Versatile Use of Intraoperative Ultrasound Guidance for Brain Puncture

Tugrul Cem Unal, MD, FEBNS
Cafer Ikbal Gulsever, MD
Duran Sahin, MD
Huseyin Emre Dagdeviren, MD
Ilyas Dolas, MD
Pulat Akin Sabanci, MD
Yavuz Aras, MD
Altay Sencer, MD
Aydin Aydoseli, MD

Department of Neurosurgery, Istanbul Faculty of Medicine, Istanbul University, Istanbul, Turkey

Correspondence:
Tugrul Cem Unal, MD, FEBNS,
Department of Neurosurgery,
Istanbul University,
Istanbul Faculty of Medicine,
Istanbul Tip Fakultesi,
Nörolojik Blimler Binası,
Kat:3, Beyin ve Sinir Cerrahisi,
Fatih/Istanbul, 34093, Turkey.
Email: tugrulcem@gmail.com

Received, April 8, 2021.
Accepted, July 18, 2021.

© Congress of Neurological Surgeons 2021. All rights reserved. For permissions, please e-mail: journals.permissions@oup.com

BACKGROUND: Intraoperative ultrasound (iUS) is an effective guidance and imaging system commonly used in neuro-oncological surgery. Despite the versatility of iUS, its utility for single burr hole puncture guidance remains fairly underappreciated.
OBJECTIVE: To highlight the simplicity, versatility, and effectiveness of iUS guidance in brain puncture by presenting the current case series and technical note collection.
METHODS: We present 4 novel uses of iUS guidance for single burr hole brain puncture: cannulation of normal-sized ventricles, endoscopic third ventriculostomy (ETV) guidance, evacuation of interhemispheric empyema, and stereotactic biopsy assistance.
RESULTS: All techniques were performed successfully in a total of 16 patients. Normal-sized ventricles were cannulated in 7 patients, among whom 5 underwent Ommaya reservoir placement and 2 underwent ventriculoperitoneal shunt placement for idiopathic intracranial hypertension. No more than 1 attempt was needed for cannulation. All ventricular tip positions were optimal as shown by postoperative imaging. iUS guidance was used in 5 ETV procedures. The working cannula was successfully introduced to the lateral ventricle, providing the optimal trajectory to the third ventricular floor in these cases. Interhemispheric subdural empyema was aspirated with iUS guidance in 1 patient. Volume reduction was clearly visible, allowing near-total evacuation of the empyema. iUS guidance was used for assistive purposes during stereotactic biopsy in 3 patients. No major perioperative complications were observed throughout this series.
CONCLUSION: iUS is an effective and versatile guidance system that allows for real-time imaging and can be easily and safely employed for various brain puncture procedures.

KEY WORDS: Endoscopic third ventriculostomy, Idiopathic intracranial hypertension, Interhemispheric empyema, Intraoperative ultrasound, Ommaya, Stereotactic biopsy, Ventriculoperitoneal shunt

Operative Neurosurgery 0:1–9, 2021 https://doi.org/10.1093/ons/opab330

Over the last few decades, intraoperative ultrasound (iUS) has emerged as an essential guidance system in neurosurgical practice, particularly in the field of neuro-oncology.[1] iUS has been utilized as a valuable assistive tool for maximizing safety of intracranial tumor resection given that it provides real-time imaging and feedback.[2,3] It also allows for localizing anatomical landmarks and certain anatomical structures throughout the procedure.[4] Despite the versatility of iUS, its utility for puncture guidance remains fairly underappreciated. Although several series have described ventriculoperitoneal shunt (VPS)[5-8] or external drain placement[9] in hydrocephalus, only 2 teams have reported catheter placement in normal-sized ventricles,[10,11] which may be the ideal use of iUS. Despite its remarkable suitability, iUS has not been reported to be used so far for endoscopic third ventriculostomy (ETV) guidance. Likewise, despite being used for single burr hole abscess aspiration,[12] no reports can be found regarding its use for the treatment of interhemispheric subdural empyema. Regarding brain biopsies, iUS can be used as a guidance modality for freehand biopsy,[13-16] as well as an assistive system in stereotactic biopsy, although without the need of any additional devices.[17] The current technical note collection therefore aimed to highlight the simplicity, versatility, and effectiveness of iUS

ABBREVIATIONS: ETV, endoscopic third ventriculostomy; **iUS,** intraoperative ultrasound; **VPS,** ventriculoperitoneal shunt

Downloaded from https://academic.oup.com/ons/advance-article/doi/10.1093/ons/opab330/6384798 by Istanbul University Library user on 01 November 2021

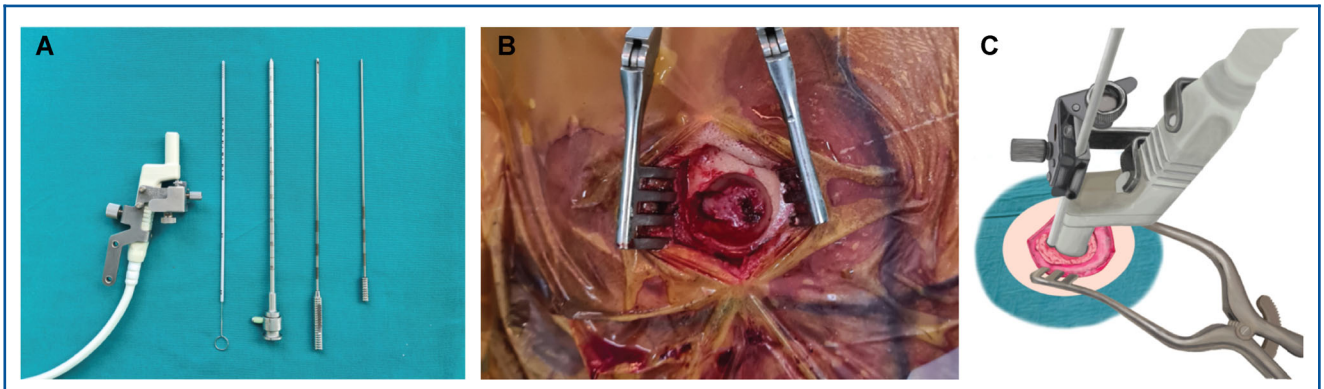


FIGURE 1. **A**, *The burr hole probe and the catheters used in this series.* **B**, *The extended burr hole for puncture.* **C**, *Illustration of single burr hole iUS-guided cannulation. Artist: Cristina Brinza.*

guidance for brain puncture. We herein present a series of 16 patients and 4 novel uses of iUS guidance for brain puncture: cannulation of normal-sized ventricles, ETV guidance, evacuation of interhemispheric empyema, and stereotactic biopsy assistance.

