INTRAOPERATIVE ULTRASOUND OF THE CENTRAL NERVOUS SYSTEM

HOSPITAL DE DIAGNÓSTICO

TECHNICAL ASPECTS AND IMAGES OF INTRAOPERATORY ULTRASOUND IN NEUROSURGERY

Eduardo Lovo M.D.

This page intentionally left blank

PROLOGUE

The use of ultrasound scanning especially, for tumors of the central nervous system as an intraoperative adjunct has proven to be very practical and useful for looking at residual tumor. With its ease of use this ultrasound machines can be used by neurosurgeons on their own without relying on other technical help. In his book Dr. Lovo very clearly and succinctly outlines the techniques for the use of the ultrasound machine for neurosurgeons in the intraoperative setting. This very well written book is divided into easy to follow chapters. Beginning with the history of the use of ultrasound in the central nervous system the ultrasound and MRI images along with the illustrations make this very clear to follow and to comprehend. The image quality is great and this book provides some very good examples of brain tumors before and after surgery performed in a busy neurosurgical practice. I congratulate the authors on this excellent book which I believe will be a very useful addition to the libraries of hospitals and neurosurgeons alike who use the ultrasound as an intraoperative adjunct. I believe this will also be a very useful guide for medical students and neurosurgery residents who want to familiarize themselves with basics of the intraoperative ultrasound of the central nervous system.

Sujit S. Prabhu, MD, FRCS
Associate Professor in Neurosurgery,
University of Texas MD Anderson Cancer Center
Houston, Texas , USA

PREFACE

Neurosurgery is a specialty driven by technology.
These technological advances are what allow to push the limits of surgical technique, to become even more accurate, causing less damage and operate injuries that were previously considered inoperable, and as a result improving the quality of life of patients.
Intraoperative ultrasound in neurosurgery is not new, nor highly sophisticated when compared against other systems of Image Guided Surgery (IGS). It has been present in neurosurgery for over 50 years and will probably continue in use in its current form, or some of its variants for years to come. What has made this tool reliable is probably its simplicity, it does not require any previous images or programming, it has no calibration problems, it is not affected by deformity or displacement of intracerebral structures and information provided to neurosurgeon is in real time. Finally, ultrasound is widely available in most centers where neurosurgery is practiced.

This work is a collection of cases where the images of with intraoperative ultrasound are displayed with correlation of magnetic resonance imaging (MRI), all efforts have been made to find the MRI images that more closely resemble the ultrasound cut in the operating room, taking into account the immense variability of angles provided by ultrasound, therefore some of the MRI images do not correlate with the absolute accuracy to ultrasound image, however, MRI images are intentional to facilitate the "mental transition" of the neurosurgeon between a familiar image (MRI) to one that is not (Ultrasound).
In the description of the technical aspects the most essential and practical elements are considered on what neurosurgeon needs to know about ultrasound and how to apply them in the operating room.
Ultrasound is a tool in neurosurgery that is being exploited and pushed to its maximum capacity around the world, knowing this technology will bring great benefit to surgeons.

The intention of this work is to achieve ease of use of this valuable tool for those emerging and established programs that seek to have information beyond what the human eye can deliver. Ultrasound is just that, a tool that facilitates, like any tool must be used with clear judgment that only surgical experience can deliver, which at the long run is what characterizes a successful intervention.

ACKNOWLEDGEMENTS

I would like to thank all colleagues who participated in the preparation of this work, in particular Dr. Rafael Martinez Cortez, Emilio Ahués, Mario Minervini, Juan Antonio Alfaro, Rodolfo Millaflor, to the Instituto de Neurociencias of the Hospital de Diagnóstico (INC) and the whole operating room staff from Hospital de Diagnótico (HD), team of exceptional human qualities with whom I had the honor of working with. To Dr. Rodrigo Brito and administrative staff of the HD, who have driven the development of neurosurgery nation wide.

Thanks to the patients who have placed their lives in our care.

Above all, I would like to thank my family: my parents and brothers for all their continued teaching, but in particular Francisca and Sofia who have been a constant source of motivation, love and support.

Dr. Eduardo Lovo

San Salvador, El Salvador

May 2010

INDEX

About the author.

Dr. Eduardo Lovo did his neurosurgery residence at the Pontificia Universidad Católica de Chile, afterwards he continued his neurosurgical oncology studies at MD Anderson Cancer Center in Houston Texas. At the beginning of 2007 when he returned to El Salvador he integrated the first Neuro- Oncological Program at the Hospital de Diagnóstico in El Salvador, under this program the Hospital de Diagnóstico rapidly acquired advanced neurosurgical technology necessary to perform tumor resections with compliance to international standards. Three years later the Hospital de Diagnóstico had experienced an unprecedented growth in the Central American region, shifting from basic neurosurgical technology to advanced Image Guided Surgery techniques, awake craniotomy surgeries with cortical mapping and recently the creation of the first International Cancer Center in the country, this Cancer Center gives support with regards to treatment to the Neuro-Oncological Program as it is the first Tomotheraphy based Radiosurgical Program in Latin America.

Currently Dr. Eduardo Lovo is head of the Neuro-Oncological Program and the Cerebrum and Spinal Radiosurgery Program of the International Cancer Center of the Hospital de Diagnóstico.

HISTORY OF ULTRASOUND

Dra. Raquel Soto, Dr. Héctor Moreira, Dr. Franklin Mónico y Dr. Eduardo Lovo.

The development of diagnostic ultrasound has been relatively slow in comparison with the development of X-Rays and its medical applications.

In 1794, Spallanzani observed bats flying in the dark and avoiding barriers, he assumed they were guided by sound, not light. He theorized that the sound produced by the bats was not perceived by the human ear.

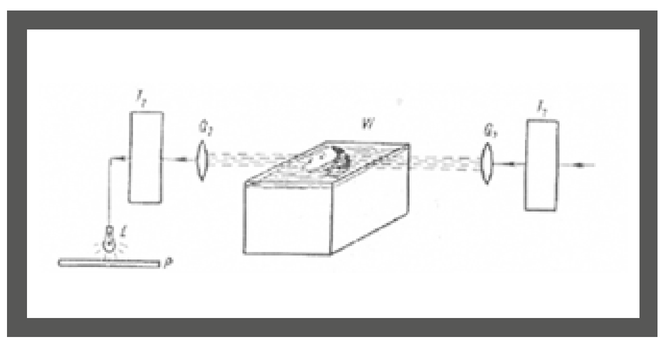
Principle "sonar" of the bat. Bats emit sounds at a frequency of 50,000 to 200,000 vibrations per second, these sounds are repeated between 20 and 30 times per second, allowing them to understand by the eco their environment and detect their prey.

In 1880 Pierre and Jacques Curie discovered the piezoelectric effect, in which an electrical charge is produced in response to the application of mechanical stress on materials such as quartz and other ceramics. One year later the Curie brothers demonstrated that an electrical potential applied through a quartz caused rotation and expansion, i.e. vibrations through the surrounding medium as sound waves that could be recorded on appropriate devices.

Interest in ultrasound imaging showed a rise with the sinking of the Titanic in 1912 as an effort to detect obstacles under the sea. Paul Langevin, French physicist and his associates during the First World War developed the use of high frequency ultrasound to detect enemy submarines, which was the forerunner of the system (SONAR) Sound Navigation and Ranging, a system for the detection of objects under the water, developed by the United States.

