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An International Course on Intraoperative Ultrasound in Neurosurgery: Evaluation of a Multicenter, Hands-On Course in Promoting Familiarity and Use of Intraoperative Ultrasound in Neurosurgery

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■ OBJECTIVE: **Intraoperative ultrasound (ioUS) is a real-time imaging tool with the potential to improve neurosurgical outcomes; however, its adoption is hindered by the need for specialized training. Structured educational programs have been successful in improving proficiency and promoting their utility. This study evaluated the impact of an international ioUS training course on participants' familiarity, comfort, and ability to apply ioUS in routine neurosurgical procedures.**

■ METHODS: **Twenty-one ioUS courses were held across 12 countries (brainultrasound.org), featuring lectures, simulations, and hands-on training sessions. The curriculum covered ultrasound physics, artifacts, tumor characterization, 3-dimensional navigated ultrasound, and ioUS-guided procedures. Precourse and postcourse surveys were administered at 4 courses—Cape Town (December 2023), Edinburgh (January 2024), Barcelona (April 2024), and Porto (May 2024)—to assess changes in knowledge and comfort.**

■ RESULTS: **Sixty-seven neurosurgeons and residents participated (19 in Cape Town, 20 in Edinburgh, 16 in Barcelona, and 12 in Porto), with a 100% survey response rate. The median scores improved for familiarity with ioUS (4—8), comfort with its functionality (4—7), probe selection (4—8), image acquisition (4—8), and interpretation (4—8). Comfort in ioUS-guided procedures improved for ventricular catheter insertion (3—7), endoscopy (3—6), tumor resection (4—7), and Chiari I decompression (3—6). Participants reported a median likelihood of 9 (of 10) for using ioUS in future practice.**

■ CONCLUSIONS: **The course significantly improved the participants' confidence and skills in performing ioUS. Structured training effectively bridges knowledge gaps and supports the broader adoption of ioUS in neurosurgical practice.**

Key words
- Global neurosurgery
- Hands-on training
- Image-guided surgery
- Intraoperative ultrasound
- Neurosurgical education
- Surgical simulation
- Tumor resection

Abbreviations and Acronyms
3D: 3-dimensional
CEUS: Contrast-enhanced ultrasound
CT: Computed tomography
EOR: Extent of resection
ioMRI: Intraoperative magnetic resonance imaging
ioUS: Intraoperative ultrasound
IQR: Interquartile range
MRI: Magnetic resonance imaging
US: Ultrasound

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INTRODUCTION

History of Ultrasound

Ultrasound (US) is widely used in medicine for both diagnostic and therapeutic procedures due to its diagnostic capabilities and ease of use. While the skull has limited intracranial US, neurosurgical procedures provide a unique opportunity to leverage the acoustic window provided by craniotomy and allow for the use of intraoperative ultrasound (ioUS) to visualize neural structures and enhance surgical decision-making in real-time.[1,2]

The use of US in neurosurgery was first reported in the 1950s, when A-mode was used to detect brain tumors in excised tissue or postmortem analysis. In the 1960s, A-mode US was used for intraoperative imaging through transdural encephalography with US probes applied to the dura mater during craniotomy to detect and localize subcortical lesions during surgery. Later, the B mode was introduced to simplify imaging interpretation and is now the most frequently used mode in neurosurgery. More advanced US techniques, such as Doppler imaging, contrast-enhanced ultrasound (CEUS), elastosonography, and navigated ioUS, enable multiparametric imaging.[3,4]

Ultrasound in Neurosurgery

Neurosurgical ioUS is used to identify anatomy, brain lesions, intraparenchymal hemorrhage, ventricles, abscess, and assess for the extent of resection (EOR).[2,5,6] Intraoperatively, brain shift affects the accuracy of neuronavigation based on preoperative or static intraoperative imaging. Thus, ioUS provides an opportunity to improve real-time assessment when compared to intraoperative magnetic resonance imaging (ioMRI) or intraoperative computed tomography (CT).[7–9] Moreover, the widespread use of ioMRI is limited by economic barriers and requires significant infrastructure. The ideal intraoperative imaging and navigation modality is accurate, real-time, cost-effective, and user-friendly.[2,3,10–16]

IoUS is a cost-effective imaging modality for intraoperative evaluation of the EOR and has several advantages over ioMRI and intraoperative CT, including immediate, real-time image acquisition capabilities,[16] portability, less interruption to the surgical workflow,[17] user-friendliness, relatively low cost,[16–20] non-invasiveness,[21] lack of ionizing radiation,[22] and intraoperative repeatability.[15,16] US is readily available[23] and has a shorter acquisition time than CT. The real-time imaging capabilities of ioUS can be used throughout surgery without delay.[8,9,17] Despite these advantages, the use of ioUS has been limited.[3,24] Unfamiliarity with ioUS imaging with nontraditional imaging planes has learning curves that are different from traditional axial, coronal, and sagittal imaging on neuronavigation systems.[25,26] Programs that provide education and hands-on training in ioUS techniques are needed to promote the intraoperative adoption of ioUS.

Objective

The International Intraoperative Ultrasound in Neurosurgery Group consists of 8 neurosurgeons who provide education and hands-on training through single-day or 2-day courses. This study sought to evaluate the utility and impact of the International Intraoperative Ultrasound in Neurosurgery course on participants' familiarity and comfort with the functionality of the ioUS device, image acquisition and interpretation, its use in several common neurosurgical techniques, and the likelihood of adoption into their future practice after course attendance.

METHODS

The International Course

A total of 21 courses were hosted across 12 countries (Figure 1A). This study reports on the participants' evaluations of the last 4 courses hosted in Cape Town, South Africa from December 4, 2023—December 8, 2023; Edinburgh, United Kingdom held on January 27, 2024 (Figure 1B); Barcelona, Spain held from April 18, 2024—April 19, 2024; and Porto, Portugal from May 7, 2024—May 8, 2024. The courses are held over either one day (Cape Town, Edinburgh) or 2 days (Barcelona, Porto) and comprise multiple sessions (Figure 2), including live surgery transmitted to the lecture room in the 2-day course.

The course objectives were as follows: enhance the understanding of the basic principles of US; apply these principles to the optimal acquisition of intraoperative 2-dimensional US images, reduction of common artifacts, and improvement of high-quality diagnostic US images; orientation in neuronavigated US; differentiation between the most common subtypes of brain tumors; coregistration of images (magnetic resonance imaging [MRI]/US); tractography and segmentation in neuronavigated US; evaluation of residual tumor in the operating room; use of navigated instruments in 3-dimensional (3D) US volumes; application of CEUS and elastography in brain tumors; and guided puncture with neuronavigated US (biopsies, ventricular punctures). Description of example tasks performed in the course is outlined in Table 1.

