El-Tantawy *et al.*
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Intra-operative ultrasound (IOUS) value in cases of AVM and cavernoma excision: single-center experience

Ibrahim M. S. El-Tantawy[1*], Mohammed A. Kassem[2], Ashraf A. El-Badry[3] and Khaled M. AbdElwahab[4]

Abstract

Objective: The aim of the study is to use ultrasound to get maximal lesion resection without doing harm to the brain tissue in the absence of neuronavigation system in neurovascular cases as AVM and cavernoma.

Methods: The study is held in Mansoura University Hospitals, Department of Neurosurgery. Two different cases (AVM and cavernoma) were operated, and IOUS was used to assess its value during the surgery. Postoperatively the patients are followed up clinically and radiologically.

Results: In 2 different parenchymal lesions: AVM and cavernoma, IOUS was valuable in accurate localization of the lesions and the related vascularity specially in AVM case. It also helped to evaluate the extent of resection and confirm total excision. It also helped to determine the site of cortical incision and so to minimize brain tissue manipulation to prevent development of postoperative neurological deficit.

Conclusion: IOUS can be very helpful in cases of parenchymal neurovascular lesions such as AVM and cavernoma.

Keywords: Intra-operative, Ultrasound, IOUS, AVM, Cavernoma

Background

Introduction

Intra-operative ultrasonography (IOUS) is being progressively used in neurosurgery. It also can be compatible with neuronavigation system to get accurate intra-operative imaging of the surgical field. Many modes of ultrasound have been developed for different purposes such as grayscale B-mode, Color Doppler and spectral Doppler, and recently, elastography and contrast-enhanced ultrasound have been developed. It enables real-time imaging of the brain tissue intra-operative. Moreover, it is much cheaper than any other imaging modalities and easy to use. It can detect the vascularity of tissue of interest by using Doppler [1]. Other pros for IOUS use, there is no risk of radiation exposure to the patient and decreased time of surgery as it directly guides the surgeons intra-operative to facilitate decision making during surgery [2].

AVM

AVMs are abnormal connections between an artery and a vein without blood capillaries in between which may cause seizure or rupture leading to intracerebral hematoma leading to neurological deficit or endangers the patient's life according to its size or site, and it also causes abnormal flow pattern that can be detected by Doppler sonography and helps in its detection and complete resection [3].

Major concerns during excision of the AVM include accurate localization of the lesion, especially if it is deep and determination the best cortical approach and the adequate depth required for excision. One of the basic principles for AVM excision is to identify the feeding arteries to be clipped or coagulated first before coagulation of any draining veins; otherwise, unfavorable

*Correspondence: ibrahimeltantawy93@std.mans.edu.eg

[1] Mansoura University Hospitals, El Mansoura, Egypt
Full list of author information is available at the end of the article

congestion may result, and the procedure may be hazardous.

We believed that using ultrasound intra-operatively may help to overcome these challenges and make the excision much easier and safer with less time consumption and less manipulation of the cerebral cortex.

Cavernoma

Cavernomas are thin-walled dilated vascular channels with no brain tissue in between. They can be found cortical or subcortical or more challenging in eloquent areas or critical areas as brain stem. It may be silent or cause intractable fits [4]. Most of cavernomas are of small size in comparison with AVMs or gliomas which makes its excision challenging as it needs precise localization for the lesion to prevent excessive manipulation of the brain tissue.

Patients and methods

Prospective observational descriptive study was held in Mansoura University Hospitals, Department of Neurosurgery, on 2 different patients of different brain lesions: one patient with left occipital AVM and the other with right frontal cavernoma who are operated, and IOUS is used to facilitate and maximize the benefit of surgical intervention.

After each patient is diagnosed by different imaging tools, the decision of surgical intervention is discussed with the patient and his relatives and the possibility of ultrasound use intra-operative is explained to them and the consent is taken.

The ultrasound device used in this study is bk 5000 with 2 different transducers used: The first one is N11C5s (9063) Burr-Hole Transducer for small craniectomy flab or through burr hole and N13C5 (9062) Craniotomy Transducer for wider craniectomy flab with more detailed images. After elevation of the craniotomy flap and exposure of the dura, ultrasound is used to detect the lesion in each case and decide the appropriate approach for excision. Also, while the surgery is going on, intra-operative using of ultrasound is performed to detect degree of the resection and presence of any residual. Color Doppler was used to observe the blood supply of the lesion and the relationship between the lesion and the important adjacent blood vessels. Postoperatively, the patient is followed up clinically and radiologically.

Results and case presentation

AVM case

IOUS could exactly localize the lesion, the depth of the lesion, could identify the appropriate approach and could define the lesion. Also, it defines the residual of hemosiderin from the previous hematoma as hyperechogenicities surrounding the AVM. It also helped to identify the feeding artery to be clipped first before excision. It also confirmed the total excision o the lesion.

Case presentation

A 43-year-old male patient complained of syncopal attack, headache and blurring of vision 3 months ago of progressive course with history of seizures 4 years ago which are controlled on triple antiepileptic therapy. On examination: GCS 15 with normal motor and sensory function. The MRI images show evidence of serpentine flow void nidus seen in the left occipital lobe measuring ~$27 \times 42 \times 30$ mm with no surrounding edema or mass effect (see Fig. 1), and CTA shows diffuse superficial serpiginous dilated vascular structures seen in left occipital lobe (mainly cortical and subcortical in location reaching the trigon of left lateral ventricle), with central nidus supplied by relatively dilated left PCA (measuring 2.5 mm), drained by cortical veins draining mainly into left transverse sinus with no associated edema, no hemorrhage, no mass effect, no aneurysms, no ischemic insult (Spetzler scale = 3) (see Fig. 2).