Langevin's observations, included ultrasound waves that could destroy small fish when making contact with them and cause pain in the hand when placing it in a pond of water and applying high frequency insonation, hence in Germany high frequency ultrasound was first used for cancer treatment and not as diagnostic and imaging technology. During the 50s in neurosurgery William Fry and Russell Myers at the University of Iowa used focused ultrasound to destroy basal ganglia in patients with Parkinsonism.

In 1941, in England, Donald Sproule developed a transducer system that detects echoes returning after an application of pulses. The first clinical application in radiology and imaging of ultrasound was reported successful by the Austrian neurologist and psychiatrist Karl Dussik and his brother Friedericke Dussik physicist, during 1942 and 1947, the Dussiks introduced Hyper-phonograph, "Through Transmission Technique" used to obtain an eco-image of the ventricles of the brain or ventriculograms via transcranial using a rudimentary system of sound transmission with a water interface.



Dussik original diagram. T1 - ultrasonic generator, Q1 - Transmitter, Q2 - Receiver, T2 - Amplifier Converter, W - Water Tina, L - light, P - thermal photo paper

In the United States, George Ludwin in 1949, from the Naval Military Research Institute, experienced to detect gallstones and foreign bodies embedded in tissues using a similar method.

At the University of Minnesota, John Wild, English, tried to use ultrasound to measure thickening of the intestinal wall in the diagnosis of acute bowel and showed a different pattern of echoes for the various intestinal layers, distinguishing the normal pattern of those with tumor infiltration.

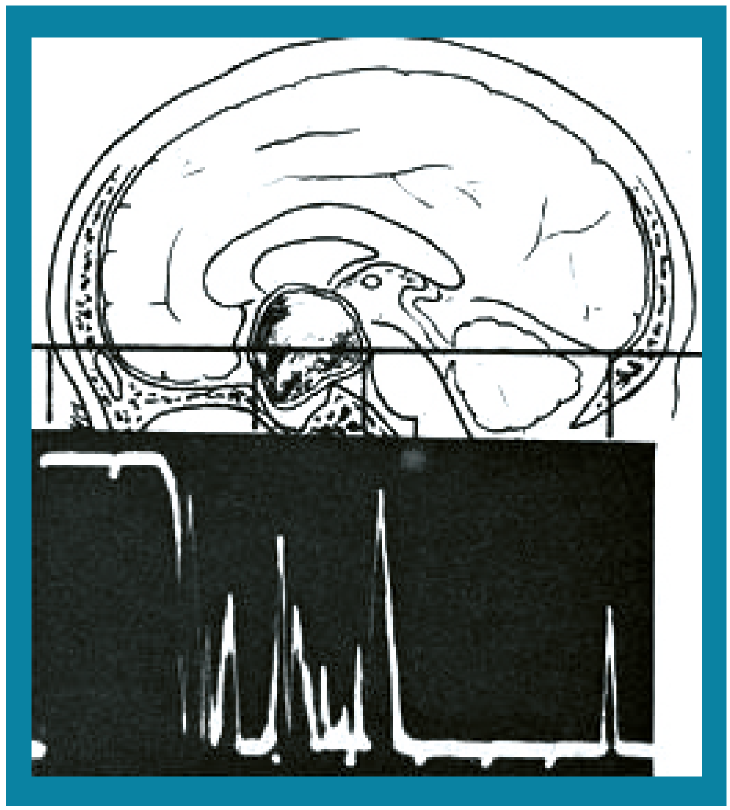
In collaboration with engineer John M. Reid, Wild developed the Two-dimensional scanning system (Mode B) between the years 1951 to 1956 and introduced the first portable contact scanner for exploration of the breast. Reid subsequently developed the first eco-cardiograph in the United States during his PhD (1957-1965)

In Colorado, Douglas Howry in collaboration with the Engineer Roderic Bliss, initiated the idea of using an ultrasound device directly on the body that may reflect the tissue interfaces. Their system was built from a radar amplifier; scans are made from a transducer immersed in water which allowed the transmission of sound waves towards the object under investigation.

In 1957 - 1958, Pan Scanner was designed, where the transducer rotates in an aqueous solution around the patient, capable of producing 2-D image quality and reproducible. Then Holmes and William Wright in collaboration with Ralph Meyerdick in 1962 developed the first compound contact scanner, which was the forerunner of modern ultrasound.

Intra-Operative Cerebral Ultrasound.

In 1950, French et al. (1) extends his research on patterns of echoes using the technique of pulsed echoes from the abdomen and the breast to the brain. After animal tests showed the safety of the method, the handheld transducer was used directly in the human brain (post craniotomy) wich managed to locate a brain tumor using ultrasound uni-dimensional "A" mode, with a transducer of 15Hz. They found that the texture of the tumor varied in intensity ultrasonographically twice of that of healthy tissue. Subsequently, Dr. William Peyton, University of Minnesota in 1951, using an ultrasound transducer in the operating room achieved to locate a Glioblastoma Multiforme located in the parietal region. In 1953, Leksell (2) uses the ecoencefalography with a low frequency transducer that allowed deep penetration in tissues with less dispersion, he was the first to use ultrasound in the skull of children, which by its thinness allowed less dispersion of waves. Two years later he reported the use of ultrasound to locate complications of trauma caused in the supratentorial space.



Ultrasound mode "A" for locating brain tumors. Tanaka K, Ito K, T Wagai JNS 1965, 23, 135-147.

Kurze et al in 1965 (3) report their experience on the use of ultrasound in the operating room in brain surgery in 159 cases. He like other authors of the period (4,5) had already demonstrated the usefulness that this tool could bring to neurosurgery.

Dr. Earl Walker in 1966 (6) at Johns Hopkins Hospital in Baltimore MD, writes:

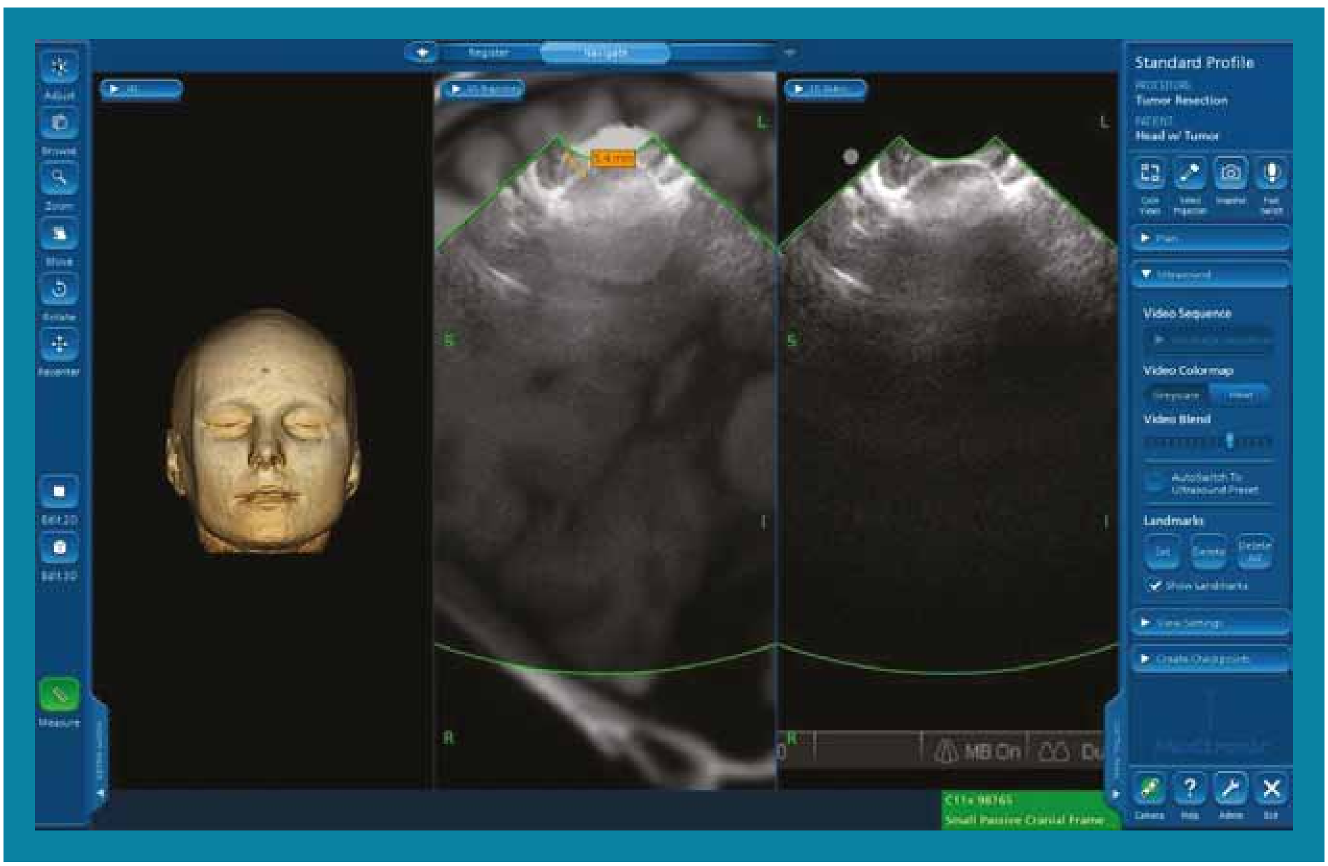
"For the neurosurgeon to perform a dural opening properly, he must have a precise knowledge of the limits of the lesion underneath, ecoencefalography is a simple and safe method of obtaining this information". Words that were valid then as they are today.

However, it was not until the early 1980s that technology allowed a sectorial scan ultrasound in real time in mode "B" that dramatically improved real-time visualization. Simultaneously different groups started to use this new modality in the operating room with intent to locate intraparenchymal brain lesions (7,8), basically coming all to the same conclusion, which was that the improvement in image allowed to locate pathology in all cases and to define more direct surgical paths to them.

Ultrasound in the early 80s, so "B" of intraparenchymal brain tumor.

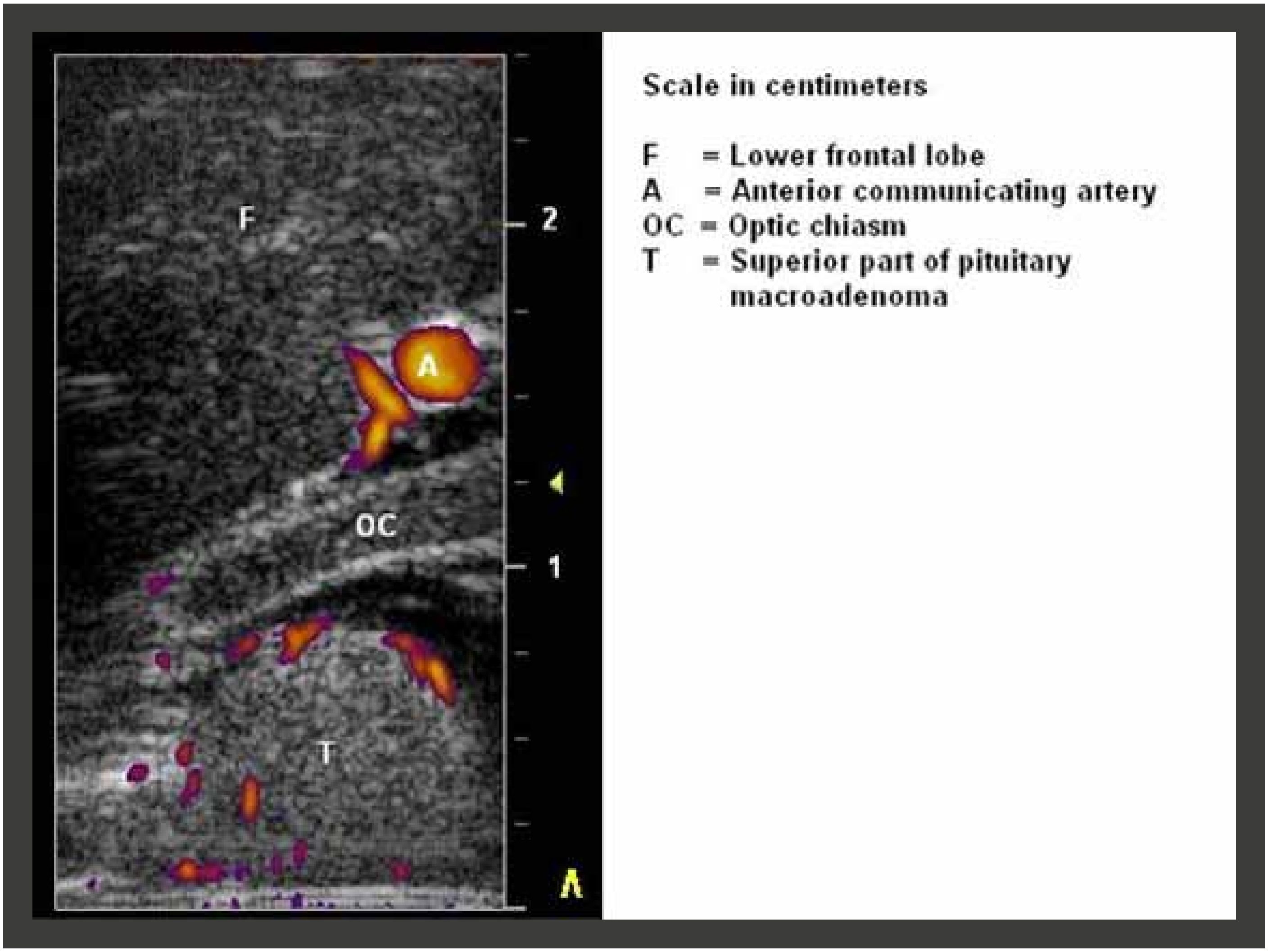
In the era of the 90s and 2000, with the advent of Image Guided Surgery (CGI) intraoperative ultrasound (USGIOP) continued to show its importance in tumor surgery used by itself or in addition to CGI (9,10,11,12).

Currently the most significant ultrasound imagining advances for neurosurgery have been in 3D reconstruction (13,14,15,16,17,18), 4D (3D in real time), co-registration and correction of parenquimal brainshift during brain tumor surgery.



StealthStation® S7® Navigation System and SonoNav™ Intraoperative Imaging System. The 3-up view with landmarks and degree of brainshift measurement. Images provided by Medtronic. Inc. Minneapolis, Minnesota USA.

Other significant advances have been in the transducers which have allowed the taking of USG-guided biopsies, and visualization of small, deep spaces as the sellar region (19). Integration with color Doppler techniques has helped define permeability of blood vessels in vascular neurosurgery, tumor irrigation, etc.



2010 intrasellar transsphenoidal ultrasound. Courtesy of Ole Solheim MD.
Department of Neurosurgery St. Olavs University Hospital, Trondheim Norway.