METHODS

Patient Population

All patients who underwent cannulation of normal-sized ventricles, ETV, evacuation of interhemispheric empyema, and stereotactic biopsy using iUS guidance/assistance were included in this series. Thereafter, clinical and surgical records of the patients were examined, after which the technical aspects of the procedures were presented and discussed. Informed consent was obtained from all patients prior to surgery. The patients consented to the publication of their images. Since data were collected retrospectively and fully anonymized, no institutional review board approval was needed.

Ultrasound System

An iUS system (Hitachi Arietta 70, Tokyo, Japan) was used for all procedures. The puncture adapter was attached to the burr hole probe for ventricular catheter, cannula, or biopsy needle advancement (Figure 1).

Extended Burr Hole for Puncture

After creating a 15-mm-wide burr hole using a drill, iUS was utilized to determine the optimal cannulation point. The extension site that allowed the most suitable puncture trajectory was chosen following burr hole probe assessment. The extension site was rongeured using 3-mm Kerrison rongeurs. The ventricular puncture technique requires the extension site to be in either the lateral or medial side of the burr hole for coronal visualization of the ventricles (Figure 1). Given that the extended part must be the entry point during stereotaxy assistance, the burr hole site must be selected accordingly.

Technical Aspects

Cannulation of Normal-Sized Ventricles

An extended burr hole was planned over the Kocher's point, 1 to 2 cm anterior to the coronal suture and 3 cm lateral to the midline (9-10 cm posterior to the glabella). The coronal section of the ventricles was captured using the probe. Thereafter, irrigation was applied to achieve proper visualization. The visible landmarks included the falx and ventricles (Figure 2). The selected target must be in front of the choroid plexus in order to stay in front of the foramen of Monro for optimal ventricular cannulation to the frontal horns. Once the proper trajectory is determined using iUS, the catheter slowly slid inside the puncture adapter. Real-time visualization of the entry to the ventricle was accompanied by a pop sensation. The catheter should not be advanced past the foramen of Monro. The position of the catheter inside the ventricle can be verified following cannulation (Figure 2 and Video).

ETV Guidance

After placing the burr hole over Kocher's point, the coronal section of the ventricles was captured. Landmarks were similar to those during iUS-guided cannulation. The choroid plexus, falx, and foramen of Monro were visualized using an anteroposterior search in the coronal section. A trajectory that passes from the foramen of Monro reaching the third ventricular floor was then selected, either from lateral or medial side of the burr hole. Thereafter, the burr hole was extended in the same manner to the adequate side. The puncture adapter was adjusted to the diameter of the working cannula so that the former can be slid inside the puncture adapter. Entry to the ventricle was visualized, while a pop sensation can be felt (Figure 3). The procedure then proceeds as planned.

Evacuation of Interhemispheric Empyema

The ideal placement of the burr hole was slightly lateral to the midline in the posterior parietal area. The empyema can be visualized after the burr hole was opened again in the coronal section. The burr hole was then extended medially while ensuring that the puncture zone does not cross the superior sagittal sinus. Following the burr hole extension, the catheter was slid from the puncture adapter into the empyema, which was then aspirated through the catheter (Figure 4). The anterior and posterior interhemispheric fissure can be visualized following the aspiration. The procedure can be repeated in case of residual empyema. The real-time

Downloaded from https://academic.oup.com/ons/advance-article/doi/10.1093/ons/opab330/6384798 by Istanbul University Library user on 01 November 2021