For the hands-on activity, 4 to 7 US machines and different phantoms were available. To increase practical learning, we had a preferred upper limit of 5 participants per machine. The simulation activity during the course was conducted via the Neurostream platform using the participants' smartphones (Figure 3). This Internet platform allows every registered user to interact with other users to organize webinars, discuss clinical cases, and rehearse the library of neurosurgical operations where 3D ioUS data were acquired and matched with preoperative MRI data. Using the phone's accelerometer, the device acts as a virtual US probe connected to the Neurostream website. Within the simulation, participants were prompted with a series of assessment questions aimed at identifying key anatomical components visible on US images.[27]

Course Participant Presurveys and Postsurveys

An anonymized precourse and postcourse survey containing 10 questions was administered to trainees and qualified neurosurgeons at the beginning of the course (presurvey) and the end of the course (postsurvey). The surveys were administered in English, as the course was conducted in English across all sites. All sites listed of workshop participants had a basic understanding of English. The survey was designed by the faculty neurosurgeons of the course. It assessed each participant's familiarity with ioUS

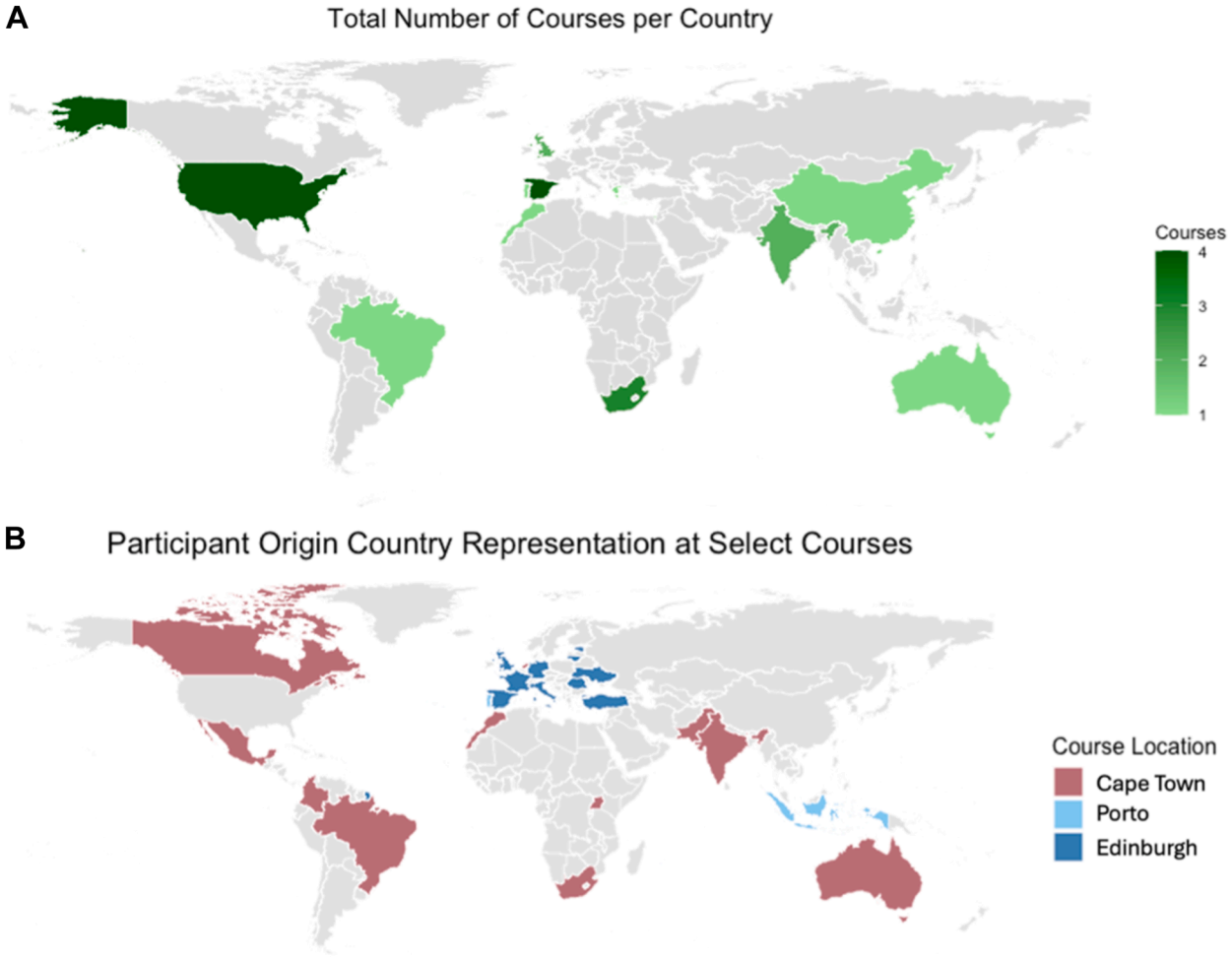

Figure 1. Countries participating in the International ioUS course. (**A**) Overall, there have been a total of 21 courses held across the world, including Australia (1 course); Boston, Massachusetts, USA (1); Brazil (1); China (1); Deer Valley, Utah (1); Edinburgh, United Kingdom (1); Thessaloniki, Greece (1); India (2); Israel (1); Morocco (1); Porto, Portugal (1); San Francisco, California, USA (1); Scotland, United Kingdom (1); Cape Town, South Africa (3); Spain (4); and Salt Lake City, Utah, USA (1). (**B**) For country-of-origin representation at selected courses: At the Cape Town course demonstrated in red, there were 19 participants (11 qualified neurosurgeons and 8 trainees) and 13 countries represented. At the Porto course demonstrated in light blue, there were 12 participants, and 10 countries represented. Training status was not collected at the Porto course. At the Edinburgh course demonstrated in dark blue, there were 20 participants (2 qualified neurosurgeons and 14 trainees; 4 participants' training level was unknown) and 10 countries represented. There were 16 participants at the Barcelona course (not demonstrated). Training status and geographic location were not collected for the Barcelona courses. ioUS, intraoperative ultrasound.

and their comfort in multiple domains of ioUS, including the functionality and settings of the machine, probe function and selection, principles of US image acquisition, and principles of US image interpretation. Moreover, participants ranked their comfort level in using ioUS guidance for several procedures, including ventricular catheter insertion, endoscopic procedures, tumor resections, and Chiari I decompression. Finally, respondents were asked about their likelihood of adopting ioUS in their future practice. Participants' responses were based on a 10-point scale. The presurveys and postsurveys were identical. Institutional review board approval and patient consent were not required, as this study did not include patients.