Despite advances in 3D ultrasound, conventional 2D ultrasound in its "B" mode remains the most widely used, even when compared against Intraoperative Magentic Resonance (IOPMR) (20). Venelin et. al, recently demonstrated how valuable this tool in neuro-oncology by comparing it against IOPMR, in this study in only two cases of 27 patients who had residual tumor <1cm, ultrasound failed to detect it when compared against 1.5 RMIOP tesla (21).

Intraoperative Ultrasonography in El Salvador C.A.

Experience in the use of this technology was acquired during the years 2003-4 at the Pontificia Universidad Catolica de Chile, during production of the first report on the necessary technical aspects for adequate intraoperative ultrasonography (22). Although the transducer that was used on that occasion was not ideal for neurosurgery (model L38/5-10 Mhz), as it was linear with a length of 38mm, it had the Mhz necessary to achieve adequate visualization of subcortical lesions.

2005, Photography in the operating room (Pontificia Universidad Catolica de Chile), initial cases of intraoperative ultrasonography visualized with a model Titan ™ (Sonosite Inc. Bothell, WA. USA) ultrasound.

The story about the application of intraoperative ultrasound in neurosurgery in El Salvador C.A. is relatively recent. It was not until 2007 in which the Hospital de Diagnostico of El Salvador acquired their own Titan ™ Sonosite ultrasound system, with a specific transducer for use in neurosurgery, about the same time in that hospital was obtained the first conventional stereotactic frame, which allowed to carry out resection of intraparenchymal lesions guided by intraoperative ultrasonography (USGIOP) alone or combining both techniques in guided stereotactic craniotomies. With the advent of the first set of CGI in the Hospital de Diagnostico in mid 2008, the Neuro-oncology Program virtually abandoned the use of conventional stereotaxy (frame) to guide craniotomies but continued to depend on the USGIOP to assist tumor localization in combination with the neuronavigation system.

During 2009 a study was begun (still open) on intraoperative MRI (RMTOP) to detect residual tumor; at the time of this report, seven cases had been enrolled of which only in one case tumor remnant was confirmed by RMTOP, information that was known in advance since it had been detected by means of USGIOP too. The biggest limiting USGIOP in this case is the delivery of information in 2-D and the difficulty of obtaining in a practical way an accurate estimate of the residual tumor volume which makes the RMTOP more accurate.

For the beginning of 2010 the USGIOP had been used in more than 85 cases in removal of tumors, cavernomas, AVM's, abscesses, epilepsy surgery for hippocampal and ventricle localization and evacuation of hematomas, solidifying its usefulness within the Neuro-oncology Program and the general practice of neurosurgery at the Hospital de Diagnostico of El Salvador C.A.

The USGIOP has proved its worth worldwide, not just in neuro-oncology but also in other intracerebral and spinal cord pathologies. It is useful, practical, affordable and widely available, making it an ideal tool for emerging programs neurosurgery or well-established programs that want to increase their ability to locate and resect intraparenquimal lesions.

REFERENCES:

1) FRENCH, L. A., WILD, J. J., NEAL, D. The experimental application of ultrasonics to the localization of brain tumors. J. Neurosurg., 1951, 8:198-203.

2) Leksell, L. Echo-encephalography. I. Detection of intracranial complications following head injury. Acta. chit. scand., 1955, 110:301-315.

3) Kurze, T., Dyck, P., and Barrows, H. S. Neurosurgical evaluation of ultrasonic encephalograph. Journal ofNeuro-surgery, 1965, 22:437-440.

4) Kenji Tanaka, M.D., Kazufumi Ito, M.D., and Toshio Wagai, M.D. The Localization of Brain Tumors by Ultrasonic Techniques A Clinical Review of 111 Cases 135 Journal of Neurosurgery Aug 1965; 23, 135-147.

5) Ter Braak, J. W. G., Grandia, W. A. M., and De Vlieger, M. 'Echo-encephalography' as an aid in the diagnosis of subdural and extradural hematomas: In: Recent neurological research. A. Biemond et al., Ed. Amsterdam: Elsevier Publishing Co. 1959, viii, 380 pp. 87-45

6) Walker AE, Euemasu S. Dural echoencephalography.J Neurosurg. 1966; 25:634-7.

7) Rubin JM, Mirfakhraee M, Duda EE, Dohrmann GJ, Brown F. Intraoperative ultrasound examination of the brain. Radiology. 1980; 137(3):831-2.

8) Masuzawa H, Kamitani H, Sato J, et al: Intraoperative application of sector scanning electronic ultrasound in neurosurgery. Neurol Med Chir 1981; 21:277–285,

9) Hammoud MA, Ligon BL, elSouki R, Shi WM, Schomer DF, Sawaya R: Use of intraoperative ultrasound for localizing tumors and determining the amount of resection: a comparative study with magnetic resonance imaging. J Neurosurg 1996; 84:737–741

10) Woydt M, Krone A, Becker G, Schmidt K, Roggendorf W, Roosen K: Correlation of intra-operative ultrasound with histopathologic findings after tumour resection in supratentorial gliomas: a method to improve gross total tumour resection. Acta Neurochir (Wien) 1996; 138:1391-1398

11) Hata N, Dohi T, Iseki H, Takakura K: Development of a frameless and armless stereotactic neuronavigation system with ultrasonographic registration. Neurosurgery 1997; 41:608–614,

12) Roth J, Biyani N, Beni-Adani L, Constantini S: Real-time neuronavigation with high-quality 3D ultrasound SonoWand in pediatric neurosurgery. Pediatr Neurosurg 2007; 43:185–191

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

14) Regelsberger J, Lohmann F, Helmke K, Westphal M: Ultrasound guided surgery of deep seated brain lesions. Eur J Ultrasound 2000; 12:115–121

15) Unsgaard G, Rygh OM, Selbekk T, Selbekk T, Brostrup Müller T, Unsgaard G: Intra-operative 3D ultrasound in neurosurgery. Acta Neurochir (Wien) 2006; 148:235–253

16) Unsgaard G, Selbekk T, Brostrup Muller T, Ommedal S, Torp SH, Myhr G, et al: Ability of navigated 3D ultrasound to delineate gliomas and metastases—comparison of image interpretations with histopathology. Acta Neurochir (Wien) 2005; 147:1259–1269

17) Jödicke A, Deinsberger W, Erbe H, Kriete A, Böker DK: Intraoperative three dimensional ultrasonography: an approach to register brain shift using multidimensional image processing. Minim Invasive Neurosurg 1998; 41:13–19

18) Lindner D, Trantakis C, Renner C, Arnold S, Schmitgen A, Schneider J, et al: Application of intraoperative 3D ultrasound during navigated tumor resection. Minim Invasive Neurosurg 2006; 49:197–202

19) Solheim, Ole MD; Selbekk, Tormod MSc; Løvstakken, Lasse MSc; Tangen, Geir A. MSc; Solberg, Ole V. MSc; Johansen, Tonni F. MSc; et al. Intrasellar Ultrasound in Transsphenoidal Surgery: A Novel Technique. Neurosurgery: 2010; 66:173–186

20) Rubin JM, Quint DJ: Intraoperative US versus intraoperative MR imaging for guidance during intracranial neurosurgery. Radiology 2000; 215:917–918

21) Venelin M.G., Amir S., Arasch A., Lennart S., Madjid S., Rudolf F. Reliability of intraoperative high-resolution 2D ultrasound as an alternative to high–field strength MR imaging for tumor resection control: a prospective comparative study Clinical article 512 Journal of Neurosurgery 2009; 111:512-519

22) Lovo E., Villanueva P., Torrealba G., Campos M., Vargas R., Tagle P. Ultrasonido Intraoperatorio en Neurocirugía: Aspectos Técnicos. Rev. Chil. Neurocirug. 2006; 26:60-64.