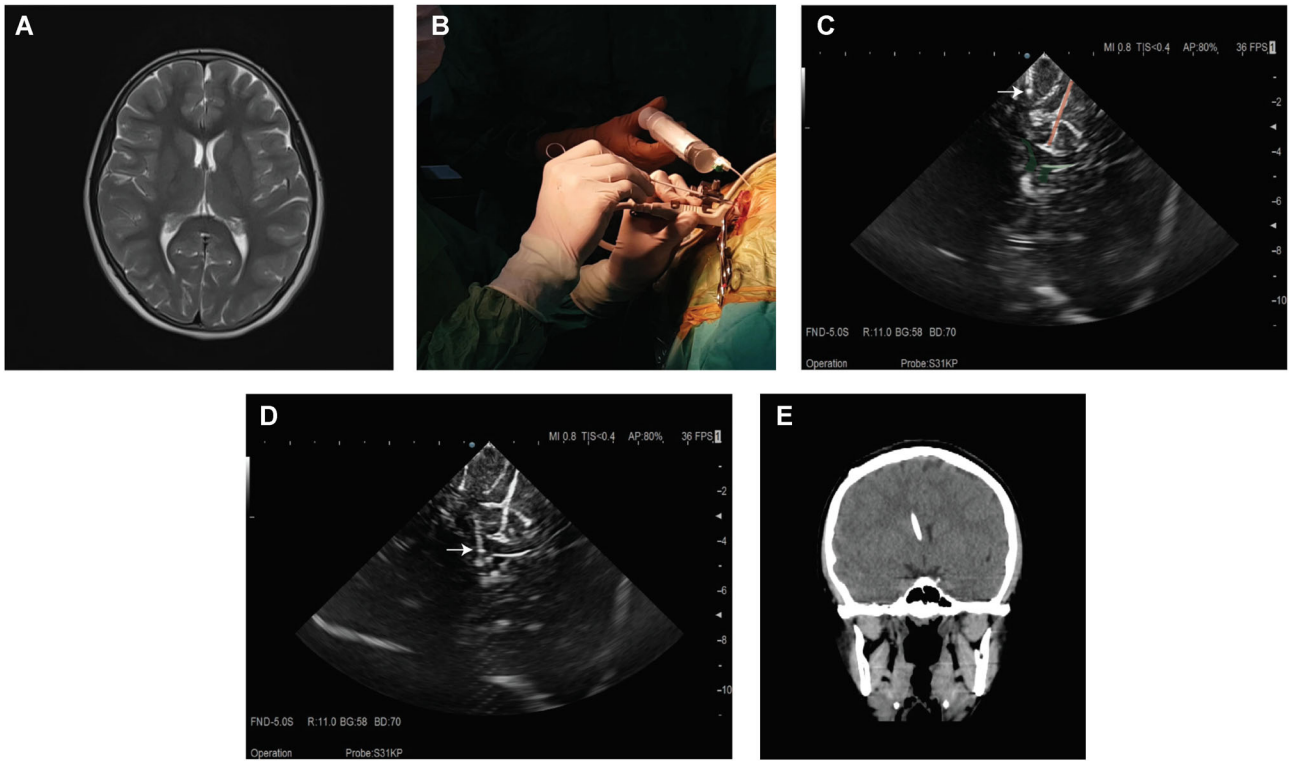


FIGURE 2. *Cannulation of normal-sized ventricles.* **A**, *T2-weighted MRI of a patient with idiopathic intracranial hypertension who had normal-sized ventricles.* **B**, *The catheter was slid inside the puncture adapter of the burr hole probe with continuous irrigation.* **C**, *The falx (red) and lateral ventricles (green) were observed while targeting the ipsilateral ventricle (white arrow: catheter tip).* **D**, *A popping sensation and real-time visualization of the catheter tip entry into the lateral ventricle were used to confirm ventricular puncture.* **E**, *Postoperative CT showed the ventricular catheter inside the frontal horn of the lateral ventricle.*



VIDEO. *Cannulation of normal-sized ventricles, ETV guidance, evacuation of interhemispheric empyema, and stereotactic biopsy assistance.*

decrease in the empyema volume can be observed via iUS (Figure 4 and Video).

Stereotactic Biopsy Assistance

The stereotactic frame was fixed to the head of the patient, after which computed tomography (CT) was performed. The coordinates of the target for biopsy were then calculated. The frame was fixed to the operating table with the patient in supine position. After determining the entry point using the coordinates placed into the frame, an extended burr hole was made. After the arc was positioned, the burr hole probe was used without the puncture adapter (Figure 5). The biopsy needle was then inserted into the target point after dural opening, which was accompanied by the burr hole probe for iUS. The target was visualized before advancing the needle, with the biopsy needle needing to be aligned with the probe and slowly advanced to the target. After reaching the target, needle aspiration was visualized in real time. The iUS images were checked for hyperechogenicity of possible hemorrhages (Figure 6). Biopsy could also be performed freehand via the puncture adapter attached to the probe in case another part of the tumor needs biopsy or a negative frozen result was obtained (Figure 5 and Video).

RESULTS

A total of 16 patients underwent surgery with the aforementioned techniques (Table). iUS was capable of guidance in all procedures with adequate visualization of the intracranial structures.

Downloaded from https://academic.oup.com/ons/advance-article/doi/10.1093/ons/opab330/6384798 by Istanbul University Library user on 01 November 2021

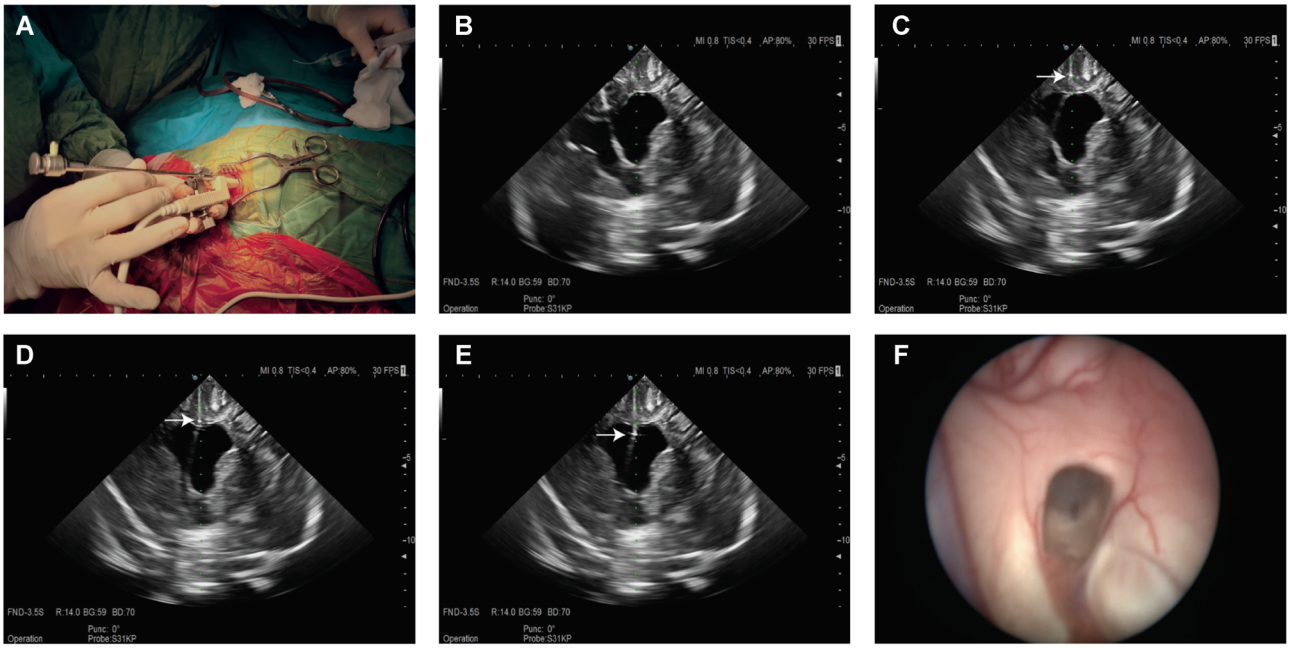


FIGURE 3. *ETV guidance.* **A**, *The endoscope cannula was inserted through the puncture adapter. An image of the lateral ventricles, third ventricle, and third ventricular floor was captured using the probe, after which the optimum trajectory to the floor passing by foramen of Monro was selected.* **B-D**, *The cannula was advanced slowly, with the white arrow showing the tip of the cannula.* **E**, *Entry into the ventricle was felt and visualized in real time.* **F**, *The endoscope was advanced inside the cannula. The foramen of Monro, mammillary bodies, and tuber cinereum are observed at the center of the image, suggesting that the optimal trajectory for ventriculostomy had been achieved.*