The CTA was of very high quality and the neurovascular committee (formed of neurosurgeons, neurologists and neuroradiologists) decided to do surgical excision without the need for digital subtraction angiography (DSA) and without preoperative embolization. The steps of the surgery were explained to the patient and his relatives and the also the expected advantages and disadvantages of the ultrasound use intra-operative, and the consent was taken.

Operative room setup

The operating table was put in the middle and supplied with an extension piece to apply a Mayfield clamp to fix the patient's head and the ventilator was put to the left of the surgeons and the ultrasound device was put in front of the operating surgeon to the right (see Fig. 3).

Intra-operative

As the lesion is occipital, the patient's head was fixed on Mayfield Clamp and the patient was put in prone position, and U-shaped skin incision was made and left occipital craniectomy flap was elevated and the dura is exposed then we used ultrasound to define the borders of the lesion, upper, lower, medial and lateral borders to design the dural incision and focus it on the site of interest to prevent unwanted brain tissue exposure. At first, the craniectomy was inadequate which is detected by the ultrasound as the lateral border of the AVM was not reached (Fig. 4), so the operator had to extend the bone

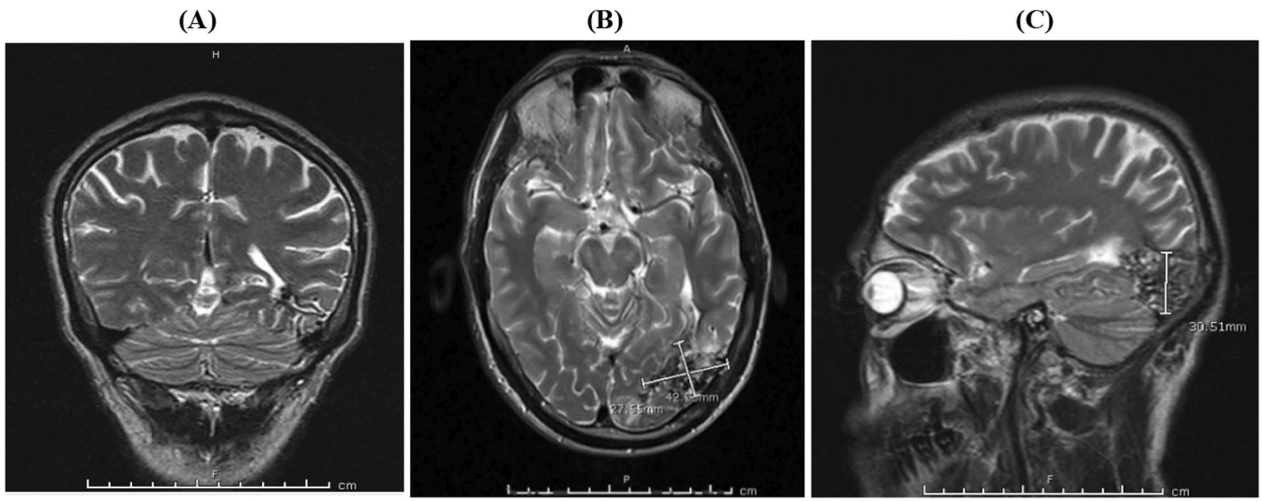

Fig. 1 MRI of AVM case. **A** Coronal view. **B** Axial view. **C** Sagittal view. Evidence of serpentine flow void nidus seen in the left occipital lobe measuring ~ 27 × 42 × 30 mm. No surrounding edema or mass effect

flap laterally. It also visualized its relation to the surrounding structure as adjacent dural folds (see Fig. 5). Then after dural incision and exposure of the AVM, the color Doppler mode was used to detect the flow in the related vessels in grades of red and blue color (red in vessels where the flow is directed toward the probe mostly the arteries and blue color in vessels where the flow directed away from the probe mostly the veins) and the spectral mode defines the flow velocity and its pattern in these vessels (see Fig. 6). So, we could detect the feeding arteries and draining veins. Then, clipping of the artery is done first and the excision is done. At the end, we use ultrasound again to confirm total excision of the AVM with no residual left (see Fig. 7). To get adequate ultrasound image, we irrigated the field with saline as the air is bad conductor to the sound; however, water is a good conductor which leads to better image quality (See Figs. 3, 4).

Intra-operative microscopic images was obtained to show accurate localization of the AVM based on intra-operative ultrasound without unwanted brain tissue exposure (see Fig. 8). The lesion was taken for pathological examination which revealed admixture of malformed vessels, and some have thick-walled vessels and others thin-walled capillaries with hemorrhage, inflammatory cells and hemosiderin pigment, compatible with arteriovenous malformation (Figs. 8, 9).

Postoperative

The patient was fully conscious with GCS 15 with no neurological deficits or attacks of seizures and stayed in the neurosurgical ICU for 2 days and then discharged to the wards for 5 days and discharged to home with stable hemodynamics and with no complications with regular follow-up at the outpatient clinic. Follow-up CT brain was done in the second day postoperatively which is the hyperdense shadow of the clip with no ischemia (Fig. 9).