Statistical Methods

Surveys were distributed to the participants before and after the course. The results were analyzed using the Wilcoxon matched-pairs signed-rank test in GraphPad Prism 10 (San Diego, California, USA). P value significance was set at $P < 0.05$.

RESULTS

Course Participants

Precourse Survey. The precourse survey had a response rate of 67 of 67 (100%) participants across all courses. There were deficiencies in knowledge and comfort among participants

Programme:

Intra-operative Ultrasound and Imaging in Brain Tumor Surgery Workshop

Date: 4 December 2023

Time: 08h00 -16h00

08h00 – 08h20 Registration

08h20 – 08h30 Introduction to course

08h30 – 08h50 Basic principles, sonographic anatomy, and indications for IOUS in Neurosurgery

08h50 – 09h30 Hands-on: Basic functionality of machine settings

09h30 – 09h50 Imaging in Brain Tumors

09h50 – 10h10 Advanced MRI Techniques for planning in Brain Tumor Surgery

10h10 – 10h30 IOUS in glioma surgery

10h30 – 10h50 Navigated and 3D Ultrasound

10h50 – 11h10 ***Tea Break***

11h10 – 11h30 Ultrasound for non-invasive assessment of ICP

11h30 – 11h50 IOUS in hydrocephalus, craniosynostosis and neuroendoscopy

11h10 – 11h30 Multiparametric IOUS imaging

11h50 – 12h10 Advances in ultrasound-based navigation

12h10 – 12h30 Discussion and feedback

12h30 – 13h30 ***Lunch***

13h30 – 16h00 Hands-on session (all faculty)

Figure 2. Course program example for one day. The agenda outlines the structure of a single-day international course held on December 4, 2023, focused on the use of intraoperative ultrasound (ioUS) in neurosurgery. The course includes a mix of didactic sessions and hands-on training, covering ultrasound principles, imaging applications in brain tumors, advanced MRI techniques, 3D ultrasound, and ultrasound-based navigation. Dedicated sessions at this specific event address ioUS in hydrocephalus and endoscopy, as well as multiparametric imaging and assessment of intracranial pressure. The program concludes with a faculty-led simulation session emphasizing practical skill acquisition. MRI, magnetic resonance imaging; 3D, 3-dimensional; ioUS, intraoperative ultrasound.

Table 1. Example Descriptions of Course Tasks

Example Course Tasks	Description of Example Tasks
Basic use of ultrasound and knobology	Knobology refers to the knowledgeable use of the ultrasound equipment to optimize image settings such as finer adjustments to the depth and gain. This allows the user to gain familiarity of the ultrasound machine and its components such as the monitor, the right transducer, the image quality, depth penetration, zoom, resolution, focal zone, freeze function, etc. Participants practiced adjusting depth, gain, and focal zones while observing changes during real-time on the screen, gaining hands-on familiarity with each control.
Optic Nerve Sheath Diameter (ONSD) demonstration	To start measuring the ONSD, the optic nerve has to be located by means of ultrasound. Once the optic nerve has been located, a vertical line is drawn along the optic nerve from the midpoint of the optic disc. A perpendicular line is drawn 3 mm down the vertical line along the optic nerve from the midpoint. The ONSD measurement is deduced by the distance of the 2 points along the perpendicular line that demarcates the outer wall of the optic nerve sheath.
Image interpretation of implanted models	Ultrasound appearances allow for analysis and interpretation of whether a mass can be characterized as hard or soft tissue tumors based on echogenicity and borders. Localization of the various brain model lesions by identifying its borders.
Ventricular catheter placement	The use of real-time ultrasound images allow for a successful single placement attempt with correct positioning of the ventricular catheter tip with higher accuracy. Each brain model was implanted with a lesion and neurosurgeons use both the ultrasound-guided imaging and the catheter to ensure the correct positioning.
Aspiration of brain model lesion	Each brain model has lesions that may be aspirated as they are localized using ultrasound and undergo aspiration as it allows.

regarding the use of ioUS. Specifically, 70% of participants reported a level of familiarity of "5 or below" on the use of ioUS in neurosurgery prior to commencement of the course, 78% had a comfort of "5 or below" on using the basic functionality and settings of an US machine, and 78% expressed a comfort level of "5 or below" with probe function and selection. There were 70% and 75% of the participants reported a level of "5 or below" when asked about their comfort in US image acquisition and interpretation, respectively. Furthermore, for before preforming the simulation assessments, 84% reported comfort level of "5 or below" using ioUS-guided ventricular catheter insertion, 95% reported comfort level of "5 or below" using ioUS-guided endoscopic procedures, 72% reported comfort level of "5 or below" using ioUS-guided tumor resection, and 93% reported comfort level of "5 or below" using ioUS-guided Chiari I decompression.

Postcourse Survey. The postcourse survey had a response rate of 67 of 67 (100%) participants. Knowledge significantly increased in postcourse surveys compared to precourse surveys regarding the familiarity of ioUS use in neurosurgery (precourse median = 4, interquartile range [IQR]: 2–6; postcourse median = 8, IQR: 7–9). Participant comfort significantly increased in the areas of ioUS functionality (precourse median = 4, IQR: 2–5.5; postcourse median = 8, IQR: 6–9), probe function and selection (precourse median = 4, IQR: 2–6; postcourse median = 8, IQR: 7–9), ioUS image acquisition (precourse median = 4, IQR: 2.5–6; postcourse median = 8, IQR: 7–8.75), and ioUS image interpretation (precourse median = 4, IQR: 3–6; postcourse median = 8, IQR: 7–8) (**Figure 4**). For the simulation assessments, participant comfort in using ioUS to guide procedures significantly increased for ventricular catheter insertion (precourse median = 3, IQR: 2–5; postcourse median = 8, IQR: 6–9), endoscopic procedures (precourse median = 3, IQR: 1–4; postcourse median = 7, IQR: 5–8), tumor resection (precourse median = 4, IQR: 2–6; postcourse median = 8, IQR: 60.5–9), and Chiari I decompression (precourse median = 2, IQR: 1–4; postcourse median = 6, IQR: 5–8). Participants reported a median score of 9 for how likely they were to use ioUS in their neurosurgery practice after the course (precourse median = 5, IQR: 2.5–8; postcourse median = 9, IQR: 8–10) (**Figure 5**; **Table 2**). The postsurvey results for each course location are compiled in **Supplementary Table 1**.

Precourse and Postcourse Survey Responses Based on Training Status

To evaluate the effectiveness of the course based on training status, we investigated the presurvey and postsurvey responses from the Cape Town and Edinburgh courses between participants who were "trainees" and those who were "qualified neurosurgeons." There were 4 participants whose training status was unknown, and their responses were excluded from this subanalysis. Training status was not collected at the Barcelona or Porto courses, and all participants were not included in this subanalysis. **Table 3** shows the combined results based on participants' training status.

