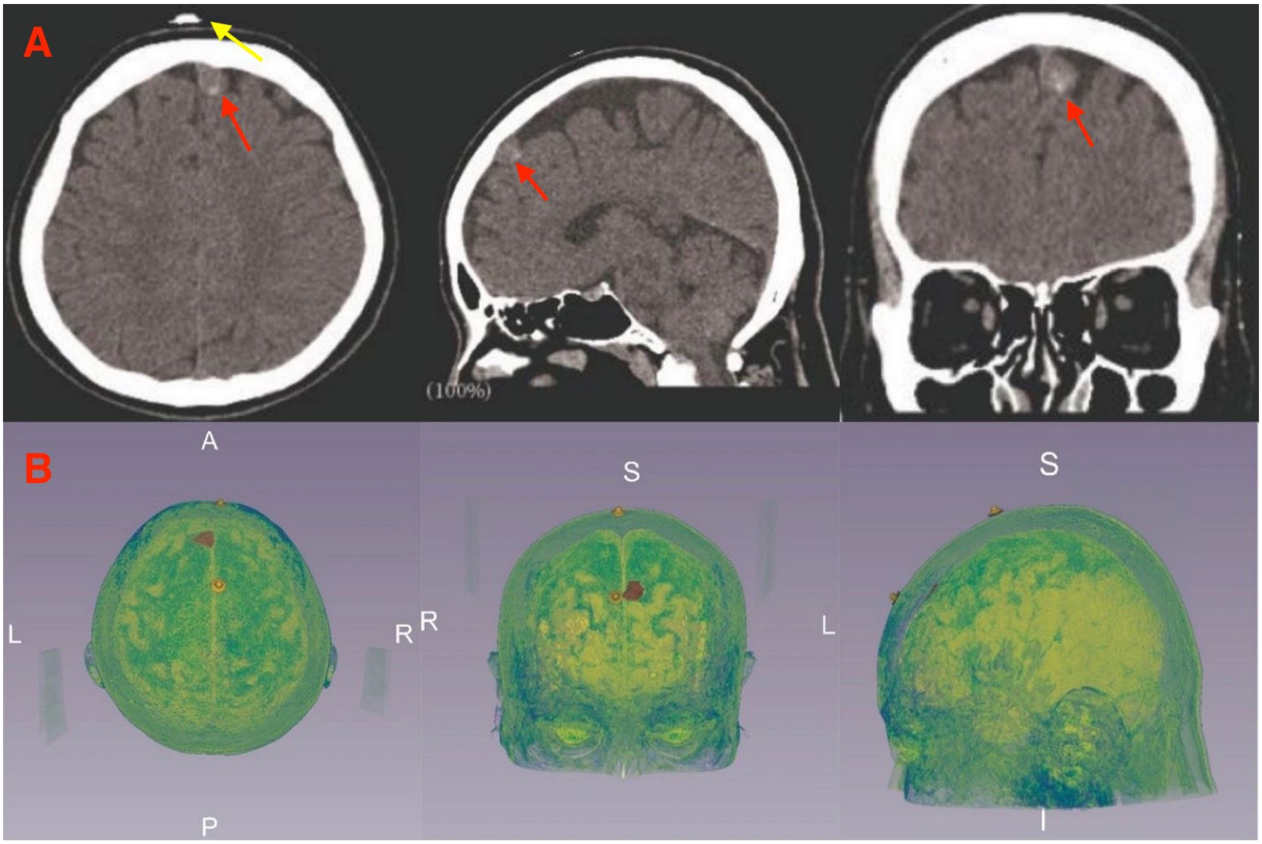

Fig. 2 **A** The data obtained from the thin-layer CT scan before the operation can see the tumor and the electrode piece. **B** The CT-Fat sequence reconstructed with the volume reading tool can display the tumor, marker, and its surrounding anatomical structure completely. The yellow arrow shows the position of marker and the red arrows show the tumor's position. *A* anterior, *P* posterior, *S* superior, *I* inferior, *L* left, *R* right

carefully peel off the dura mater, maintain the integrity of the sinus, and avoid rupture and bleeding. Remove the bone flap and identify that the real tumor location is consistent with the preoperative calculation.