PHYSICAL PRINCIPLES OF ULTRASOUND

Dr. Raquel Soto, Dr. Héctor Moreira and Dr. Eduardo Lovo.

The sound is reflected like a mirror reflects light. The basis for the application of ultrasound in medical diagnosis is the detection and representation of the acoustic energy reflected (echoes) from the different interfaces of body tissues, generating high-resolution two-dimensional images recorded on a Computer in grayscale or to represent flow patterns.

Ultrasound waves are generated by piezoelectric crystals located in the transducer, they are directed into the tissues, which are the interfaces with important differences in acoustic impedance (determined by the density of the medium and the propagation velocity of sound in the medium). The interfaces of tissues such as bone, reflect all incident sound energy and muscle and fat tissues as part of the incident energy that is reflected allowing the propagation of sound. These interfaces are "specular reflectors" echoes going back to the transducer when the sound beam is perpendicular to the interface. Solid organs and tissues are "diffuse reflectors." The ultrasound allows assessment of the size, shape, position and texture of an organ.

To produce the sonographic image sound waves of high frequency and low intensity are used, produced by the vibration of quartz crystals or ceramics called piezoelectric materials, which are capable of converting electrical impulses into sound waves, they are located in the transducer, which is in contact with the patient and himself works as a transmitter and receiver of sound waves being emitted at a frequency of 20,000 cycles per second or Hertz (frequency above the audible by humans). These waves are directed into the tissues of interest by moving the transducer, changing the angle of incidence of the ultrasonic beam, the characteristics of body tissue can be followed. Determining the extent of the beam to be reflected, producing echoes of various intensities, which are collected by the same transducer, where they collide with the piezoelectric crystals to be converted into electrical impulses. These in turn are analyzed by computer processes displaying grayscale images formed from bright spots produced by the ultrasound beam reflected from each tissue.

The resolution power of the equipment depends on the frequency of sound waves. Higher frequencies show better image detail, but little penetration. While lower frequencies provide higher penetration at the expense of resolution. The most commonly used transducers are 3.5, 5 and 7.5 megahertz (MHz) which are usually linear or sector.

The basic plans are cross-sectional ultrasound, sagittal and coronal these in turn are subdivided into oblique. For the interpretation of an image is used as follows:

HYPERECHOIC or HYPERECOGENIC: images produced by bodies that reflect the entire ultrasound beam that strikes them (stones, fat and dense tissue), they are observed "white" or bright on the monitor.

HYPOECHOIC, or HYPOECOGENIC: the images are caused by soft tissue in texture, reflect in part the ultrasound beam (such as muscle), they are observed less bright.

ANECOIC, SONOLUCIDO OR NON ECOGENIC: images produced by structures that not only reflect but transmit all ultrasound waves that affect them (bladder, gall, cysts) and will be seen black on the screen.

ISOECHOIC: normal ultrasound image of the tissue itself.

Representation of the image

B mode or real time image in grayscale shows white more intense images, no signal is black and intermediate signals are shown in shades of gray.
Linear transducers are used to study small parts, obstetrics and vascular structures.
Convex or curved transducers are used in studies of the abdomen, pelvis, pediatric, obstetric, and when they are small and high-frequency in transvaginal studies, transrectal or intraoperative as in neurosurgery.

Selecting the transducer

The highest ultrasonic frequency 7.5 to 10 MHz is used for surface vessels, thyroid and breast which are 1 to 3 cm. from surface.
Lower frequencies (2.25 to 3.5 MHz) are used for structures that warrant further penetration or depth (more than 12cm from the surface), such as studies of the abdomen and pelvis.
The quality of the image depends on factors such as spatial resolution, contrast resolution and temporal resolution and the absence of artifacts.
On ultrasound, the quality of the information obtained is determined by the browser's ability to recognize and eliminate artifacts and misinterpretations.
Artifacts are of reverberation of refraction, or lateral lobes or beams, and acoustic shadow.

Technical aspects of intraoperative ultrasonography of the central nervous system (CNS)

The ability to ultrasonographically see tumors within the brain parenchyma is due to tissue density that is known as "acoustic impedance", the greater the difference in density between the lesion and normal tissue, the easier it is to identify the tumor boundaries. This phenomenon explains why low-grade infiltrative tumors, which are histologically similar to normal brain tissue, are more difficult to visualize (ultrasonographically) when compared against high-grade infiltrative tumors or metastases, which vary greatly by histology from normal brain tissue.

Equipment and transducer

Diagnostic ultrasound uses sound waves pulsed at high frequency (> 2MHz) which are issued by a piezoelectric crystal, these waves bounce off tissues and are received back by the probe station (transducer), this information is processed and expressed in the form of images. The frequency of ultrasound has a direct influence on the quality of the images. In the case of our Center we use the TITAN ™ Sonosite Company Inc. Bothell, WA. USA ultrasound, with the transducer model C11/8-5: Broadband Curved Array, the number before the slash specifies the size of the transducer tip, 11 mm, the number that comes after the slash corresponds to the range 8-5 MHz used according to the depth you want to display, in general in neurosurgery on average of 7.5 Mhz provide adequate visualization. The Array refers to the scattering of waves in space: linear dispersion (linear array), which could be envisaged as a rectangular noise from the transducer into the tissue and there is curved dispersion (curved array) which can be figured as a range which goes from a smaller space to a larger one like a fan shape.
The tip of the transducer that we use is small (11mm) and easily enters the craniotomies or resection cavity. This ultrasonographic model was chosen because it is compact and easy to transport (see Figure 1), these factors are very useful in an operating room where in addition to ultrasound in general we have an equipment of Image Guided Surgery (CGI), operating microscope, ultrasonic aspirator, anesthetic machine and other appliances.

imagen 1

Image showing the compactness of model used in our center and its "docking-station" that facilitates the transport in the operating room.

Transducer cuts

The ultrasound transducer usually has a reference that is palpable with the index finger ,

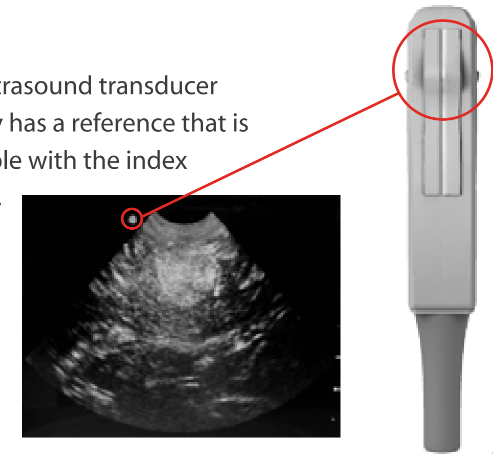
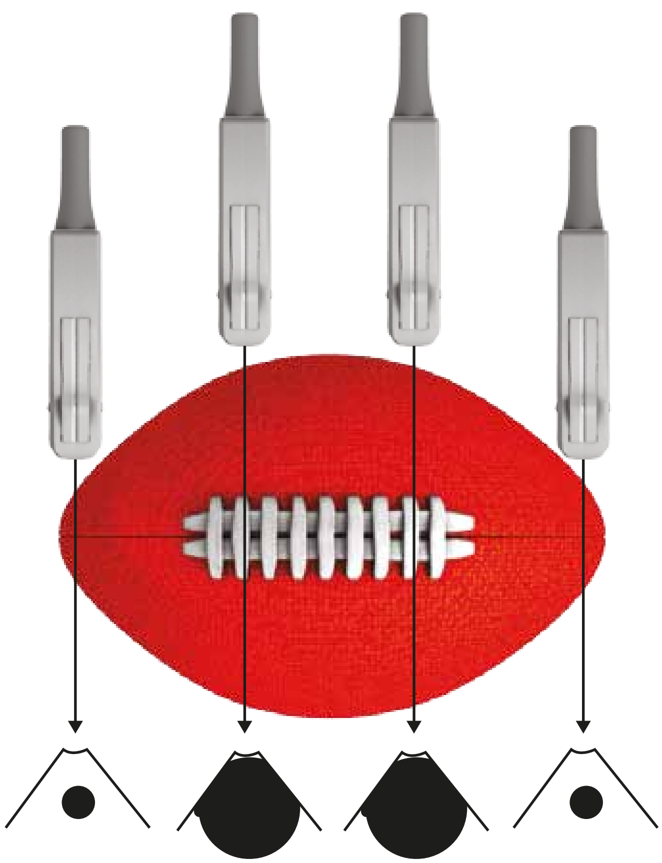