DISCUSSION

The use of ioUS has increased in neurosurgery owing to advances in its technological capabilities. However, adoption remains limited because of nontraditional imaging planes (axial, coronal, and sagittal) and unfamiliarity with US imaging. To address these barriers, the International Team for Intraoperative Ultrasound in Neurosurgery developed courses that provide educational didactics and hands-on simulations. Precourse assessments revealed significant gaps in participants' familiarity and comfort with ioUS functionality, probe selection, image acquisition, interpretation, and intraoperative use. Postcourse, participants reported significant increases in familiarity and comfort across all domains, irrespective of training level, and a high likelihood of incorporating ioUS into practice. These results highlight the value of structured training programs in bridging knowledge gaps and improving skills in advanced surgical techniques.

Figure 3. Course components, set-up, and participants. (**A**) The simulation activities were conducted via the Neurostream platform on participants' smartphones. Using the phone's accelerometer, the device acts as a virtual ultrasound probe, connected to the Neurostream website. Within the simulation, participants are prompted with a series of assessment questions aimed at identifying key anatomical components visible on ultrasound images. (**B**) Cranial molds used for simulations. (**C**) Cranial mold storage during the course. (**D**) Simulation activities using participants' smartphones. (**E**) Example images of MRI/ultrasound. (**F**) Example images of ultrasound. (**G**) Instructors and participants at one course. MRI, magnetic resonance imaging.

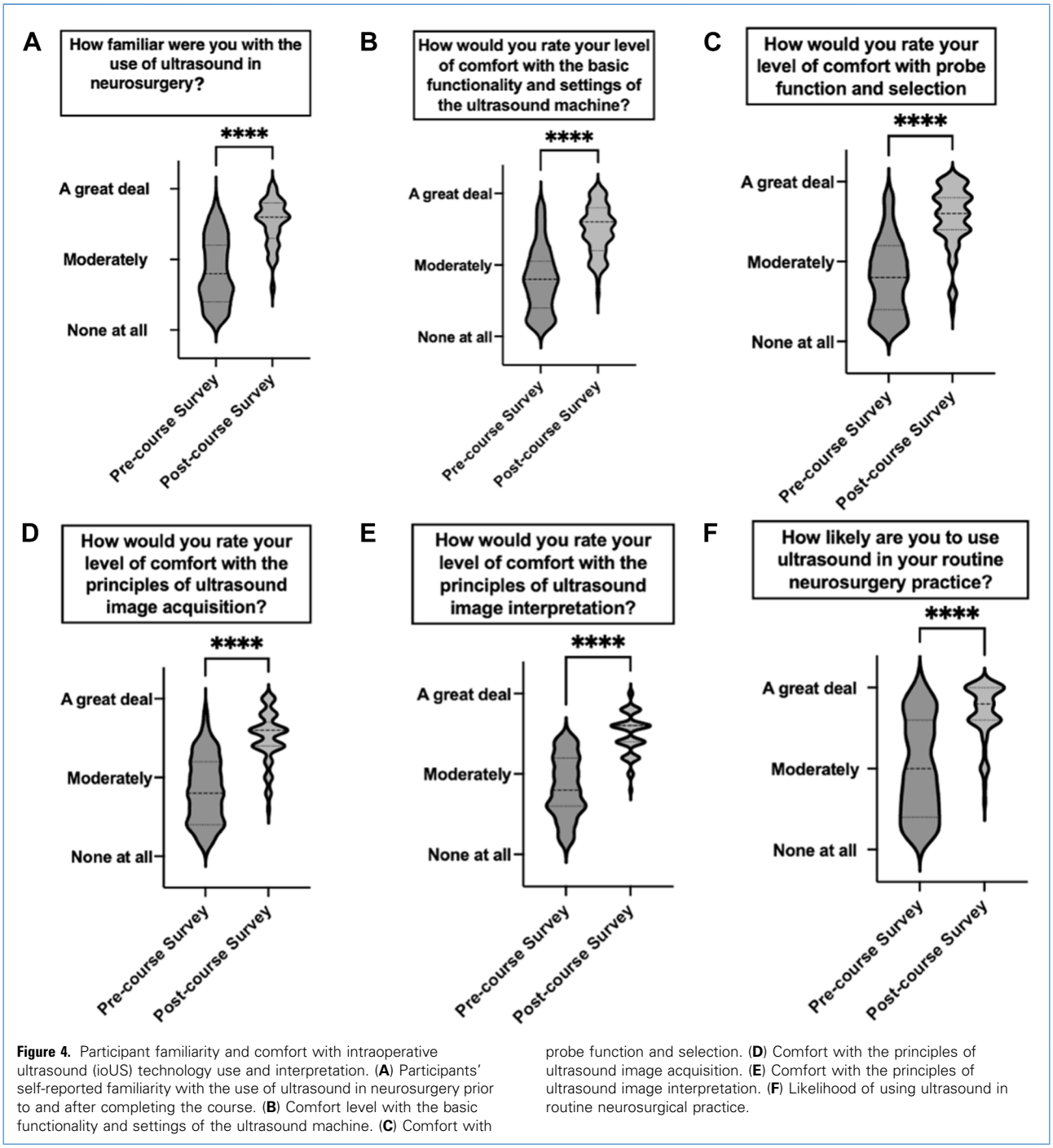

Figure 4. Participant familiarity and comfort with intraoperative ultrasound (ioUS) technology use and interpretation. (**A**) Participants' self-reported familiarity with the use of ultrasound in neurosurgery prior to and after completing the course. (**B**) Comfort level with the basic functionality and settings of the ultrasound machine. (**C**) Comfort with probe function and selection. (**D**) Comfort with the principles of ultrasound image acquisition. (**E**) Comfort with the principles of ultrasound image interpretation. (**F**) Likelihood of using ultrasound in routine neurosurgical practice.