A total of 7 normal-sized ventricle cannulations were made: 2 VPS for idiopathic intracranial hypertension and 5 for Ommaya reservoir placement. All procedures were completed successfully, with no more than 1 attempt needed for cannulation. Temporary loss of iUS visualization occurred in 1 patient following advancement of the ventricular catheter, perhaps due to metallic artifacts. However, the catheter eventually nested in the optimal position given that the trajectory was set before the loss of visualization. The tip position in this patient was also checked after catheter placement. All catheter tips were in the optimal position (ie, frontal horn of the lateral ventricle) without making contact with the choroid plexus, as shown by postoperative CT images (Figure 2).

Five patients underwent ETV with iUS guidance. The working cannula was successfully introduced into the lateral ventricle via iUS guidance. Entry into the ventricle with the appropriate trajectory using iUS guidance provided easy access to the foramen of Monro and the third ventricular floor (Figure 3).

One interhemispheric empyema was aspirated with iUS guidance. A total of 45 cc pus was evacuated. The reduction in volume at posterior portion of the interhemispheric fissure was clearly visible. Postoperative magnetic resonance imaging (MRI) showed near-total evacuation of the empyema (Figure 4).

iUS guidance was used to assist stereotactic biopsy in 3 patients. Given that 2 patients had chronic kidney failure, perioperative contrast-enhanced CT was not possible. However, tumor visualization with iUS was possible in the aforementioned patients (Figure 5). The trajectories also became visible during the procedure (Figure 6). One patient developed microhemorrhage at the biopsy site, which prompted the termination of specimen acquisition. Moreover, 2 patients required additional freehand biopsy with iUS guidance given that the calculated point was deemed insufficient for optimal specimen acquisition as the frozen results were inconclusive. Sufficient amounts of pathological tissue could be collected from all 3 patients.

DISCUSSION

VPS placement for hydrocephalus has been one of the most common procedures in neurosurgical practice. However, long-term reoperation rates can be as high as 46%.[18] Thus, the use of guidance systems is crucial for optimal catheter positioning, thereby increasing overall survival following VPS.[19,20] Besides stereotaxy and neuronavigation systems, iUS has been widely used for patients with hydrocephalus.[5-8,21] According to a study by Wilson et al,[22] ultrasound-guided catheter placement was significantly more accurate than freehand placement and was equivalent to stereotaxy-guided placement. However, iUS remains

Downloaded from https://academic.oup.com/ons/advance-article/doi/10.1093/ons/opab330/6384798 by Istanbul University Library user on 01 November 2021