In this case, the tumor thinned out the dura mater. After cutting the dura along the lateral side of the tumor, there is still an arachnoid membrane between the tumor and the cerebral cortex. The tumor was separated from the cerebral cortex to the edge of the sagittal sinus. Due to infiltration of the sagittal sinus, and the preoperative MRV scan showed the patency of superior sagittal sinus remained, in order to keep the sinus integrity, a Simpson grade II resection was achieved [10]. After grossly total resection of tumor under the microscope, the cortical vessels were well preserved. Under the premise of the accurate location of the tumor, the dura mater can meet the needs of surgery only by limited incision. In this case, we found that this method provided an accurate localization of the small intracranial lesions, a limited craniotomy could meet the need for lesion resection (Fig. 6).

Results

The described technique enables a proper and exact localization of a tumor. It was helpful for the resection of the whole tumor with only a small and minimal craniotomy. The patient recovered well after the operation, and no complications such as bleeding and infection occurred. The patient was discharged from the hospital 3 days after the surgery.

Discussion

The term "parasagittal meningioma (PSM)" is applicable to tumors involving the sagittal sinus and adjacent dura and falx cerebri [8]. It accounts for 19.5–45% of intracranial meningiomas. The lateral wall of the sagittal sinus may be partially or completely invaded by a tumor in the sinus cavity. In some cases, the tumor may partially or completely block the sagittal sinus [8]. Parasagittal meningioma is a challenge for neurosurgeons all over the world [1]. Especially if it invades the superior sagittal sinus cavity and the bridging veins are wrapped or adhered, it is likely to suffer severe