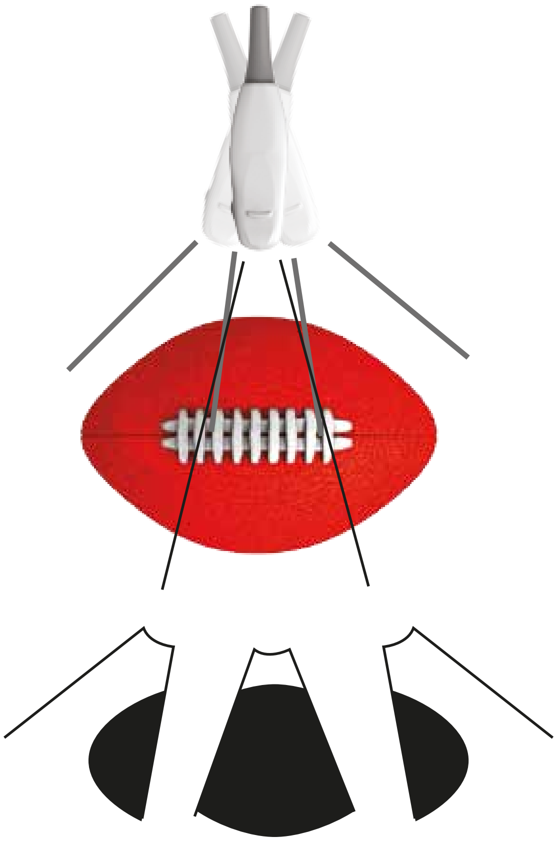
image 2

this reference indicates the direction of sonic beams (see image 3). In the case of curved transducers the operator can imagine a range that cuts the structures in a similar shape as a fan and delivers the images according to the cutting beam.

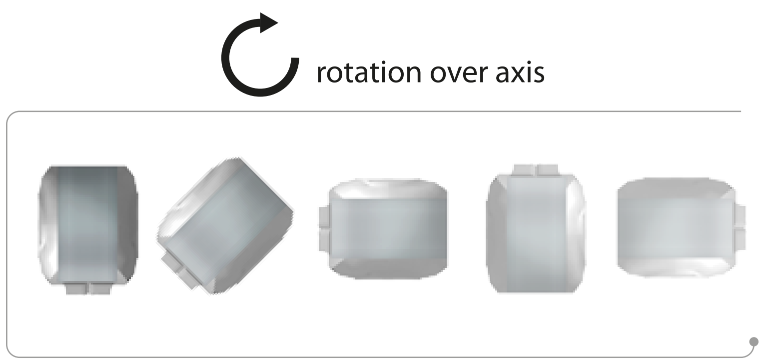
images 3

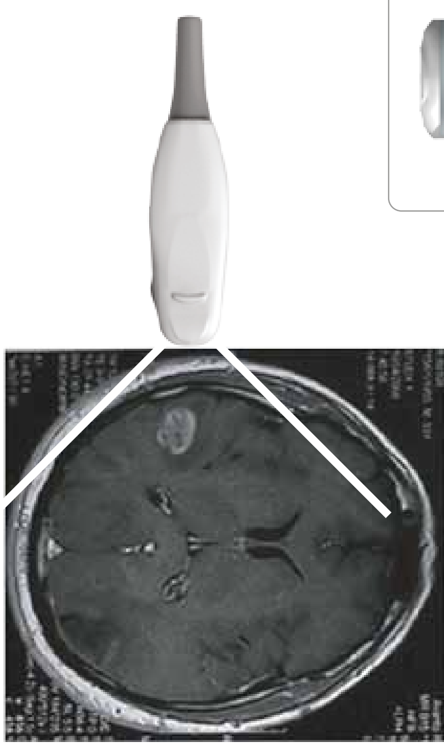


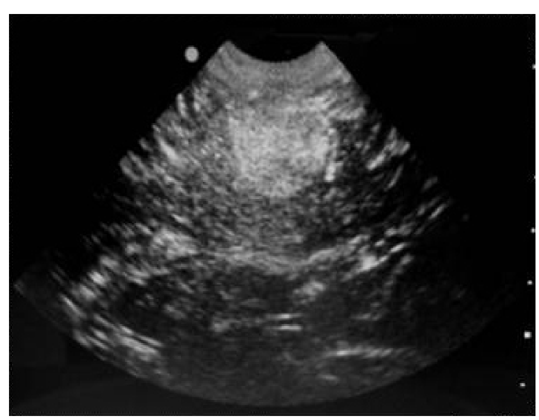
images 4



The screen usually displays a small circle (see image 2) or indicator on whether the sonic beam is anteriorly or posteriorly in relation to the benchmark, within the ultrasound board dials the capacity exists to change it from anterior to posterior and vice versa. It is important to find the orientation of this plane as soon the study begins, this is achieved by finding the most recognizable anatomical structures first, the structures of the midline within the brain, the ventricle and choroid plexus are easily identifiable structures that give guidance on the plane being displayed. By manipulating the transducer, sectional cuts in either direction are possible, in neurosurgery it is accustomed to use the three cuts: sagittal, coronal and axial. Angle of the transducer on the same point provides different views (see photos 4)