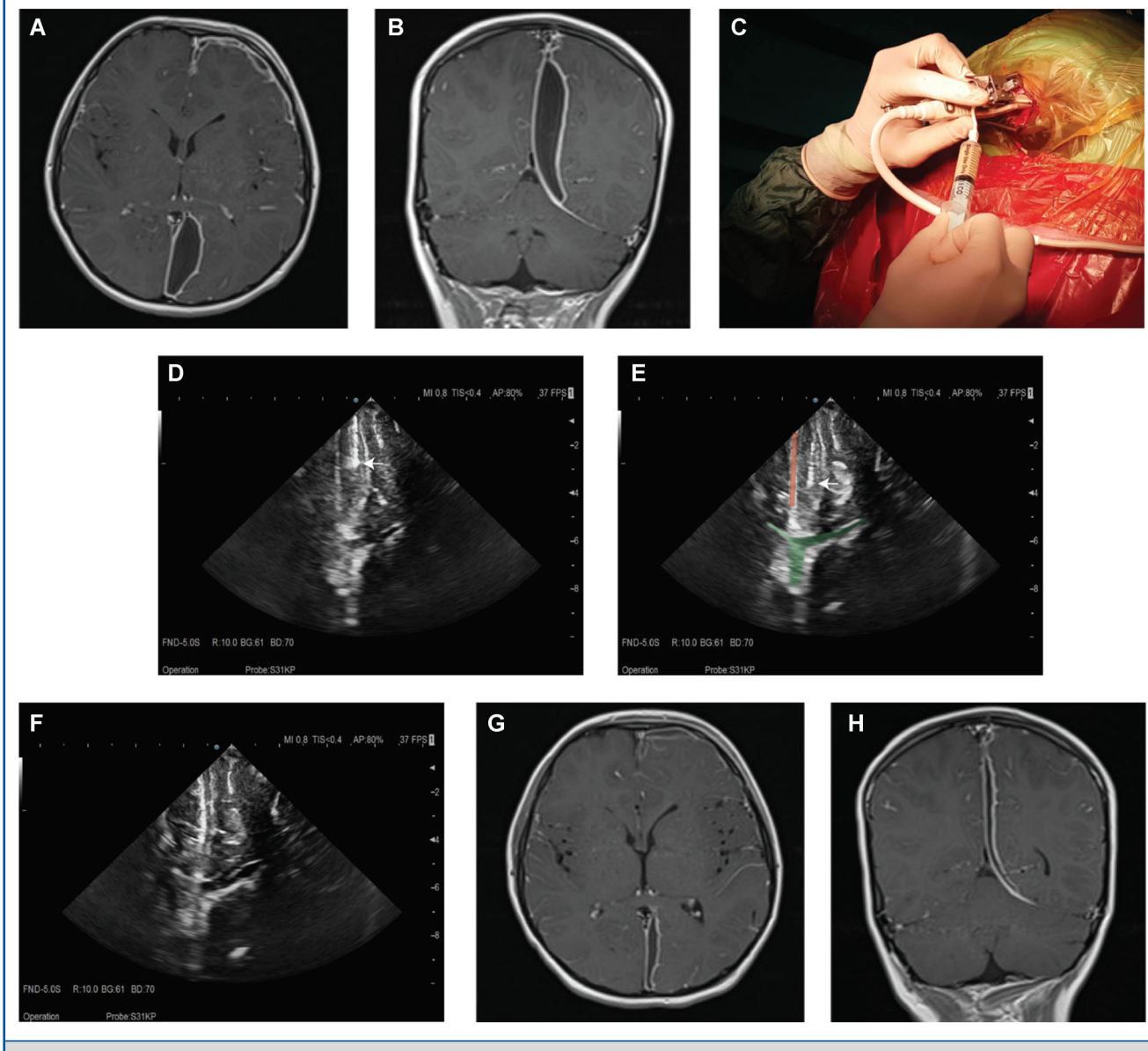
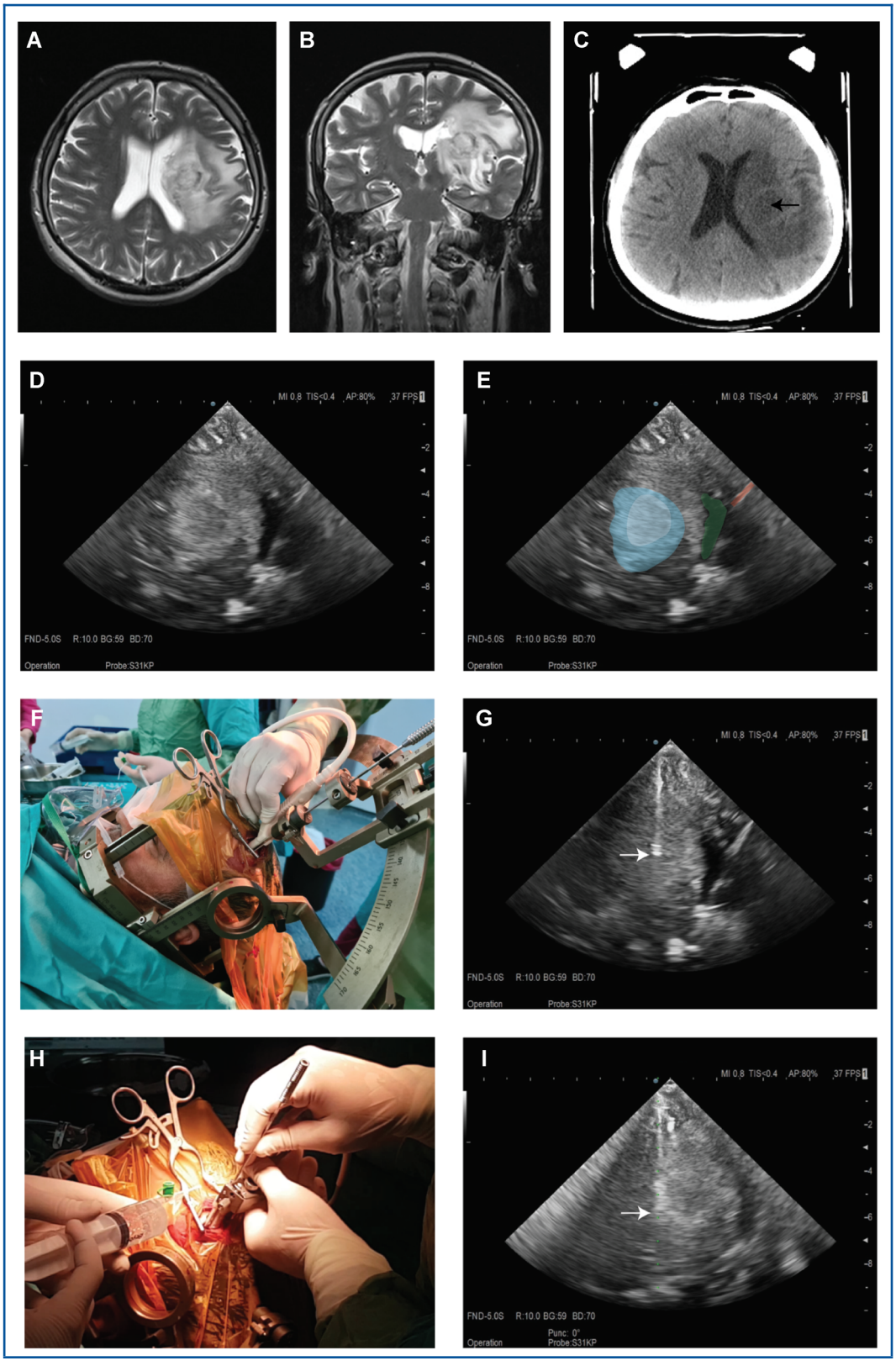


FIGURE 4. *Evacuation of interhemispheric empyema.* **A** *and* **B**, *Preoperative T1-weighted contrast-enhanced MRI showed an interhemispheric subdural empyema located in the posterior interhemispheric fissure.* **C**, *A ventricular catheter was used for the procedure.* **D**, *The catheter was inserted into the empyema using iUS guidance.* **E**, *The falx (red area) and lateral ventricles (green area) are shown in the image.* **F**, *Real-time volume reduction was observed on the ultrasound image.* **G** *and* **H**, *Postoperative MRI demonstrated near-total evacuation of the empyema.*

quite underused for cannulation of patients with small ventricles despite being particularly ideal for such cases. Yim et al[10] reported 1 case in their series of idiopathic intracranial hypertension, and Unal et al[11] published a technical note with a patient with normal-sized ventricles and cavum septum pellucidum. Even with the guidance of stereotaxy and neuronavigation systems, ventricular catheter placement in the aforementioned patients remains rather challenging. Multiple cannulation attempts, particularly with neuronavigational guidance, may be needed given the lack of real-time imaging. Nevertheless, catheters can easily be placed into the slit-like ventricles under ultrasonic guidance,[11] with the position being verifiable after insertion (Figure 2 and Video). In our series, all of the catheters nested in the optimal position, without the need for more than 1 puncture attempt.