Cavernoma case

Ultrasound is used to accurately localize the cavernoma being small in size and subcortical in position with difficult localization depending on preoperative MRI or CT. Thanks to the fact that ultrasound gives real-time images, it could overcome the brain shift phenomenon occurring during resection and detect the lesion successfully in contrast to other intra-operative imaging modalities. In grayscale B-mode, the lesion appeared as hyperechoic rounded lesion with surrounding brain tissue. It also could detect the required depth for resection and the extent of resection. It provided convincing alternative to neuronavigation systems in institutes lacking them.

Case presentation

A 45-year-old male patient presented with sudden attacks of seizures 3 months ago with intact sensory and motor functions. CT brain showed rt frontal hyperdense lesion measuring 20.1 × 22.7 mm mostly bleeding cavernoma (see Fig. 10). MRI brain was done and revealed rt frontal cavernoma (see Fig. 11). Then the patient is admitted for surgical excision of the cavernoma which is subcortical and needs excellent localization.

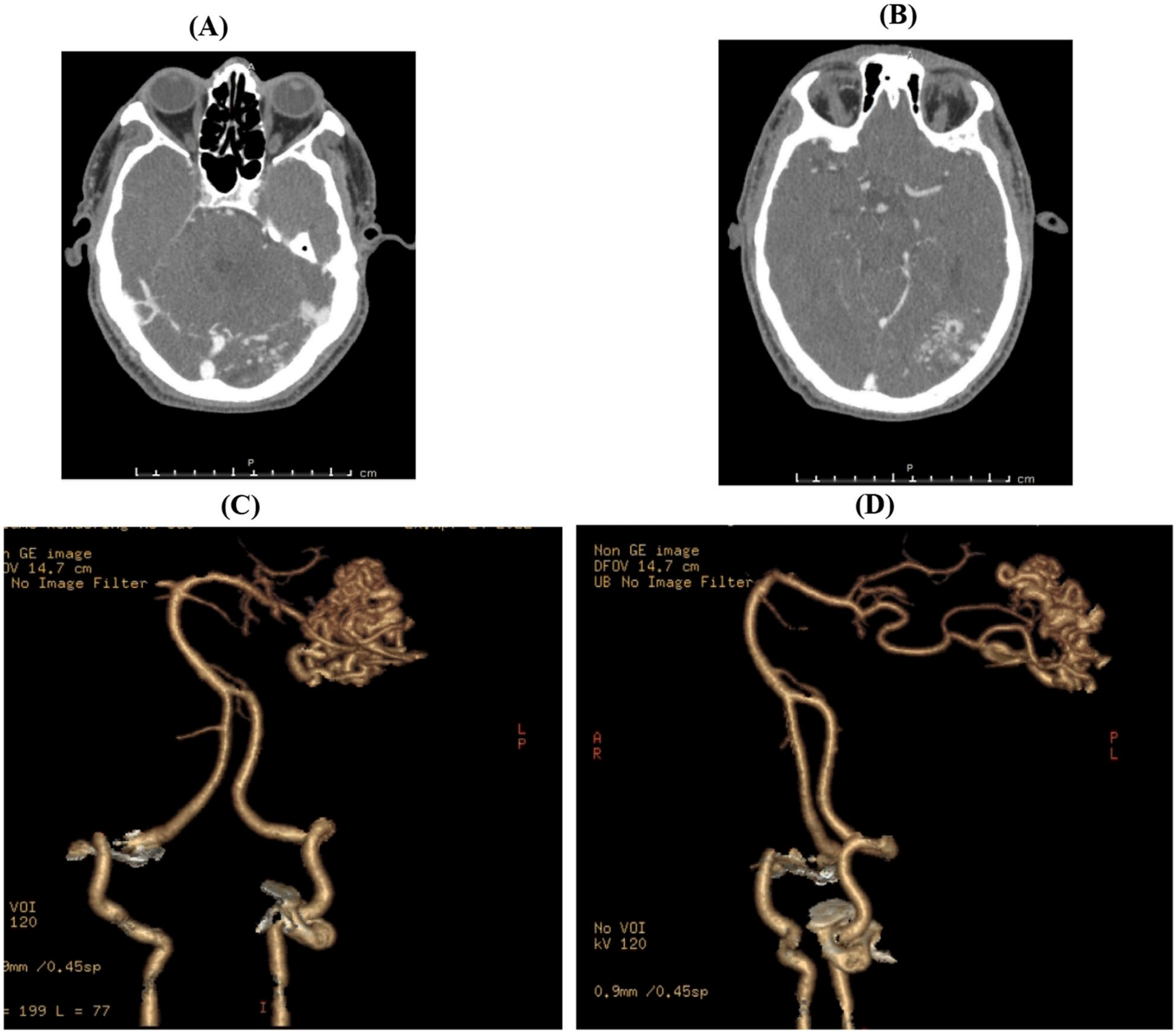

Fig. 2 CTA of AVM case. **A** At the level of tentorium cerebelli. **B** At higher level. **C** CT3D—AP view. **D** CT3D—lateral view

Intra-operative

The patient is put in supine position and the ultrasound device was on the left to the surgeon and the ventilator was to the right. Then, U-shaped skin incision and craniectomy bone flap were elevated. Then before dural incision, the ultrasound is used to take an image to localize the lesion and determine its depth and decide the best approach to reach. The lesion appeared as hyperechoic lesion surrounded by normal brain tissue (see Fig. 12). Then after dural incision, the IOUS is used to get real-time images of the lesion, while resection is going on to guide the surgeon intra-operative and assess the extent of resection. For better resolution, we used saline bath in the cavity of resection underneath the probe. Then after complete resection IOUS image was taken to confirm complete excision (see Fig. 13).