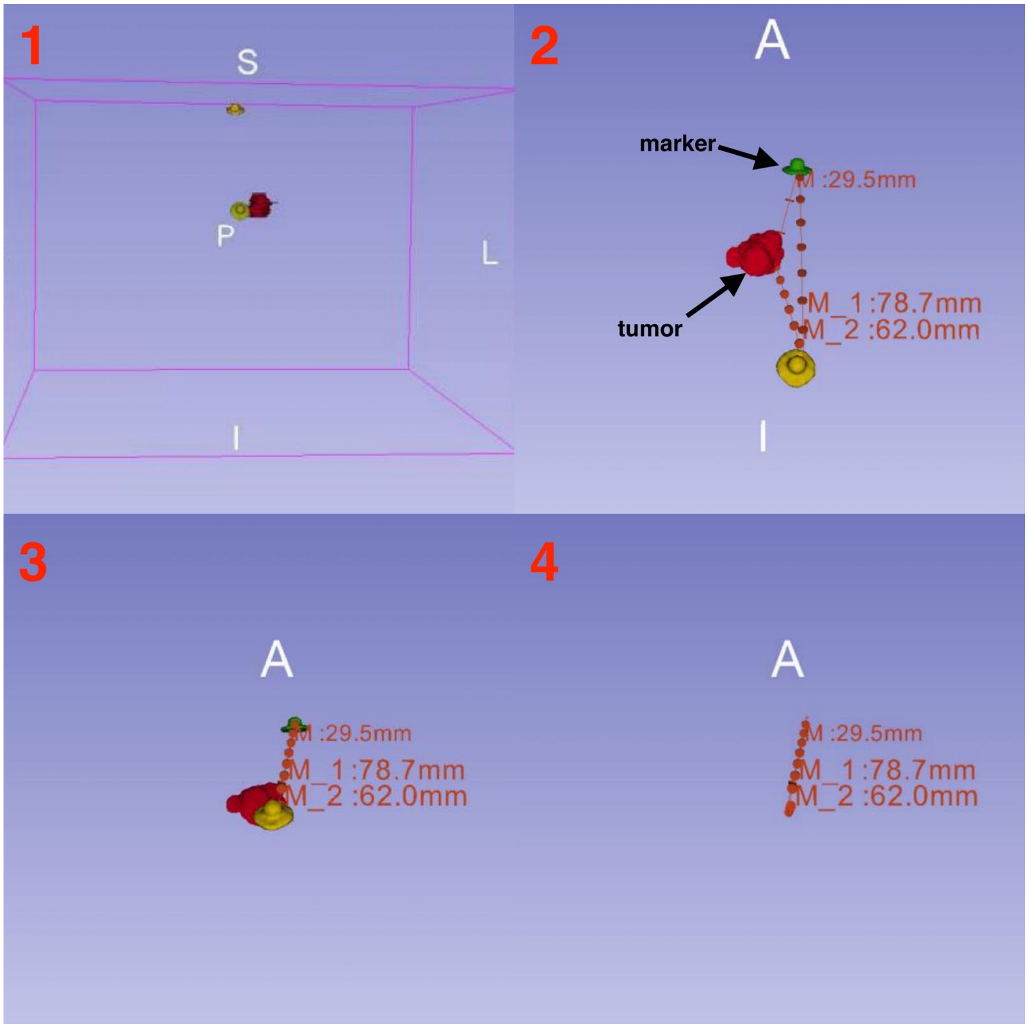

Fig. 3 (**1**) Through the reconstruction function of the software, the spatial relationship between tumor and markers can be observed. (**2**) The measurement tool measures the distance between the three models. (**3**) By rotating the model angle, make sure that the three-line segments are in the same plane. (**4**) After closing the model, it is more convenient to confirm whether the three-line segments are in the same plane, and each two line segments intersect at one point. *A* anterior, *P* posterior, *S* superior, *I* inferior, *L* left, *R* right

neurological sequela if any vascular injury occurs during the procedure [9]. In these cases, tumors may invade the sagittal sinus in varying degrees. According to the literature, the main treatment options for these tumors are surgical resection and radio surgery [1]. The best surgical procedure for parasagittal meningioma is a complete resection with minimal complications [9]. The premise of safe operation is to locate the tumor accurately. The localization of an intracranial tumor is a skill that every neurosurgeon must master. In the past, it was mainly determined by experience accumulation or according to some signs on the image and based on craniometric points. Subjective factors account for a large proportion, and there is unavoidable deviation. In order to compensate for the adverse effects of errors, a large range of bone window exposure is often selected to include the lesions as much as possible. This is not compatible with the concept of precision medicine advocated now. The application of neuronavigation can solve this problem well. But in underdeveloped countries and areas neuronavigation is not available or affordable because of its high costs [3].

3D slicer (www.slicer.org) is an open-source software developed by Harvard Medical School and Massachusetts Institute of Technology (MIT). It uses computer algorithms to process medical images. It is a powerful research software and has been widely used in medical research and education [2]. Because of its open-source

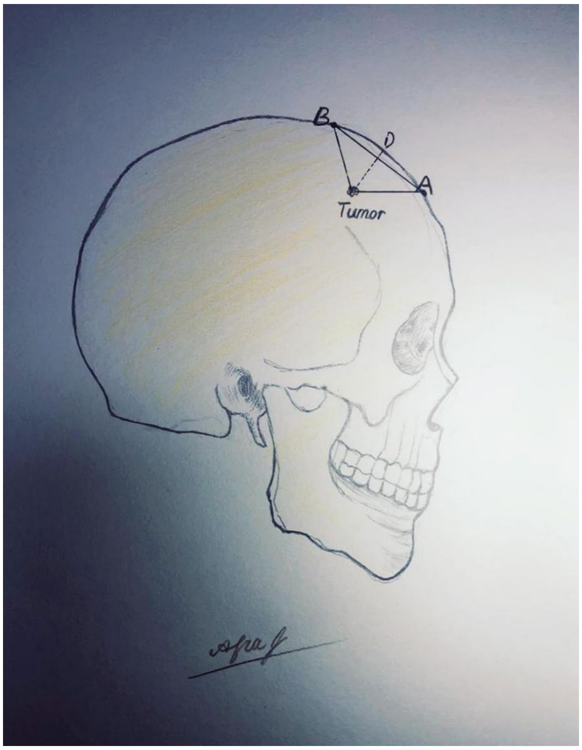

Fig. 4 According to the measurement results and the triangle Pythagorean Theorem, the projection point D of the tumor on the scalp can be calculated. And the arc AB is approximately equal to the line segment AB