Ultrasound-guided ETV is ideal for determining the trajectory of the endoscope given that the ventricles, foramen of Monro,

Downloaded from https://academic.oup.com/ons/advance-article/doi/10.1093/ons/opab330/6384798 by Istanbul University Library user on 01 November 2021



Downloaded from https://academic.oup.com/ons/advance-article/doi/10.1093/ons/opab330/6384798 by Istanbul University Library user on 01 November 2021

FIGURE 5. *Stereotactic biopsy assistance.* **A** *and* **B**, *A deep-seated lesion was shown on the T2-weighted MRI. Obtaining contrast-enhanced sequences was not possible in this patient due to chronic kidney failure.* **C**, *CT was then performed without a contrast agent, targeting the middle of the lesion (black arrow).* **D** *and* **E**, *Periphery and necrotic center of the tumor (blue area) were clearly visualized on ultrasound (red area: falx; green area: ipsilateral ventricle).* **F**, *The arc was configured for the target point, while biopsy needle was slid alongside the burr hole probe.* **G**, *The advancement and target point was clearly visualized on the ultrasound image (white arrow: needle tip).* **H**, *The decision was made to perform freehand sampling of the tumor capsule after the histopathological imprint was consistent with necrotic tissue.* **I**, *The needle is seen in the lateral side of the tumor capsule.*

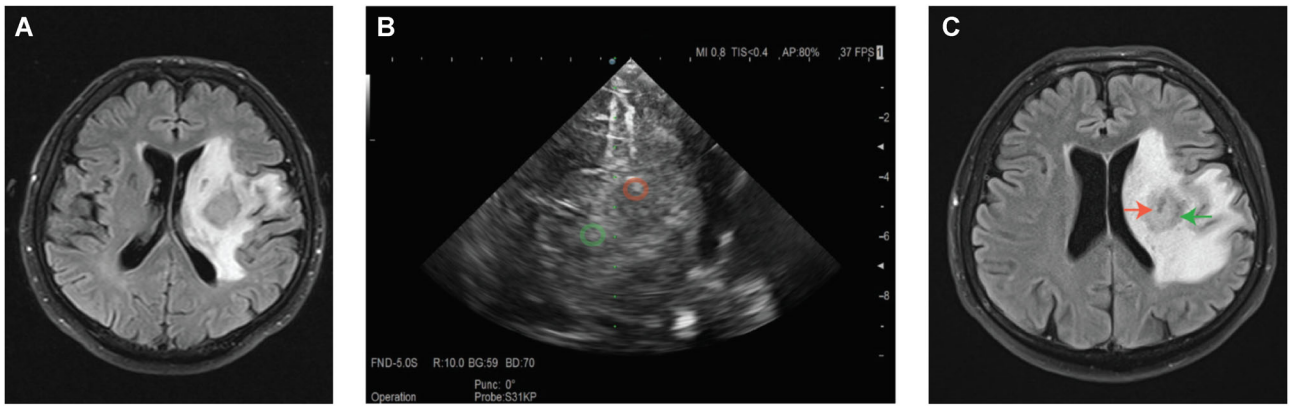


FIGURE 6. *Stereotactic biopsy assistance.* **A**, *Preoperative fluid-attenuated inversion-recovery (FLAIR) MRI,* **B**, *perioperative ultrasound,* **C**, *and postoperative FLAIR MRI images are shown. The red circle and arrow indicate the stereotactic biopsy sites, while the green circle and arrow indicate the freehand biopsy sites.*

TABLE. Patient characteristics

Patient no	Age	Sex	Procedure	Diagnosis
1	13	Female	Ventriculoperitoneal shunt placement	Idiopathic intracranial hypertension
2	31	Female	Ventriculoperitoneal shunt placement	Idiopathic intracranial hypertension
3	54	Female	Ommaya reservoir placement	Breast carcinoma
4	56	Female	Ommaya reservoir placement	Diffuse large B cell lymphoma
5	64	Female	Ommaya reservoir placement	Breast carcinoma
6	63	Female	Ommaya reservoir placement	Breast carcinoma
7	44	Female	Ommaya reservoir placement	Breast carcinoma
8	45	Female	Endoscopic third ventriculostomy	Aqueduct stenosis
9	45	Female	Endoscopic third ventriculostomy	Operated cerebellar metastasis
10	4	Male	Endoscopic third ventriculostomy	Germinal matrix hemorrhage + shunt dysfunction
11	3	Male	Endoscopic third ventriculostomy	Operated medulloblastoma
12	8	Male	Endoscopic third ventriculostomy	Mucopolysaccharidosis type VI + foramen magnum stenosis
13	8	Male	Evacuation of interhemispheric subdural empyema	Interhemispheric and bilateral frontal subdural empyema
14	61	Male	Stereotactic biopsy	Left occipitotemporal lesion (low grade glioma)
15	57	Male	Stereotactic biopsy + freehand biopsy	Left thalamic lesion (lymphoma) + chronic renal failure
16	68	Male	Stereotactic biopsy + freehand biopsy	Bifrontal lesion (low grade glioma) + chronic renal failure

and third ventricular floor can be clearly visualized (Figure 3). Di Somma et al reported a neuroendoscopic tumor resection series with the same device used here; however, a mini-craniotomy was needed for their larger endoscope.[23] This is the first series that report iUS guidance for ETV. Neuronavigation is commonly used for endoscope guidance.[24,25] iUS guidance for endoscopy retains all the advantages of neuronavigational guidance with the added benefit of allowing real-time visualization of the endoscope's position. The only drawback iUS guidance compared to neuronavigation guidance is that it cannot determine the entry point. Therefore, a neuronavigation system may be used or the entry point may be calculated meticulously beforehand in reference to the midline and coronal suture. Nevertheless, even with a suboptimal entry point, iUS may facilitate an adequate

Downloaded from https://academic.oup.com/ons/advance-article/doi/10.1093/ons/opab330/6384798 by Istanbul University Library user on 01 November 2021

trajectory that would allow reaching the third ventricular floor. All cases included in this series had achieved optimal endoscope positioning following insertion, meaning that the endoscope provided a view of the foramen of Monro and the third ventricular floor centered upon entry (Figure 3).