Postoperative

The patient was fully conscious with GCS 15 with no neurological deficit. He stayed in the ICU for one day, then discharged to the ward for 4 days and then discharged to the home and postoperative image were done (see Figs. 14, 15).

N.B: the case was challenging due to unavailability of neuronavigation system or brain mapping techniques,

Fig. 3 Place of ultrasound device in operating room

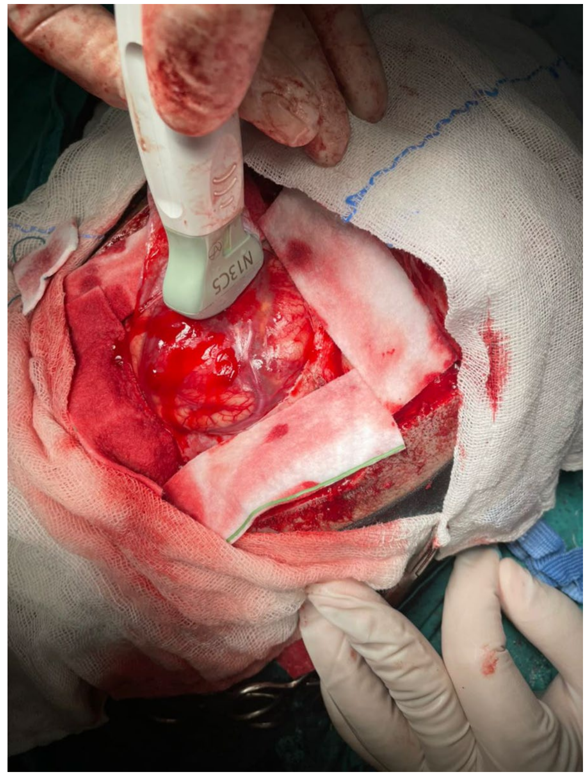

Fig. 4 Use of ultrasound probe after dural incision

and the lesion was very close to the motor cortex. So, IOUS was very helpful.

Discussion

One of the challenges faced by neurosurgeons is to localize the lesion precisely specially those which are small and deeply seated to prevent violation of normal brain parenchyma which may lead to difficult surgical excision and permanent neurological deficit. So, many imaging tools are used to facilitate the localization of the lesions such as intra-operative CT, or MRI and intra-operative ultrasound. The ultrasound has many advantages over other tools used as it provides real-time images which overcome brain shift phenomenon occurring during surgical intervention. Also, there is no risk of radiation exposure to the patients as occurs with other imaging modality. It is also much cheaper than others and can be afforded by low-resource institutions in contrast to neuronavigation systems. IOUS has wonderful spatial resolution, and it is a tomography, which allows to study the depth of tissues [5]. Also, availability of different ultrasound modes with

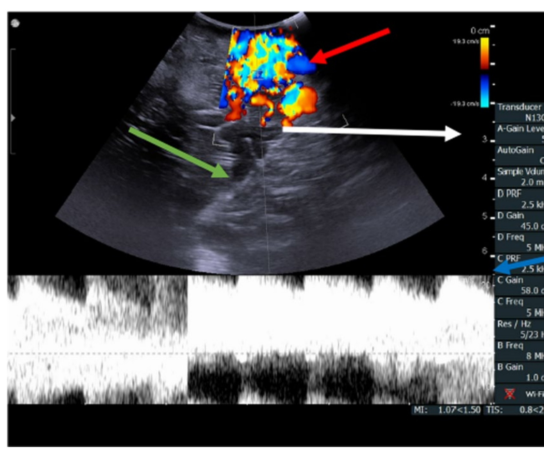

Fig. 5 IOUS of AVM Case. Color Doppler image showing bidirectional, high-blood flow within the tubular structures, suggestive of blood flow within an AVM (red arrow). It also gives an idea about the depth of resection needed (here up to 3 cm depth) (white arrow). Color Doppler and its relation to the adjacent dural folds (tentorium cerebelli) (green arrow). High pattern of flow in the nidus which exceeds 25 m/s detected by spectral Doppler US (blue arrow)