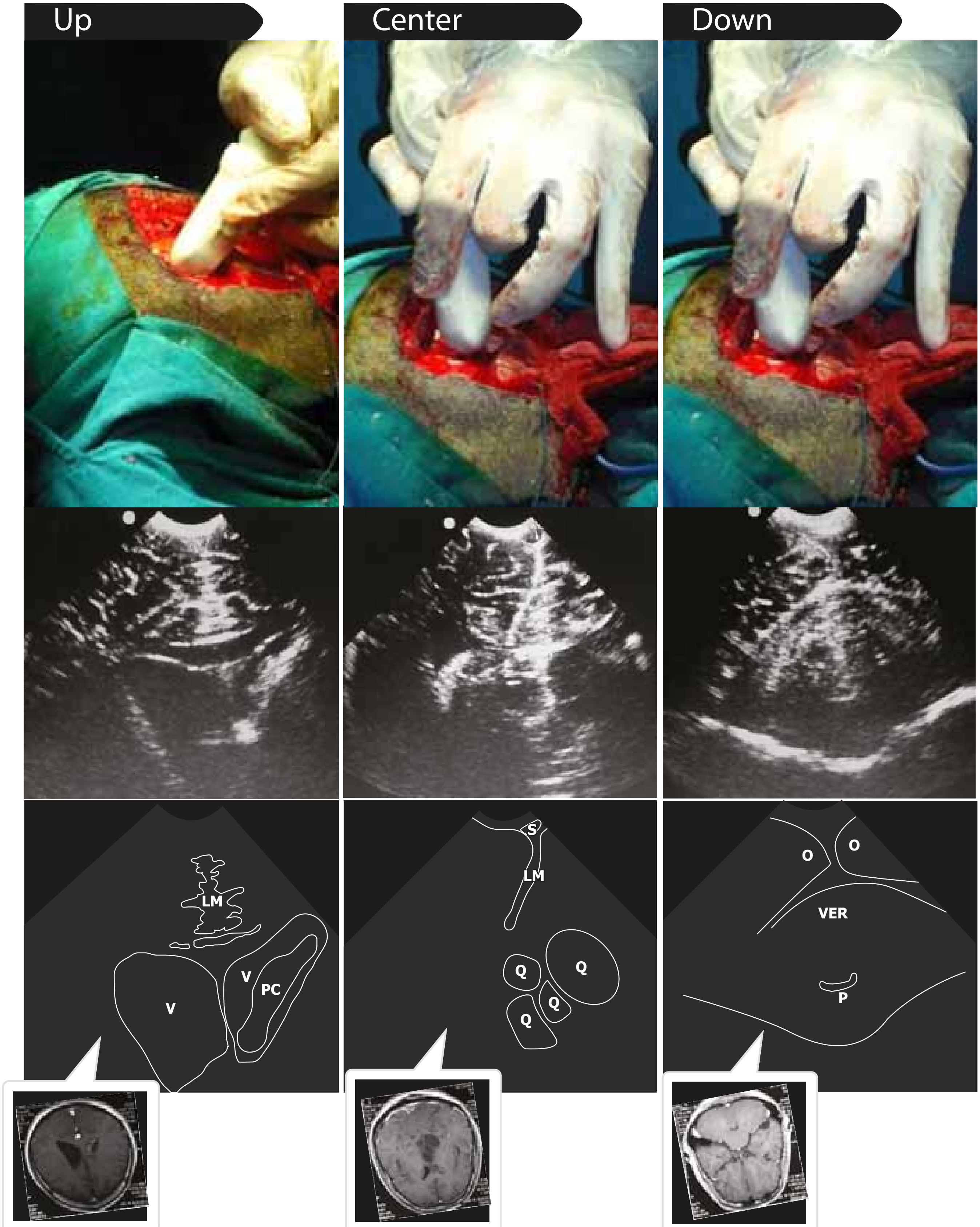






one can imagine this as the same movement of the human head to hyperextend the neck (tilt the transducer up) to go see the top or above, or in the opposite since if you flexed the neck (tilt the transducer down) you would be able to see the lower segments (see picture 5).

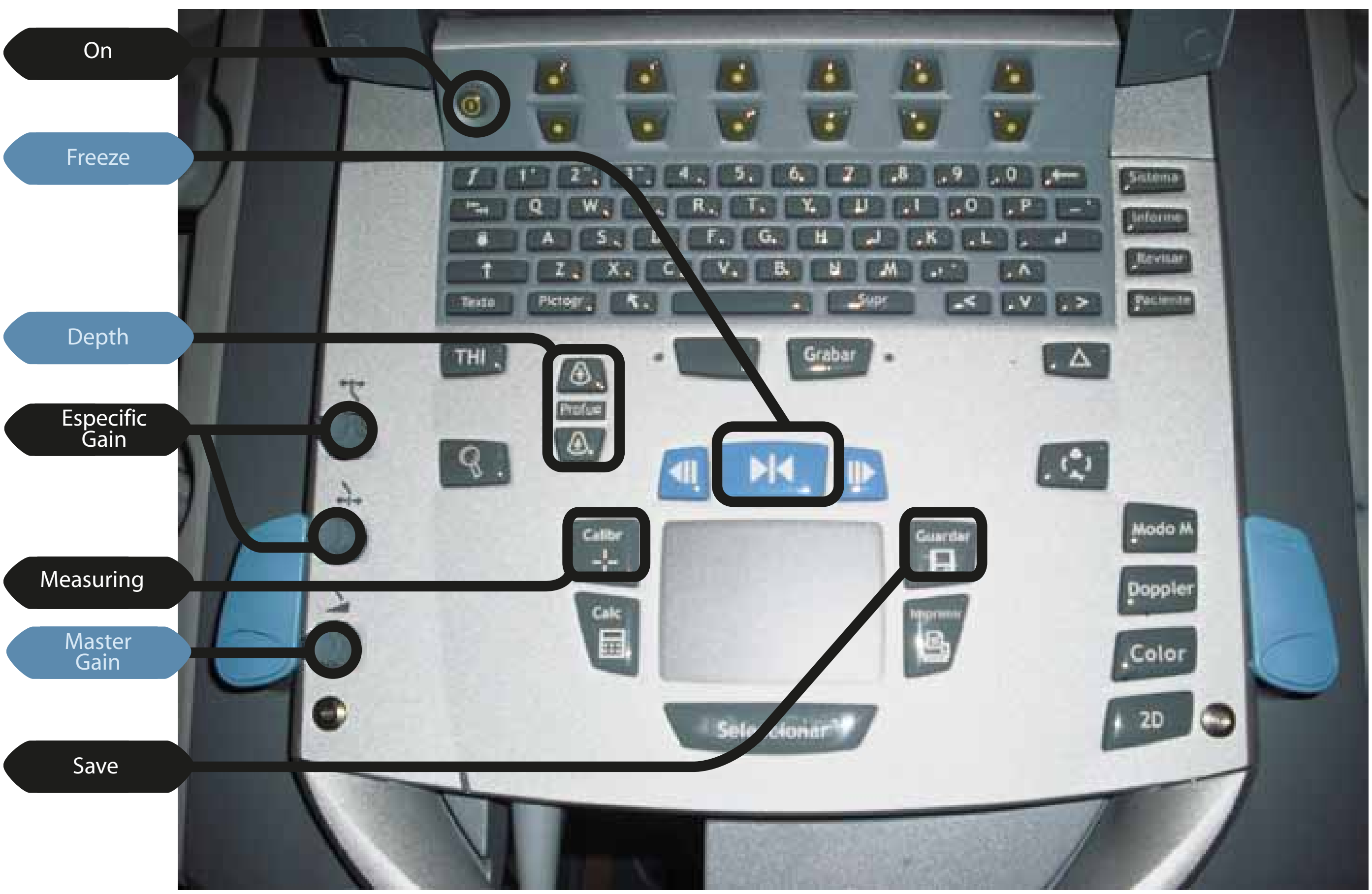
images 5



Dials

The dials and buttons that are necessary for the neurosurgeon are basically 3: Master Gain (Gain), in general all ultrasound machines have specific controls of the gains based on the depth of the image and a Master Gain a generic that controls all gains regardless of their depth. The Master Gain makes the image brighter or darker. The second button is the depth, usually more Mhz display superficially with better definition and lower Mhz viewing is deeper but with less definition, therefore the depth button causes the image to be seen larger (closer) or smaller (distant) based on the depth that is being studied. The button "freeze" (Freeze the image) is useful because the neurosurgeon who is doing the study can take measurements from the transducer location to the lesion or the lesion diameter, thickness of the residual lesion, etc. Also it is recommended that the image to be "frozen" in order to store images and be able to review them later. The explanation of these three buttons is an oversimplification and certainly an under-utilization of ultrasound equipment, but in practice are the only ones we use during surgery.