Significance of ioUS in Neurosurgery

Intraoperative imaging is a fundamental tool for maximizing tumor resection and improving patient outcomes.[28,29] As a modality, ioUS offers a flexible, reproducible, and low-impact method for point-of-care imaging to provide surgeons with an accurate, real-time evaluation of the surgical area. The implementation of ioUS has been shown to correlate with improved EOR, progression-free survival, and overall survival.[10,30–33] These benefits have been observed in supratentorial low-grade gliomas, deep high-grade gliomas, intraventricular lesions,[34] vascular lesions including arteriovenous malformations,[35] and intramedullary and extramedullary spinal

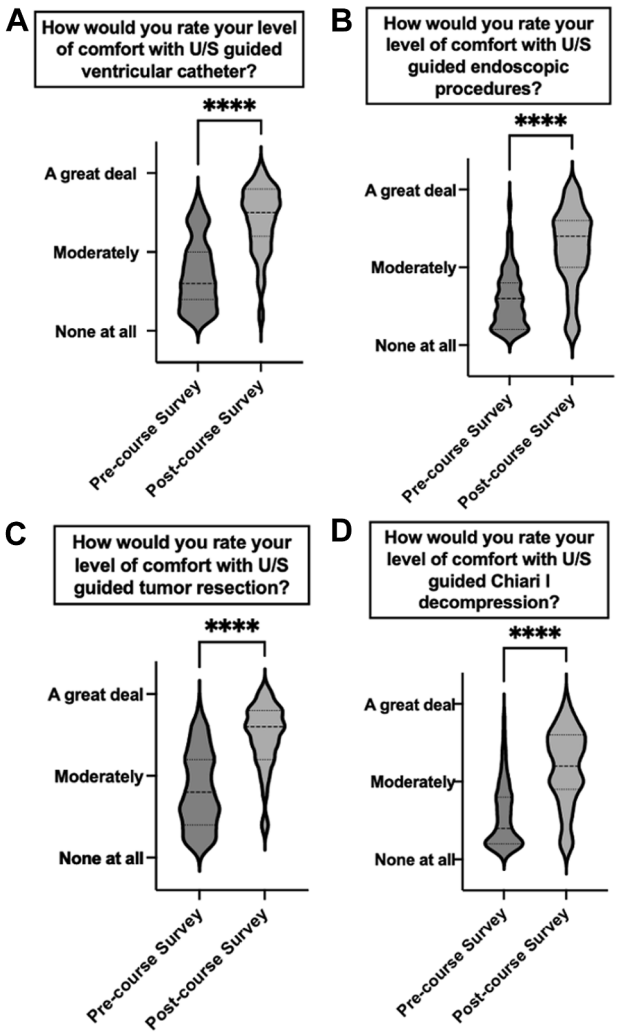

Figure 5. Participant comfort using intraoperative ultrasound (ioUS) during neurosurgical procedures. Specifically, ioUS-guided (**A**) ventricular catheter, (**B**) endoscopic procedures, (**C**) tumor resection, and (**D**) Chiari I decompression.

lesions.[36] A further advantage of ioUS is its applicability to the broad range of procedures that a neurosurgeon may be required to perform. Prior studies have demonstrated that ioUS improves both the accuracy of placement and clinical outcomes of patients during ventricular catheter insertion, including external ventricular drains and ventriculoperitoneal shunts.[37,38] It is also valuable in endoscopic procedures,[39] monitoring cerebrospinal fluid flow, and tailoring approaches to Chiari I decompression.[40,41]

IoUS provides valuable contributions in trauma settings, particularly due to its high sensitivity to fluid and its direction of flow within the skull and spinal cord.[42] This sensitivity facilitates effective detection of intraparenchymal hemorrhages. Moreover, ioUS allows differentiation of lesions based on echogenicity and their interaction with surrounding brain structures, spinal structures, and vessels.[43]

In spinal tumor assessment, ioUS can characterize and localize lesions, guiding the evaluation of tumor extent, surgical planning, and intraoperative decision-making. Real-time imaging further enhances its utility, enabling clinicians to assess the completeness of tumor resection, hematoma evacuation, or decompression.[44] For spine decompression specifically, ioUS monitoring can detect spinal cord motion and cerebrospinal fluid pulsation as an indirect marker of residual compression.[45] In addition, ioUS facilitates visualization of the ventral space anterior to the spinal cord, ensuring adequate decompression.[46]

Therefore, ioUS extends beyond trauma applications and serves as a versatile tool in the intraoperative assessment of brain and spinal pathologies. In addition to improving intraoperative decision-making, prior studies have demonstrated that the use of ioUS is associated with higher rates of gross total resection in tumor resection which correlates with improved progression-free and overall survival outcomes in glioma and pediatric tumor surgery, underscoring its role as a clinically meaningful adjunct in tumor resections.[10,30,33]

In this study, we investigated the participants' familiarity with the use of ioUS for these procedures. The majority reported low comfort levels in using ioUS for any neurosurgical procedure, with lower reported confidence for ioUS-guided endoscopic procedures (5% with $\geq$ 5 of 10 comfort), Chiari I decompression (10%), and ventricular catheter insertion (18%) than for tumor resection (28%). Following the course, participants reported a significant increase in comfort levels for all procedure types tested. The procedures with the largest increases in comfort level among participants were ventricular catheter insertion, endoscopic procedures, and tumor resection. Notably, participants gained the least comfort when using ioUS to perform Chiari I decompression. This may reflect a need to improve the Chiari I decompression curriculum of the course, a lack of participants' prior exposure to Chiari I decompression in their clinical practice, or a combination of these factors.

The primary drawbacks of ioUS are its perceived steep learning curve and the challenge of interpreting images. To address these issues, there is a clear necessity for education and hands-on training in ioUS techniques within the neurosurgical field. Improvements in participants' confidence in using ioUS following a relatively short training session is an encouraging sign that similar educational sessions may lead to the increased utilization of ioUS.

Use of Didactics, Simulations, and Interactive Training Tools in Neurosurgical Education

Building an effective surgical curriculum is complicated by the need for education programs to enable learners to build expertise across multiple domains of both specialty-specific clinical knowledge and reasoning, as well as independence and proficiency in technical skills. In recent years, the use of courses that integrate didactic sessions with hands-on simulation components has become increasingly popular, as this hybrid course structure allows for the structured delivery of theoretical clinical knowledge alongside the practice of hands-on skills needed for technical proficiency.[47,48]

Table 2. Participant Survey Data

Question	Median Precourse Score (IQR) (1–10)	Median Postcourse Score (IQR) (1–10)	*P* Value
Familiarity based on a 10-point scale			
How familiar were you with the use of ultrasound in neurosurgery prior to the course?	4 (2–6)	8 (7–8)	<0.0001
Comfortableness of ultrasound functionality based on a 10-point scale			
How would you rate your level of comfort with the basic functionality and settings of the ultrasound machine?	4 (2–5.5)	7.5 (6–8.5)	<0.0001
How would you rate your level of comfort with probe function and selection	4 (2–6)	8 (6.5–9)	<0.0001
How would you rate your level of comfort with the principles of ultrasound image acquisition?	4 (3–6)	7.5 (7–8.5)	<0.0001
How would you rate your level of comfort with the principles of ultrasound image interpretation?	4 (3–6)	7.5 (7–8.5)	<0.0001
Comfortableness of using ultrasound for specific procedures based on a 10-point scale			
How would you rate your level of comfort with US-guided ventricular catheter insertion?	3 (1.5–5)	7 (6.5–8)	<0.0001
How would you rate your level of comfort with US-guided endoscopic procedures?	2.5 (1.5–4)	7 (5–8)	<0.0001
How would you rate your level of comfort with US-guided tumor resection?	3.5 (2–5.5)	7 (6–9)	<0.0001
How would you rate your level of comfort with US-guided Chiari I decompression?	2 (1.5–4)	5.5 (4–7)	<0.0001
Beliefs regarding future adoption of ioUS based on a 10-point scale			
How likely are you to use ultrasound in your routine neurosurgery practice?	4.5 (2–8)	8.5 (7.5–10)	<0.0001