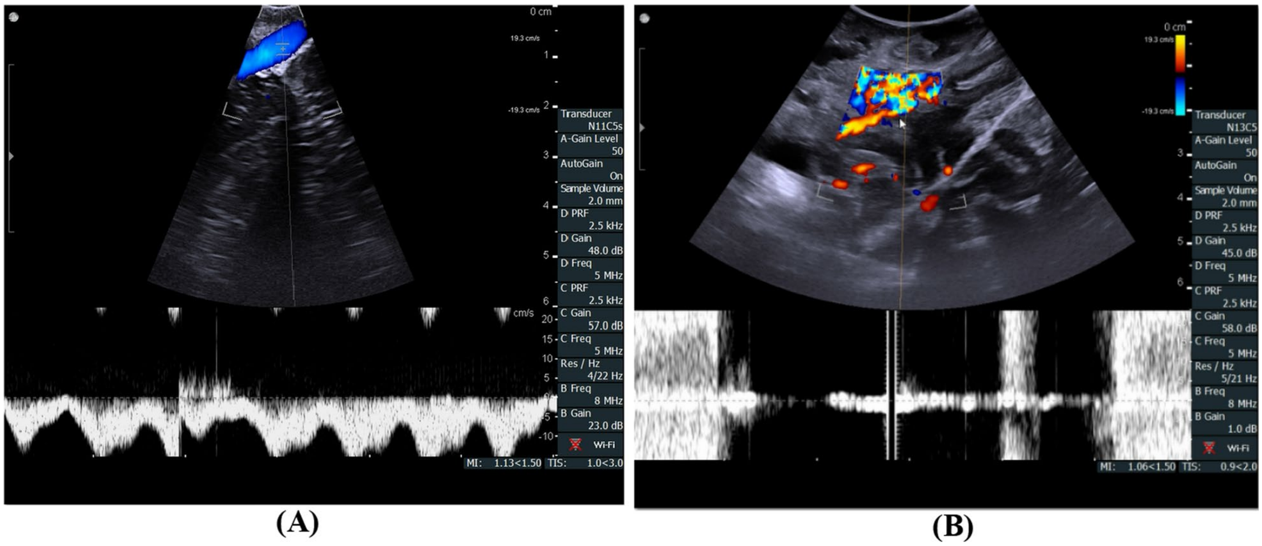

Fig. 6 Draining vein and feeding artery of AVM case. **A** Major draining veins with high flow signal intensity and pulsatile flow pattern detected by spectral Doppler. **B** Large feeding artery is shown

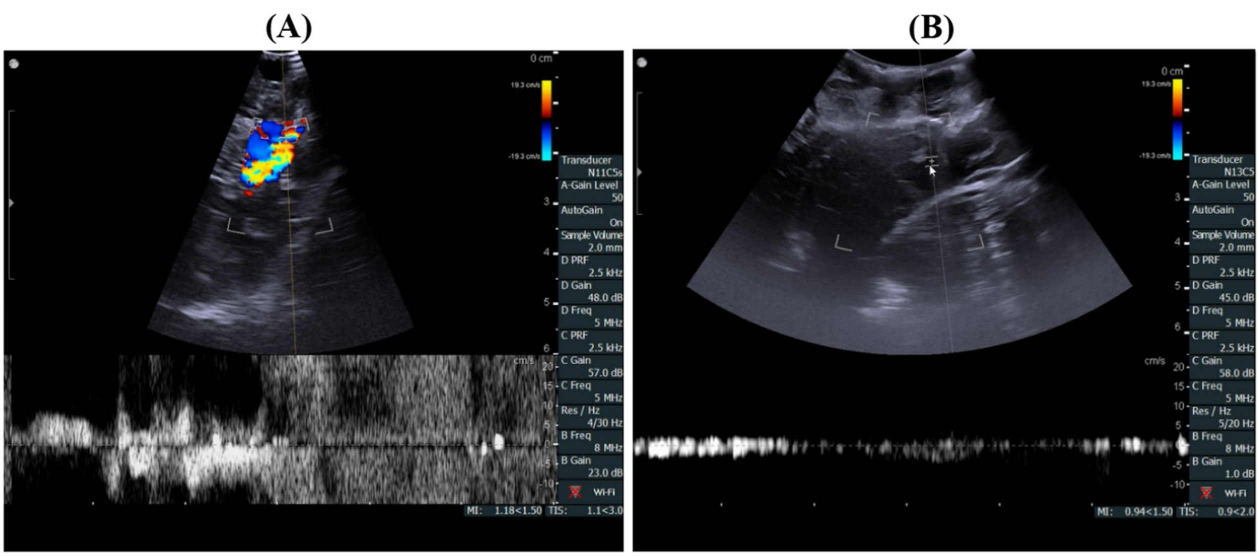

Fig. 7 IOUS of AVM case during and after resection. **A** during resection, it assesses the extent of resection. It shows smaller size of the lesion than the original size. The resection is then completed to ensure maximum resection. **B** After resection is completed, no nidus is present

different applications for each mode as grayscale B-mode can differentiate between hyperechoic and hypoechoic lesions or the related hematoma if present and can detect normal brain architecture including sulci, gyri, ventricles and dural folds. Color Doppler sonography can detect the blood flow in the vessels surrounding or included in the lesions as the feeding arteries and draining veins of the AVM. Contrast-enhanced ultrasound can be made compatible with MRI to define the lesions accurately.

Once the surgical field is exposed after removing the bone flap and the dura is exposed, it is possible to assess tissue perfusion with Doppler imaging, which depends on the Doppler effect to describe blood in the related blood vessels and so determine arteries and veins which can be made in great detail by combining B-mode and various Doppler modes (color and spectral Doppler) [6]. This is useful in vascular surgery to detect the location of interest and the real-time changes in the blood vessels