Stereotactic aspiration followed by antibiotic therapy has remained the treatment of choice for most intracranial pyogenic infections.[26] However, iUS has also emerged as an alternative technique for abscess aspiration considering that it allows the surgeon to monitor each step of the procedure, including puncture, drainage, and postoperative control of volume reduction.[12] Through this, iUS enables direct needle position monitoring and abscess drainage tracking. In case of multiple abscesses, shifting can be visualized after the first puncture, allowing the surgeon to adapt with real-time monitoring. Despite all these advantages in abscess evacuation, no study regarding the use of iUS for the treatment of interhemispheric (parafalcine) subdural empyema has yet been available. Interhemispheric subdural empyema is a rare presentation of intracranial infection that can cause neurological deterioration.[27] However, evacuation from a single burr hole can be challenging given its location, and generally a parasagittal craniotomy is needed. Salunke et al,[28] in their series of 10 patients, tried burr hole evacuation in 3 patients with parafalcine empyema. The burr hole evacuations were failed and empyemas were reaccumulated in all 3, probably due to insufficient evacuation. In such cases, iUS provides advantages for empyema aspiration given that it allows clear visualization of volume reduction, ensuring near-total evacuation with a catheter through a single burr hole (Figure 4 and Video).

Ultrasound-guided biopsy provides intraoperative real-time visualization, which enables the surgeon to closely monitor the biopsy process, particularly during lesion aspiration. In the current study, two patients with chronic kidney failure could not undergo contrast-enhanced imaging. However, iUS findings (ie, hypo- or hyperechogenicity during ultrasound) confirmed the stereotactic targets and allowed the biopsy to be conducted successfully. A sufficient amount of samples have been obtained via additional freehand biopsy when the sample from the stereotactic target was diagnostically insufficient (Figures 5 and 6, and Video). Additional tools are not needed in this technique, such as Berger's device,[17] as adequately extending the burr hole is sufficient.

Intracerebral hematoma is one of the most common and feared complications of stereotactic biopsy.[29] With iUS guidance, however, the biopsy track and biopsy site can be visualized for fresh hematoma development via the burr hole probe (Figure 6). In fact, one patient included herein developed microhemorrhage during suctioning, for which the procedure was terminated thereafter to avoid further complications. The microhemorrhage was then followed-up via iUS for 10 min before closure to ensure that the hemorrhage did not expand. The iUS therefore provides surgeons with the means to detect iatrogenic hematomas during brain puncture and act accordingly.

Limitations

Like all intraoperative imaging and guidance systems, iUS does have some limitations. Poor bone penetration in adults restricts its use for planning the burr hole site. The burr hole should be extended in ventricular catheter placements in order to fit the iUS probe and send the catheter simultaneously, although only a few millimeters of extension is sufficient. Moreover, air, blood, and metallic tools may disturb the signals. Besides, resolution can be reduced for deeper targets, and fluid-filled operative sites which is necessary for visualization, may not always be possible. A temporary loss of visualization can also occur during the cannulation, although the catheter can still be successfully placed inside the ventricle given that the trajectory had already been established before advancement. Moreover, the catheter's position can be assessed following the placement. The use of iUS requires expertise and knowledge of certain landmarks and neuroanatomical structures. During ventricular catheter placement, surgeons should recognize certain landmarks, such as the falx, choroid plexus, and ventricles. Locating the choroid plexus, for instance, is especially important for targeting the frontal horn and avoiding proximity between the catheter tip and the choroid plexus, thereby providing longer shunt survival.[19] Despite the required anatomical knowledge, the technique itself is quite easy to pick-up and master. In this series, for instance, all the procedures were successfully performed by the first author who had no prior ultrasound-guided puncture experience.

For cannulation of normal-sized ventricles and ETV guidance, iUS-guided puncture seems to be an ideal alternative to stereotaxy and neuronavigation systems to define trajectories. For interhemispheric empyema aspiration, same good results might also be obtained with conventional or robotic stereotaxy systems with intraoperative CT or MRI, although iUS has the possible advantages of cost effectiveness, ease to perform, shorter duration, and real-time visualization. As for the biopsy use of the technique, one should keep in mind that the accuracy of the free-hand biopsy is not comparable to stereotaxy systems. Also the real-time avoidance of vascular structures may not always be possible with free-hand iUS guidance; hence, the recommendation would be to use iUS as an assistive device to stereotaxy for real-time visualization of biopsy sites.

CONCLUSION

iUS is an invaluable guidance system for brain punctures given its capability for real-time imaging. It can be easily and safely employed for cannulation of normal-sized ventricles, ETV guidance, evacuation of interhemispheric empyema, and stereotactic biopsy assistance.

Funding

This study did not receive any funding or financial support.

Downloaded from https://academic.oup.com/ons/advance-article/doi/10.1093/ons/opab330/6384798 by Istanbul University Library user on 01 November 2021

Disclosures

The authors have no personal, financial, or institutional interest in any of the drugs, materials, or devices described in this article.