Median precourse and postcourse scores (IQR) are presented for participants' self-reported familiarity and comfort with intraoperative ultrasound (ioUS), including basic ultrasound functionality, image acquisition and interpretation, and use in specific neurosurgical procedures. Participants rated each domain on a 10-point Likert scale. Statistically significant improvements were observed across all categories following course completion (Wilcoxon matched-pairs signed-rank test, $P < 0.0001$ for all comparisons).

IQR, interquartile range; US, ultrasound; ioUS, intraoperative ultrasound.

Neurosurgical didactics, which typically involve lectures, presentations, and case-based interactive sessions, aim to provide learners with a foundational understanding and context for their clinical practice, often covering a wide range of topics, including anatomy, pathology, surgical techniques, and perioperative patient management. Complementing the clinical knowledge developed through didactics, simulation courses aim to ensure patient safety while providing learners with hands-on experiences where they can practice surgical procedures using nonliving, biologically, or anatomically plausible models, including 3D-printed models, virtual reality platforms, or cadaveric specimens. Although cadaveric specimens have long been the gold-standard model for surgical simulation courses owing to their anatomic fidelity, these models are becoming increasingly less available across institutions, warranting the need for different models that can provide similar visual and haptic feedback while maintaining a high degree of anatomical validity. Many noncadaveric models, whether physical or virtual-reality-based, allow repeated practice of technical skills while providing objective metrics that track performance trajectory.

In addition, interactive mobile-based tools have been developed to simulate the use of ioUS imaging for neurosurgical training. For example, Neurosteam was used in these courses and was developed as a dedicated application that can simulate an US probe in anonymized, patient-specific cases of central nervous system tumors, including gliomas, metastases, and meningiomas. This application-based approach allowed trainees to familiarize themselves with ioUS imaging as well as the semiotics of ioUS in a controlled, repeatable format on real patient cases with 3D US images matched and paired to preoperative MRIs.[27] This approach facilitates accurate and safe interpretation of ioUS data outside the operating room. This enables users to correctly identify both normal and pathological anatomical landmarks. The integration of didactics with hands-on simulation and interactive tools to practice neurosurgical techniques provides learners with tactile feedback to refine their skillsets, reinforce their core technical knowledge, and reduce medical errors in the operating room.

The International ioUS Course

To date, the ioUS course has been held 21 times across 12 countries. In our course, we delivered focused lectures on the basic principles, indications, and applications of ioUS; the use of ioUS in planning for and resecting specific types of tumors; and targeted lessons on the role of ioUS in endoscopic, ventricular catheter insertion, and Chiari I decompression, which comprised half of the day (4 hours). The lectures were interspersed with 4 hours of hands-on learning time, during which the participants

Table 3. Presurvey and Postsurvey Results by Training Status

Question	Median Precourse Score (IQR) (1–10)			Median Postcourse Score (IQR) (1–10)		
	Trainee	Qualified Neurosurgeon	*P* Value	Trainee	Qualified Neurosurgeon	*P* Value
Familiarity based on a 10-point scale						
How familiar were you with the use of ultrasound in neurosurgery?	4 (3–6)	7 (6–8)	0.35	4 (3–7)	9 (8–9)	0.24
Comfortableness of ultrasound functionality based on a 10-point scale						
How would you rate your level of comfort with the basic functionality and settings of the ultrasound machine?	4 (3–5)	6.5 (5–7.75)	0.82	4 (2–6)	8 (8–10)	0.06
How would you rate your level of comfort with probe function and selection	4 (3–6)	5 (3–6)	0.96	7 (6–8.75)	9 (8–10)	0.03
How would you rate your level of comfort with the principles of ultrasound image acquisition?	4 (3.25–5.75)	5 (2–6)	0.51	7.5 (6–8.75)	8 (8–10)	0.08
How would you rate your level of comfort with the principles of ultrasound image interpretation?	5 (3.25–6)	4 (3–5)	0.44	7 (6.25–8)	8 (7–8)	0.27
Comfortableness of using ultrasound for specific procedures based on a 10-point scale						
How would you rate your level of comfort with US-guided ventricular catheter insertion?	4 (3–5)	3 (2–5)	0.98	7 (5–8)	9 (8–9)	0.02
How would you rate your level of comfort with US-guided endoscopic procedures?	3 (1–4)	3 (2–4)	0.70	6 (3.25–8)	8 (7–9)	0.02
How would you rate your level of comfort with US-guided tumor resection?	4 (2.25–6)	3 (2–5)	0.81	7 (5.25–8.75)	8 (6–10)	0.22
How would you rate your level of comfort with US-guided Chiari I decompression?	1 (1–4)	2 (2–4)	0.20	5 (3–7)	5 (5–8)	0.22
Beliefs regarding future adoption of ioUS based on a 10-point scale						
How likely are you to use ultrasound in your routine neurosurgery practice?	5 (3–7)	7 (3–9)	0.52	8 (6.25–9.75)	9 (8–10)	0.57

Median precourse and postcourse scores (IQR) are shown for participants stratified by training status (trainee vs. qualified neurosurgeon). Both trainees and qualified neurosurgeons demonstrated significant improvements in postcourse scores, with statistical significance observed in postcourse surveys assessing comfortableness in probe function and selection ($P = 0.03$), ventricular catheter insertion ($P = 0.02$), and endoscopic procedures ($P = 0.02$).

IQR, interquartile range; US, ultrasound; ioUS, intraoperative ultrasound.

applied the techniques under the guidance of an expert. In the Barcelona and Porto courses, live surgeries were transmitted to the lecture room. In our study, the high postcourse likelihood of participants to use ioUS indicates the potential impact of such training on clinical practice and patient care, thus potentially improving patient outcomes.

The curriculum was structured to systematically address familiarity with ventricular catheter placement, tumor resection, endoscopic procedures, and Chiari decompression. We further note that Chiari decompression was integrated into broader lectures rather than addressed in a dedicated session. We now acknowledge this as a likely contributor to the lower postcourse comfort scores for Chiari decompression, and we propose including a focused Chiari module in future course agendas.