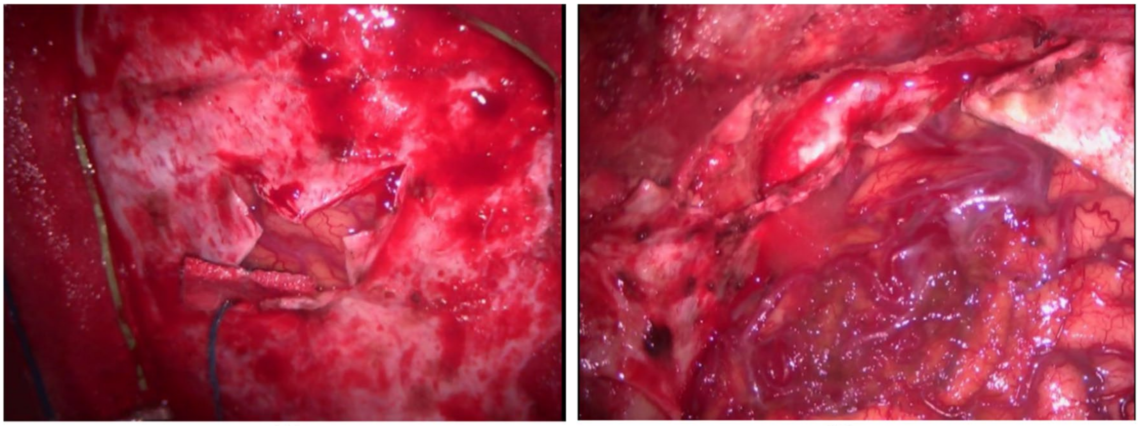

Fig. 8 Intra-operative microscopic image: **A** dural incision **B** AVM

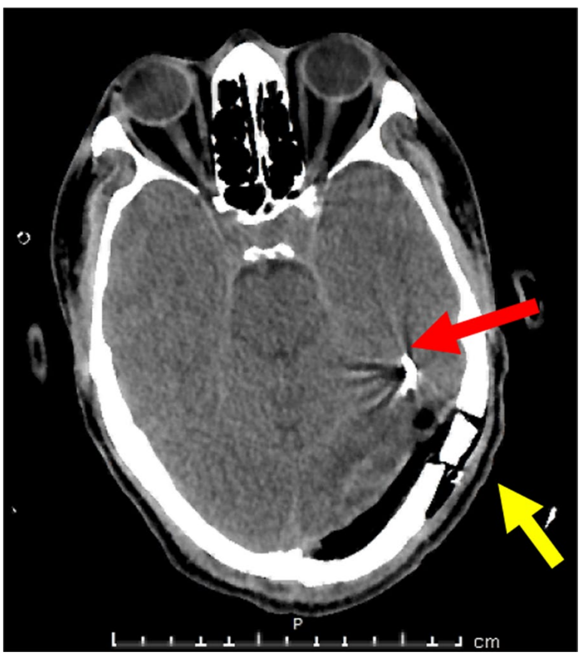

Fig. 9 CT Postoperative of AVM case. No evidence of residual nidus is present. It shows the metallic artifact of the clip (red arrow) which used to clip the feeding artery. Note: the segmented bone flab (yellow arrow)

related to the surgical maneuver [7]. Power Doppler is another different approach to Doppler imaging which relies on the Doppler signal amplitude to detect blood flow. It is not useful regarding flow speed and direction, but it can detect the quantifies of blood flow with higher sensitivity and less angle dependency than other modalities. It helps to detect and define site of vessels and to study tissue perfusion in the area of interest [6, 8]. A further development of power Doppler is the high-sensitivity Doppler, which has largely improved the degree of flow sensitivity even in very small vessels with slow flow detection [9].

This study presented 2 different lesions: AVM and cavernoma with different applications of ultrasound intraoperative in each case.

AVM represents abnormal connection between artery and vein with intervening multiple serpiginous loops of abnormal blood vessels and capillaries forming the nidus. IOUS is accurate in localizing the lesion and determining the depth of resection needed when used before dural incision and in determining the site of cortical incision which leads directly to the nidus. In AVM excision, it is essential to define the feeding artery and to be ligated or clipped first before the vein otherwise devastating consequences will develop, so color Doppler sonography could help in this issue. Also, during resection, IOUS is used to detect any AVM residual to optimize the AVM resection. The complete resection is confirmed by Doppler ultrasound with no flow signal at the end of the surgery.

In cavernoma, which was small and subcortical and adjacent to the motor cortex, it was essential for intraoperative neuronavigation and brain mapping which was unavailable, so ultrasound is used as alternate. It helped to localize the lesion accurately and identify the site for approach to prevent violation of motor cortex. It is appeared as hyperechoic shadow with no flow signal. It also helped to assess extent of its excision.