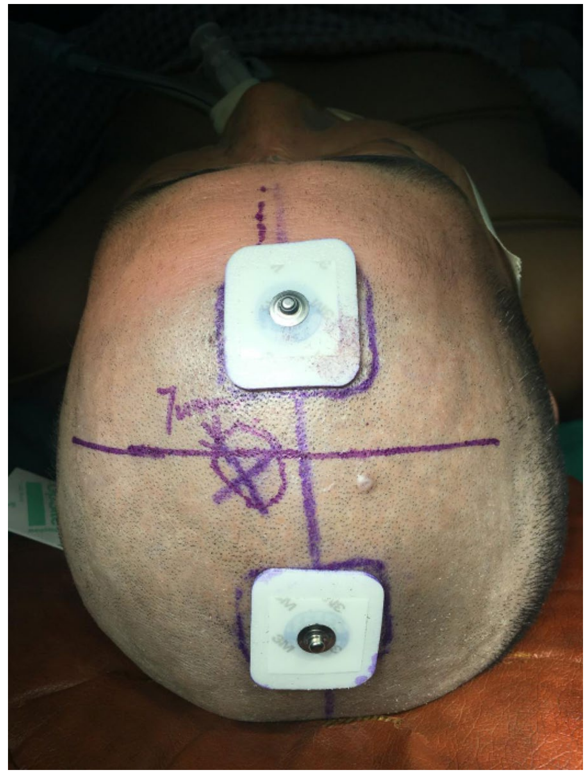

Fig. 5 After anesthesia, mark the projection position of the tumor on the scalp according to the calculation results

characteristics, scholars have developed new editing tools and algorithms to improve their functions [12]. At present, many scholars have applied its navigation function in clinical surgery [3–7, 11]. Yao et al. and Han et al. who used the software to evaluate the responsible vessels of trigeminal neuralgia or hemifacial spasm before the operation [6, 11]. Hou and Chen et al. used a smartphone combined with 3D-slicer software to realize the projection of the position of lesions [3, 5]. Hou et al. also provided a method of combining the use of 3D Slicer and a phone application named Sina to help surgeons locate giant invasive spinal schwannomas and better understand the three-dimensional (3D) relationship between the tumor and surrounding tissues [7]. But these methods described by the previous papers, are still complicated and hard to handle. Some need additional equipment like projector, or complex calculation process and file formation transform to adopt the application of smart phone [3, 5]. As a matter of fact, the 3D-slicer software is based on a simple algorithm: every pixel of the CT or MRI image has a unique spatial coordinate. Thus, according to the Descartes space coordinate equation, the distance between marker and tumor and tumor's projection location on the scalp can be easily calculated out. Meanwhile, the software also provided the Ruler Tool option that makes things much easier. We have compared the results based on Ruler Tool and Descartes space coordinate equation, the deviation is tiny. So, the protocol we introduced can be used to mark the scalp directly without any additional equipment such as projector or smart phone, which makes things easier and cheaper. After a short period of time of training or self-studying, anyone can use it via a common computer or laptop to localize a small lesion in 15 min, the results are repeatable, reliable, and stable, no matter how experienced this surgeon is or not. Therefore, this method is very practical for hospitals especially for those in developing countries and regions, and it is worth promoting.

Conclusions

We have adopted this simple and effective computer aided localization method. We have proved its functionality, accuracy, and practicability in clinical practice