REFERENCES

1. Mahboob S, McPhillips R, Qiu Z, et al. Intraoperative ultrasound-guided resection of gliomas: a meta-analysis and review of the literature. *World Neurosurg*. 2016;92:255-263.
2. Ganau M, Ligarotti GK, Apostolopoulos V. Real-time intraoperative ultrasound in brain surgery: neuronavigation and use of contrast-enhanced image fusion. *Quant Imaging Med Surg*. 2019;9(3):350-358.
3. Sastry R, Bi WL, Pieper S, et al. Applications of ultrasound in the resection of brain tumors. *J Neuroimaging*. 2017;27(1):5-15.
4. Sutcliffe JC. The value of intraoperative ultrasound in neurosurgery. *Br J Neurosurg*. 1991;5(2):169-178.
5. Leu S, Kamenova M, Mariani L, Soleman J. Ultrasound-guided insertion of the ventricular catheter in ventriculoperitoneal shunt surgery: evaluation of accuracy and feasibility in a prospective cohort. *J Neurol Surg A Cent Eur Neurosurg*. 2021;82(1):9-17.
6. Crowley RW, Dumont AS, Asthagiri AR, et al. Intraoperative ultrasound guidance for the placement of permanent ventricular cerebrospinal fluid shunt catheters: a single-center historical cohort study. *World Neurosurg*. 2014;81(2):397-403.
7. Whitehead WE, Riva-Cambrin J, Wellons JC, et al. No significant improvement in the rate of accurate ventricular catheter location using ultrasound-guided CSF shunt insertion: a prospective, controlled study by the Hydrocephalus Clinical Research Network - clinical article. *J Neurosurg Pediatr*. 2013;12(6):565-574.
8. Whitehead WE, Jea A, Vachhrajani S, Kulkarni AV, Drake JM. Accurate placement of cerebrospinal fluid shunt ventricular catheters with real-time ultrasound guidance in older children without patent fontanelles. *J Neurosurg*. 2007;107(5 Suppl):406-410.
9. Manfield JH, Yu KKH. Real-time ultrasound-guided external ventricular drain placement: technical note. *Neurosurg Focus*. 2017;43(5):E5.
10. Yim B, Reid Gooch M, Dalfino JC, Adamo MA, Kenning TJ. Optimizing ventriculoperitoneal shunt placement in the treatment of idiopathic intracranial hypertension: an analysis of neuroendoscopy, frameless stereotaxy, and intraoperative CT. *Neurosurg Focus*. 2016;40(3):E12.
11. Unal TC, Gulsever CI, Sahin D, Dolas I. How I do it: ultrasound-guided placement of Ommaya reservoir in a patient with small ventricles and cavum septum pellucidum. *Acta Neurochir*. 2021;163(3):721-724.
12. Strowitzki M, Schwerdtfeger K, Steudel WI. Ultrasound-guided aspiration of brain abscesses through a single burr hole. *Minim Invasive Neurosurg*. 2001;44(3):135-140.
13. Policicchio D, Doda A, Sgaramella E, Ticca S, Veneziani Santonio F, Boccaletti R. Ultrasound-guided brain surgery: echographic visibility of different pathologies and surgical applications in neurosurgical routine. *Acta Neurochir*. 2018;160(6):1175-1185.
14. Patil AD, Singh V, Sukumar V, Shetty PM, Moiyadi AV. Comparison of outcomes of free-hand 2-dimensional ultrasound-guided versus navigated 3-dimensional ultrasound-guided biopsy for supratentorial tumours: a single-institution experience with 125 cases. *Ultrasonography*. 2019;38(3):255-263.
15. Lunardi P, Acqui M, Maleci A, Di Lorenzo N, Fortuna A. Ultrasound-guided brain biopsy: a personal experience with emphasis on its indication. *Surg Neurol*. 1993;39(2):148-151.
16. Di Lorenzo N, Esposito V, Lunardi P, Delfini R, Fortuna A, Cantore G. A comparison of computerized tomography-guided stereotactic and ultrasound-guided techniques for brain biopsy. *J Neurosurg*. 1991;75(5):763-765.
17. Berger MS. Ultrasound-guided stereotaxic biopsy using a new apparatus. *J Neurosurg*. 1986;65(4):550-554.
18. Reddy GK, Bollam P, Caldito G. Long-term outcomes of ventriculoperitoneal shunt surgery in patients with hydrocephalus. *World Neurosurg*. 2014;81(2):404-410.
19. Dobran M, Nasi D, Mancini F, et al. Relationship between the location of the ventricular catheter tip and the ventriculoperitoneal shunt malfunction. *Clin Neurol Neurosurg*. 2018;175:50-53.
20. Yamada SM, Kitagawa R, Teramoto A. Relationship of the location of the ventricular catheter tip and function of the ventriculoperitoneal shunt. *J Clin Neurosci*. 2013;20(1):99-101.
21. Nesvick CL, Khan NR, Mehta GU, Klimo P. Image guidance in ventricular cerebrospinal fluid shunt catheter placement: a systematic review and meta-analysis. *Neurosurgery*. 2015;77(3):321-331; discussion 331.
22. Wilson TJ, Stetler WR, Al-Holou WN, Sullivan SE. Comparison of the accuracy of ventricular catheter placement using freehand placement, ultrasonic guidance, and stereotactic neuronavigation: clinical article. *J Neurosurg*. 2013;119(1):66-70.
23. Di Somma A, Narros Gimenez JL, Almarcha Bethencourt JM, Cavallo LM, Márquez-Rivas J. Neuroendoscopic intraoperative ultrasound-guided technique for biopsy of paraventricular tumors. *World Neurosurg*. 2019;122:441-450.
24. Rohde V, Behm T, Ludwig H, Wachter D. The role of neuronavigation in intracranial endoscopic procedures. *Neurosurg Rev*. 2012;35(3):351-358.
25. Hermann EJ, Esmaeilzadeh M, Ertl P, Polemikos M, Raab P, Krauss JK. Endoscopic intracranial surgery enhanced by electromagnetic-guided neuronavigation in children. *Childs Nerv Syst*. 2015;31(8):1327-1333.
26. Brouwer MC, Tunkel AR, McKhann GM, van de Beek D. Brain abscess. *N Engl J Med*. 2014;371(5):447-456.
27. Yüksel MO, Gürbüz MS, Karaarslan N, Caliskan T. Rapidly progressing interhemispheric subdural empyema showing a three-fold increase in size within 12 hours: case report. *Surg Neurol Int*. 2016;7(Suppl 37):S872-S875.
28. Salunke PS, Malik V, Kovai P, Mukherjee KK. Falcotentorial subdural empyema: analysis of 10 cases. *Acta Neurochir*. 2011;153(1):164-170.
29. Field M, Witham TF, Flickinger JC, Kondziolka D, Lunsford LD. Comprehensive assessment of hemorrhage risks and outcomes after stereotactic brain biopsy. *J Neurosurg*. 2001;94(4):545-551.

Downloaded from https://academic.oup.com/ons/advance-article/doi/10.1093/ons/opab330/6384798 by Istanbul University Library user on 01 November 2021