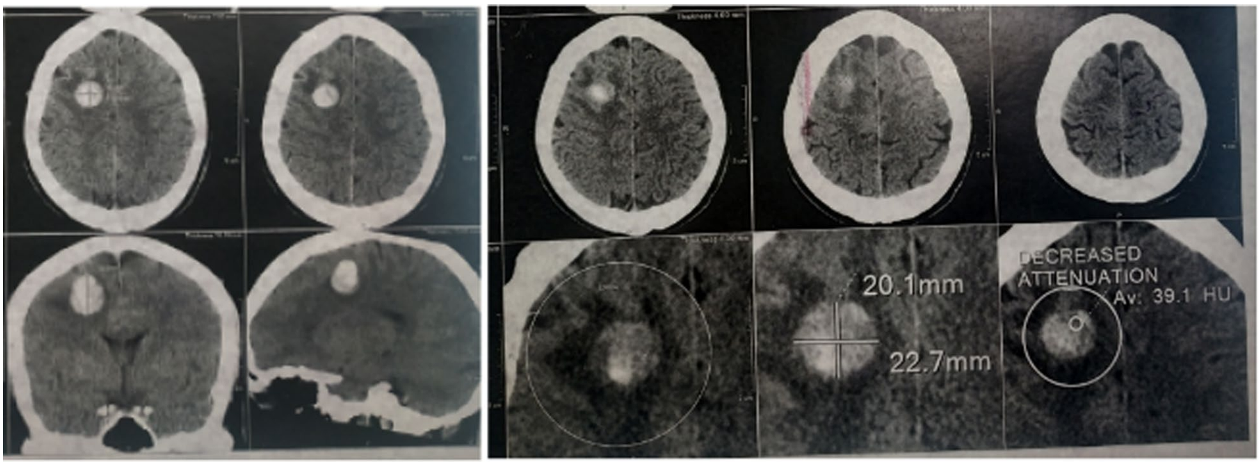

Fig. 10 CT pre-op of cavernoma case. Right frontal well defined hyperdense lesion measuring 20.1 × 22.7 mm

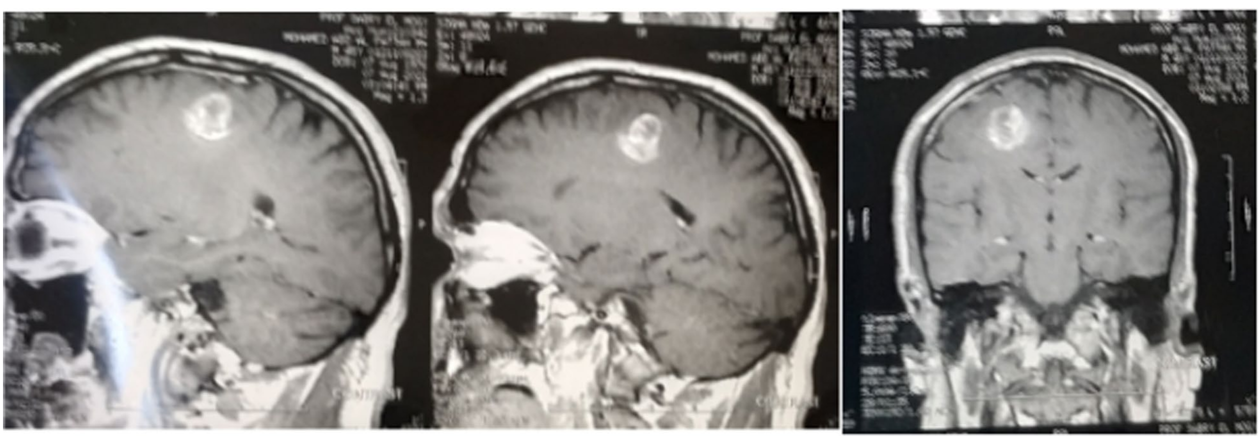

Fig. 11 MRI pre-op of cavernoma case

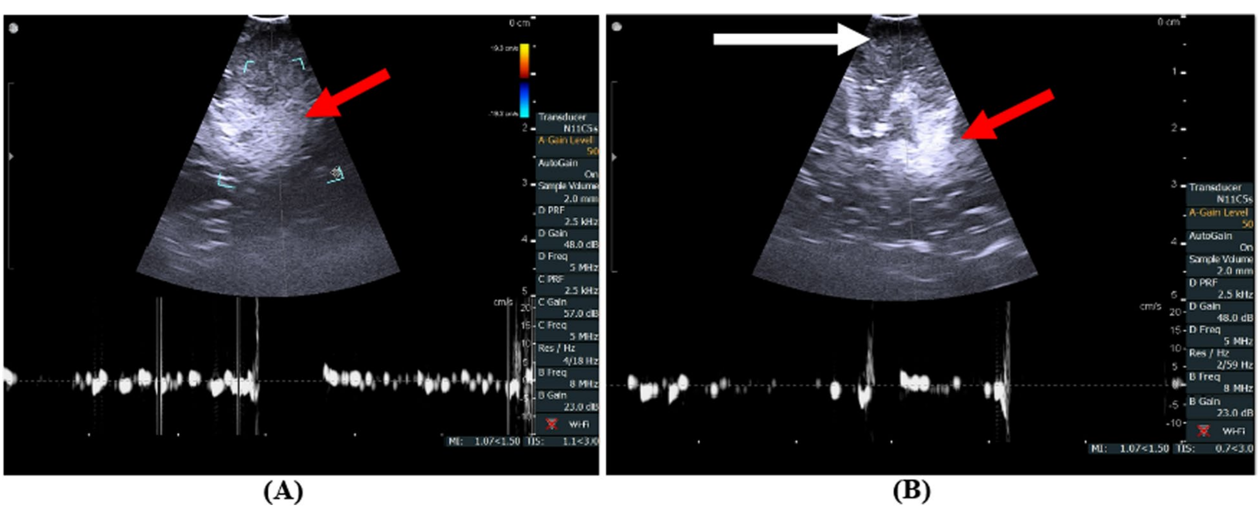

Fig. 12 IOUS of cavernoma case. **A** The cavernoma appears as hyperechoic lesion (red arrow). **B** During excision of the cavernoma (hyperechoic shadow) (red arrow). The corridor of excision appears hypoechoic (saline bath) (white arrow)