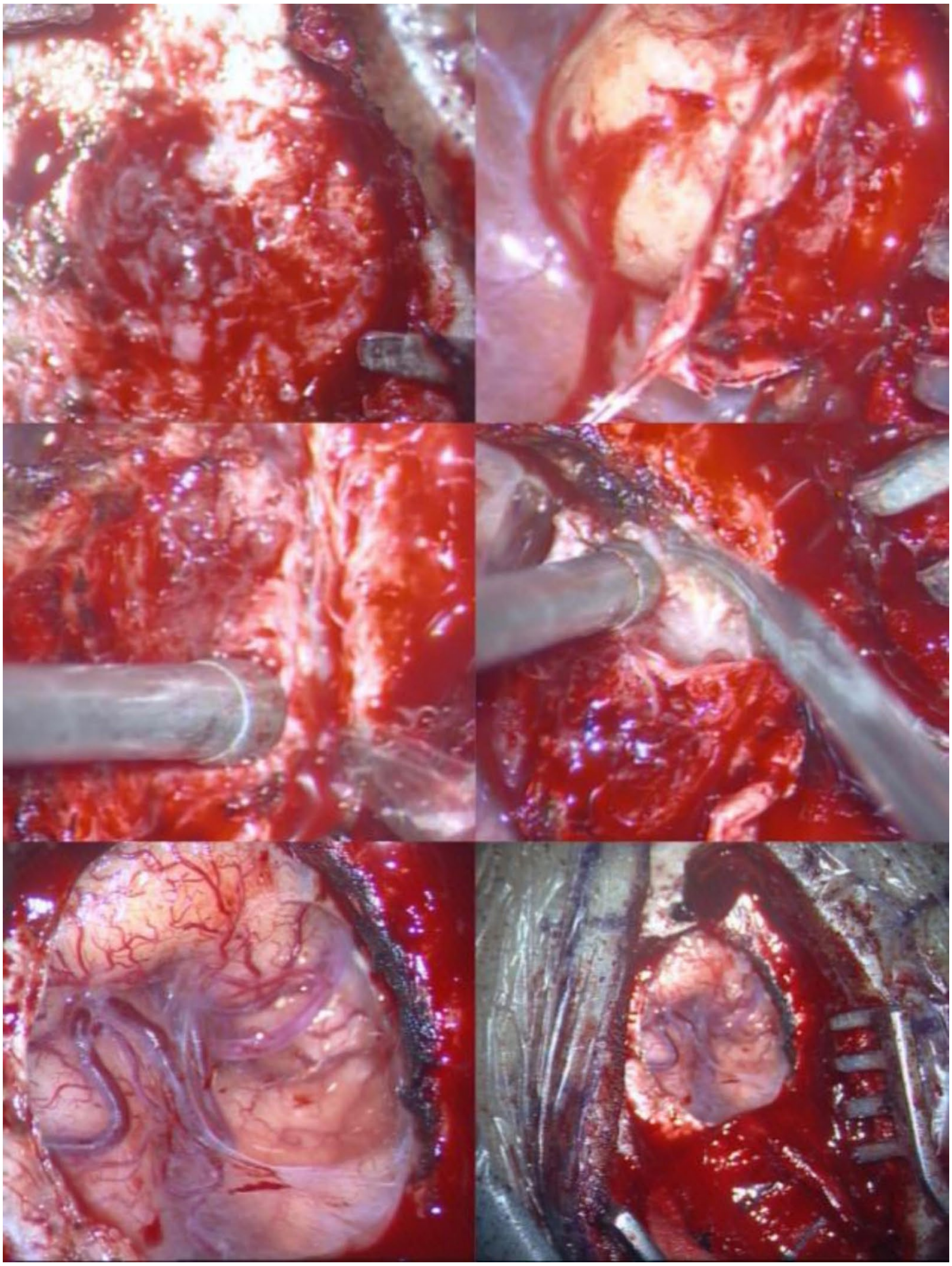

Fig. 6 Intraoperative images showing the exact location of meningioma by using the computer-aided method

displaying a cheap and suitable tool for every hospital. It can bring great convenience for the resection of small tumors in parasagittal sinus or parafalx cerebri, which is worthy of promotion.

Abbreviations

MR: Magnetic resonance; MRV: Magnetic resonance venography; CT: Computed tomography; 3D: Three-dimensional; DICOM: Digital imaging and communications in medicine.

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Author contributions
SM confirmed the scientific nature of the method, guided and modified the paper. RZ and SK applied and improved the method to make it simple and easy to use. RZ and SA wrote this manuscript. All authors read and approved the final manuscript.

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Availability of data and materials
Data used for this paper are collected from images and open source software computing. We are happy to share the methods we have established in this paper.

Declarations

Ethical approval and consent to participate
The Ethical Review Committee of Xingtai People's Hospital reviewed and approved the research process. The approval number is 2021/026.

Consent for publication
Written consent will be obtained from their legally authorized representatives. All authors agree for article publication. Patients' privacy is secured.

Competing interests
All authors declare that there is no financial and personal relationships with other people or organizations influenced our work. Further, there is no professional or other personal interest of any nature in any product, service and/or company that could be construed as influencing the position presented in, or the review of, the manuscript entitled, "Application of computer-aided image reconstruction and image guild in parasagittal Meningioma resection".

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