Limitations and Future Directions

The group of participants in each course was self-selected; thus, these results may not be generalizable across all neurosurgeons. Furthermore, US imaging modalities such as Doppler, CEUS, and elastography were not incorporated in simulators or phantoms, limiting for the time being the hand-on training mainly to B-mode only. Future studies should explore the retention of technical knowledge over time after course training and how participants have adopted ioUS into their practice since the course.

CONCLUSIONS

IoUS is a real-time imaging modality that has been shown to significantly improve neurosurgical outcomes. Despite its potential, its adoption rate is low because it relied on operator skill.

Nevertheless, there is a growing motivation to expand the integration of ioUS into neurosurgical practice given its global accessibility, lower impact than alternative modalities, and potential for higher-quality imaging with proper training. Participants expressed increased familiarity with and improved ability to employ ioUS for common neurosurgical procedures after the hands-on course. This study underscores the significant role of structured educational courses in addressing knowledge gaps and enhancing aptitude for integrating ioUS into the neurosurgical armamentarium.

CRediT AUTHORSHIP CONTRIBUTION STATEMENT

Mercy H. Mazurek: Writing — review & editing, Writing — original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Mohamed J. Bassa:** Writing — review & editing, Writing — original draft, Data curation. **Llewellyn Padayachy:** Writing — review & editing, Visualization, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Data curation, Conceptualization. **Ethan A. Wetzel:** Writing — review & editing, Writing — original draft, Data curation. **Aliasgar Moiyadi:** Writing — review & editing, Supervision. **Alessandro Perin:** Writing — review & editing, Supervision. **Cristian de Quintana:** Writing — review & editing, Supervision. **Francesco Prada:** Writing — review & editing, Supervision. **Brian V. Nahed:** Writing — review & editing, Writing — original draft, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Conceptualization. **Francesco DiMeco:** Writing — review & editing, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Data curation, Conceptualization. **Geirmund Unsgård:** Writing — review & editing, Visualization, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Data curation, Conceptualization.

REFERENCES

1. Perkins A, Liu G. Primary brain tumors in adults: diagnosis and treatment. *Am Fam Physician*. 2016; 93:211-217.
2. Giammalva GR, Ferini G, Musso S, et al. Intraoperative ultrasound: emerging technology and novel applications in brain tumor surgery. *Front Oncol*. 2022;12:818446.
3. Prada F, Del Bene M, Moiraghi A, et al. From grey Scale B-Mode to elastosonography: multimodal ultrasound imaging in meningioma Surgery—pictorial essay and literature review. *Biomed Res Int*. 2015;2015:925729.
4. Del Bene M, Perin A, Casali C, et al. Advanced ultrasound imaging in glioma surgery: beyond gray-scale B-mode. *Front Oncol*. 2018;8:576.
5. Coppola A, Tramontano V, Basaldella F, Arcaro C, Squintani G, Sala F. Intra-operative neurophysiological mapping and monitoring during brain tumour surgery in children: an update. *Childs Nerv Syst*. 2016;32:1849-1859.
6. Sawlani V, Patel MD, Davies N, et al. Multiparametric MRI: practical approach and pictorial review of a useful tool in the evaluation of brain tumours and tumour-like lesions. *Insights Imaging*. 2020;11:84.
7. Ilunga-Mbuyamba E, Avina-Cervantes JG, Lindner D, Arlt F, Ituna-Yudonago JF, Chalopin C. Patient-specific model-based segmentation of brain tumors in 3D intraoperative ultrasound images. *Int J Comput Assist Radiol Surg*. 2018;13:331-342.
8. Gerard IJ, Kersten-Oertel M, Hall JA, Sirhan D, Collins DL. Brain shift in neuronavigation of brain tumors: an updated review of intra-operative ultrasound applications. *Front Oncol*. 2021;10:618837.
9. Gerard IJ, Kersten-Oertel M, Petrecca K, Sirhan D, Hall JA, Collins DL. Brain shift in neuronavigation of brain tumors: a review. *Med Image Anal*. 2017;35:403-420.
10. Moiraghi A, Prada F, Delaidelli A, et al. Navigated intraoperative 2-Dimensional ultrasound in high-grade glioma surgery: impact on extent of resection and patient outcome. *Oper Neurosurg*. 2020;18: 363.
11. Hervey-Jumper SL, Berger MS. Role of surgical resection in low- and high-grade gliomas. *Curr Treat Options Neurol*. 2014;16(4):284.
12. Unsgaard G, Gronningsaeter A, Ommedal S, Nagelhus Hernes TA. Brain operations guided by real-time two-dimensional ultrasound: new possibilities as a result of improved image quality. *Neurosurgery*. 2002;51:402-411. ; discussion 411-412.
13. Unsgaard G, Ommedal S, Muller T, Gronningsaeter A, Nagelhus Hernes TA. Neuronavigation by intraoperative three-dimensional ultrasound: initial experience during brain tumor resection. *Neurosurgery*. 2002;50:804-812. discussion 812.
14. Unsgaard G, Rygh OM, Selbekk T, et al. Intraoperative 3D ultrasound in neurosurgery. *Acta Neurochir (Wien)*. 2006;148:235-253. discussion 253.
15. Simfukwe K, Iakimov I, Sufianov R, Borba L, Mastronardi L, Shumadalova A. Application of intraoperative ultrasound navigation in neurosurgery. *Front Surg*. 2022;9:900986.
16. Moiyadi A, Shetty P. Objective assessment of utility of intraoperative ultrasound in resection of central nervous system tumors: a cost-effective tool for intraoperative navigation in neurosurgery. *J Neurosci Rural Pract*. 2011;2:4-11.
17. Bø HK, Solheim O, Kvistad KA, et al. Intraoperative 3D ultrasound-guided resection of diffuse low-grade gliomas: radiological and clinical results. *J Neurosurg*. 2020;132:518-529.
18. Goren O, Monteith SJ, Hadani M, Bakon M, Harnof S. Modern intraoperative imaging modalities for the vascular neurosurgeon treating intracerebral hemorrhage. *Neurosurg Focus*. 2013; 34:E2.
19. Ghinda D, Zhang N, Lu J, Yao CJ, Yuan S, Wu JS. Contribution of combined intraoperative electrophysiological investigation with 3-T intraoperative MRI for awake cerebral glioma surgery: comprehensive review of the clinical implications and radiological outcomes. *Neurosurg Focus*. 2016;40: E14.
20. Sacino MF, Ho CY, Murnick J, et al. Intraoperative MRI-guided resection of focal cortical dysplasia in pediatric patients: technique and outcomes. *J Neurosurg Pediatr*. 2016;17:672-678.
21. End-of-Life care in high-grade glioma patients. The Palliat Support Perspective - PMC [Internet]. Available at: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6071221/. Accessed August 23, 2024.
22. Applications of ultrasound in the resection of brain tumors - PubMed [Internet]. Available at: https://pubmed.ncbi.nlm.nih.gov/27541694/. Accessed August 23, 2024.
23. Piezoelectric ceramics and ultrasonic transducers [Internet]. Available at: http://ouci.dntb.gov.ua/en/works/lDzxbAZ7/. Accessed August 23, 2024.
24. Moiyadi AV, Shetty PM, Mahajan A, Udare A, Sridhar E. Usefulness of three-dimensional navigable intraoperative ultrasound in resection of brain tumors with a special emphasis on malignant gliomas. *Acta Neurochir (Wien)*. 2013;155: 2217-2225.
25. West TR, Mazurek MH, Perez NA, et al. Navigated intraoperative ultrasound offers effective and efficient real-time analysis of intracranial tumor resection and brain shift. *Oper Neurosurg (Hagerstown)*. 2025;28:148-158.
26. Deep learning in medical imaging and radiation therapy - PubMed [Internet]. Available at: https://pubmed.ncbi.nlm.nih.gov/30367497/. Accessed August 23, 2024.
27. Perin A, Prada FU, Moraldo M, et al. USim: a new device and app for Case-Specific, intraoperative ultrasound simulation and rehearsal in neurosurgery. A preliminary Study. *Oper Neurosurg (Hagerstown)*. 2018;14:572-578.