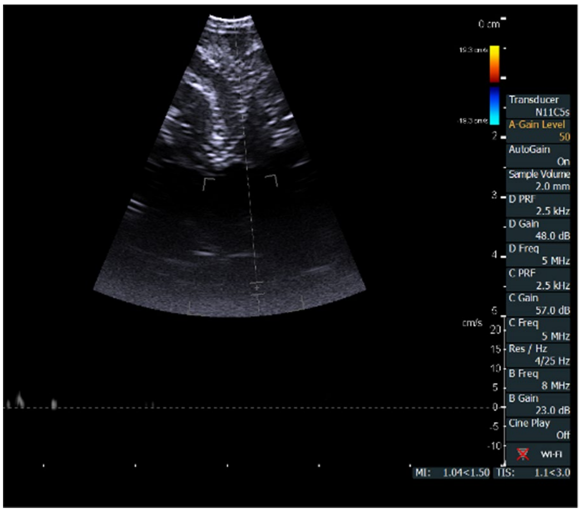

Fig. 13 IOUS of cavernoma case post-excision after closure of the dura. Note: absence of the hyperechoic lesion (cavernoma)

Fig. 14 CT post-op of cavernoma case

Advantages of the study

This study was done to assess the value of ultrasound during different lesions as AVM excision and cavernoma excision. It provides valuable alternate to neuronavigation system specially in low-resource institutions with no remarkable disadvantages. The IOUS was very helpful in both lesions with different pathologies which opens the door in front of the ultrasound to be used for different brain lesions.

Limitations

IOUS needs appropriate study by attending dedicated courses, training and practice every time possible.

Also, the study is preliminary descriptive observational study held in single neurosurgical center with low level of evidence on different lesions.

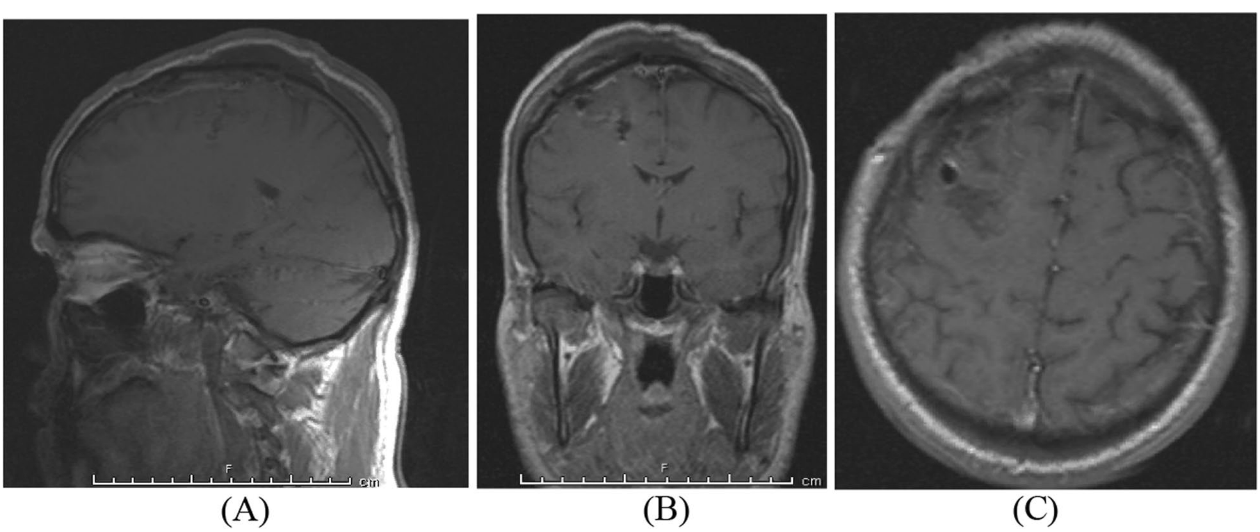

Fig. 15 MRI post-op of cavernoma case. **A** sagittal, **B** coronal, **C** axial

Recommendations

Larger studies with higher levels of evidence are needed to assess value of IOUS in different lesions.

Conclusions

IOUS is very reliable tool which provides real-time imaging during surgical intervention which can detect the lesions accurately and help to assess extent of resection.

Abbreviations

AP: Antero-posterior; AVM: Arteriovenous malformation; CT: Computed tomography; CTA: Computed tomography angiography; DSA: Digital subtraction angiography; GCS: Glasgow coma scale; ICH: Intracerebral hematoma; IOUS: Intra-operative ultrasound; MP: Motor power; MRI: Magnetic resonance image; PCA: Posterior cerebral artery; PMH: Past medical history; post-op: Postoperative; pre-op: Preoperative; PSH: Past surgical history.

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Author contributions

M.A.K. contributed to conceptualization, methodology, and supervision. A.A.E. was involved in formal analysis and review and editing. K.M.A. contributed to investigation and validation. I.M.S.E. was involved in writing—original draft preparation, and data curation. All authors read and approved the final manuscript.

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Availability of data and materials

All data generated or analyzed during this study are included in this published article.

Declarations

Ethics approval and consent to participate

The study is approved by the local Institutional Research Board (IRB), Faculty of medicine, Mansoura University, and an informed and written consent is achieved from both patients after full explanation of the procedures to be done and the expected benefits and hazards that they may be exposed to.

Consent for publication

Not applicable.

Competing interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

Author details

[1]Mansoura University Hospitals, El Mansoura, Egypt. [2]Department Faculty of Medicine, Mansoura University, El Mansoura, Egypt. [3]Faculty of Medicine, Mansoura University, El Mansoura, Egypt. [4]Oncology Center, Mansoura University, El Mansoura, Egypt.

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