28. McGirt MJ, Chaichana KL, Attenello FJ, et al. Extent of surgical resection is independently associated with survival in patients with hemispheric infiltrating low-grade gliomas. *Neurosurgery*. 2008;63:700-707. ; author reply 707-708.

29. Brown TJ, Brennan MC, Li M, et al. Association of the extent of resection with survival in glioblastoma: a systematic review and meta-analysis. *JAMA Oncol*. 2016;2:1460-1469.

30. Sæther CA, Torsteinsen M, Torp SH, Sundstrøm S, Unsgård G, Solheim O. Did survival improve after the implementation of intraoperative neuronavigation and 3D ultrasound in glioblastoma surgery? A retrospective analysis of 192 primary operations. *J Neurol Surg A Cent Eur Neurosurg*. 2012;73:73-78.

31. Moiyadi AV, Kannan S, Shetty P. Navigated intraoperative ultrasound for resection of gliomas: predictive value, influence on resection and survival. *Neurol India*. 2015;63:727.

32. Brain Sciences. Free full-text | new hope in brain glioma surgery: the role of intraoperative ultrasound. A Rev [Internet]. Available at: https://www.mdpi.com/2076-3425/8/11/202. Accessed August 23, 2024.

33. Carai A, De Benedictis A, Calloni T, et al. Intraoperative ultrasound-assisted extent of resection assessment in pediatric neurosurgical oncology. Front Oncol [Internet]; 2021. Available at: https://www.frontiersin.org/journals/oncology/articles/10.3389/fonc.2021.660805/full. Accessed August 23, 2024.

34. The benefits of navigated intraoperative ultrasonography during resection of fourth ventricular tumors in children | Child's Nervous System [Internet]. Available at: https://link.springer.com/article/10.1007/s00381-013-2103-y. Accessed August 23, 2024.

35. Wang Y, Wang Y, Wang Y, Taniguchi N, Chen XC. Intraoperative real-time contrast-enhanced ultrasound angiography: a new adjunct in the surgical treatment of arteriovenous malformations; 2007. Available at: https://thejns.org/view/journals/j-neurosurg/107/5/article-p959.xml. Accessed August 23, 2024.

36. Ganau M, Syrmos N, Martin AR, Jiang F, Fehlings MG. Intraoperative ultrasound in spine surgery: history, current applications, future developments. *Quant Imaging Med Surg*. 2018;8:261-267.

37. Janson CG, Romanova LG, Rudser KD, Haines SJ. Improvement in clinical outcomes following optimal targeting of brain ventricular catheters with intraoperative imaging; 2014. Available at: https://thejns.org/view/journals/j-neurosurg/120/3/article-p684.xml. Accessed August 23, 2024.

38. The accuracy and safety of intraoperative ultrasound-guided external ventricular drainage in intraventricular hemorrhage | Scientific Rep [Internet]. Available at: https://www.nature.com/articles/s41598-023-38567-y. Accessed August 23, 2024.

39. Resch KDM. Transendoscopic ultrasound in ventricular lesions. *Surg Neurol*. 2008;69:375-382.

40. Cui LG, Jiang L, Zhang HB, et al. Monitoring of cerebrospinal fluid flow by intraoperative ultrasound in patients with Chiari I malformation. *Clin Neurol Neurosurg*. 2011;113:173-176.

41. Management of Chiari I malformation in children: effectiveness of intra-operative ultrasound for tailoring foramen magnum decompression | Child's Nervous System [Internet]. Available at: https://link.springer.com/article/10.1007/s00381-015-2699-1. Accessed August 23, 2024.

42. Wei R, Chen H, Cai Y, Chen J. Application of intraoperative ultrasound in the resection of high-grade gliomas. *Front Neurol*. 2023;14:1240150.

43. Gomaa MA, Hussein MA, Hussein MA, Osman AA. Role of intraoperative cranial ultrasonography in detection of residual brain lesions during surgery. *Egypt J Neurosurg*. 2024;39:60.

44. Reyes Soto G, Murillo Ponce C, Catillo-Rangel C, et al. Intraoperative ultrasound: an old but ever new technology for a more personalized approach to brain tumor surgery. *Cureus*. 2024;16:e62278.

45. Kheram N, Bessen MA, Jones CF, et al. Cerebrospinal fluid pressure dynamics as a biomechanical marker for quantification of spinal cord compression: conceptual framework and systematic review of clinical trials. *Brain Spine*. 2025;5:104211.

46. Schaible P, Schaible KL. Utility of ultrasound for assessing and confirming decompression of spinal cord. *Interdiscip Neurosurg*. 2021;25:101105.

47. Konakondla S, Fong R, Schirmer CM. Simulation training in neurosurgery: advances in education and practice. *Adv Med Educ Pract*. 2017;8:465-473.

48. Davids J, Manivannan S, Darzi A, Giannarou S, Ashrafian H, Marcus HJ. Simulation for skills training in neurosurgery: a systematic review, meta-analysis, and analysis of progressive scholarly acceptance. *Neurosurg Rev*. 2021;44:1853-1867.

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