Some models are equipped with color Doppler for visualization of vascular structures, it is potentially useful in aneurysm surgery to verify the permeability of the blood vessel after clipping and arteriovenous malformations. In our experience, we



have used it in two occasions for arteriovenous malformations, but our limited experience in the interpretation of color Doppler information didn't make the study particularly useful and we preferred to rely on information from the Image Guided Surgery system and microsurgical anatomy.

Transducer preparation and normal flow of a study in the operating room

At the beginning of surgery instrumentalist staff is responsible for sterile preparation the transducer in, this is done by inserting it into a regular laparoscopy sleeve, and using the thumb of a glove No. 8 with sterile gel sono-conductor, the glove finger (latex) is adjusted so it is completely wrapped around the tip, the surgeon must verify that there are no bubbles between the tip and the latex glove, likewise should check that there is no significant layer of gel between the tip and the latex, both of which can affect ultrasound vision (usually seen darker in the screen which does not improve by increasing the gain). The remaining fingers of the glove are folded back over the sleeve of laparoscopy and secured with tape. We usually leave the sterile transducer within a sterile metal container so that it will be ready for use (see image sequences).


1


2


3


4

The study is conducted in three stages of surgery: The first step is to perform a craniotomy / laminotomy and the transducer is applied gently over the duramater while irrigating with copious normal saline (NS) to achieve a better interface (see picture). At this stage the study primarily is used for viewing the relationship between the craniotomy and the lesion, it may also be useed to confirm the accuracy of the navigation system by identifying the edges of the lesion. The next stage is over the neural tissue after opening the duramater, irrigating with NS again, at this stage of the study in addition to knowing the proximity of the injury to the cerebral cortex and the edges of the lesion, it is useful for identifying specific sulci that lead to the lesion hence promoting trans-surcal access for the removal of lesions. Finally, during the resection of the lesion filling the cavity with NS, this step is done as many times as necessary during the progression of surgery. In most high-grade infiltrative we prefer to surround it in the natural planes it has and try en-block removal more than an internal decompression (debulking), the gliotic plane that can be followed in most high-grade gliomas in our experience is less defined towards the depth of the lesion and here is where the ultrasound is particularly useful because it lets us know the amount of residual tumor remaining. When the duramater is closed there is an option to repeat the ultrasound study to determine whether there was a formation of a hematoma in the resection cavity.

With regard to patient positioning and planning of the craniotomy, it was not necessary in any patient to modify the surgical position or technique for intraoperative ultrasonography. It is important to note that in cases of posterior fossa approaches our group prefers to have the patient in "Parkbench" and / or its modifications for which the site of craniotomy remains the highest area of the patient. If seated position is preferred and ultrasonografic viewing is not appropriate when the transducer is applied directly (due to lack of NS interface), alternatives to improve the interface between the transducer and the tissue can be latex gloves with NS inside and the transducer applied to the glove using it as an "acoustic window" similar to a full bladder for visualization of the prostate through the abdomen.

Starting a program of intraoperative ultrasonography

Emerging programs that do not have sufficient resources to purchase equipment dedicated to neurosurgery or want to increase their experience before buying their own equipment, can usually find equipments in the pediatric ward of a hospital as transducers for echo-cardiograms and abdominal ultrasound in the newborn typically use Mhz ranging within the normal range (7.5MHz) for neurosurgery.

The study of intraoperative ultrasonography is "operator dependent", this usually means that there is variability in its use by the examiner's experience; the learning curve may be slow. The only way to gain experience is by doing the studies, so we recommend taking the time to do the study in as many opportunities (craniotomy or laminotomy) as possible, although the information provided (eg, anatomy) may not be useful in that particular case, it will be useful for the surgical team in terms of experience.

The recommendation is that the neurosurgeon be familiar from the first day with the ultrasound equipment and its use, some programs have incorporated a radiologist in order to carry out the studies in the operating room. In our center the neurosurgeon is the one who performs intraoperative ultrasonography mainly because he or she is the one that has the mindset of the three-dimensional surgical anatomy of the lesion and surrounding structures, he / she is the one to integrate and correlate information on ultrasound basing tumor mass, residual and its relation to non-tumor structures and finally he or she will be responsible for making the decisions based on this information, to proceed with resection or not. Lastly, we prefer that the neurosurgeon is familiar with the handling of this tool and as the availability of a radiologist in the operating room is not always possible, especially in non working hours when emergencies usually happen (intracerebral hematoma) where ultrasound also is potentially useful.

CASES

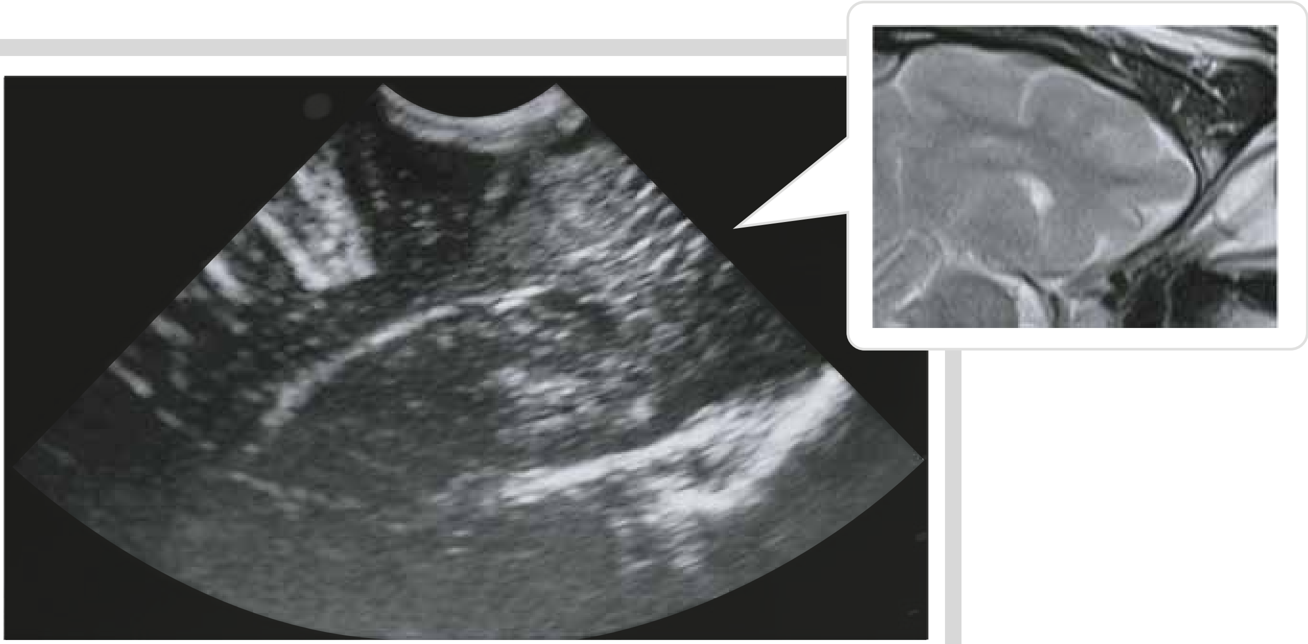
- TEMPORAL REGION
- HIGH GRADE TUMORS AND OTHER MALIGNANT LESIONS
- LOW GRADE TUMORS AND OTHER BENIGN LESIONS
- POSTERIOR FOSSA
- HEMATOMA
- OTHER AREAS

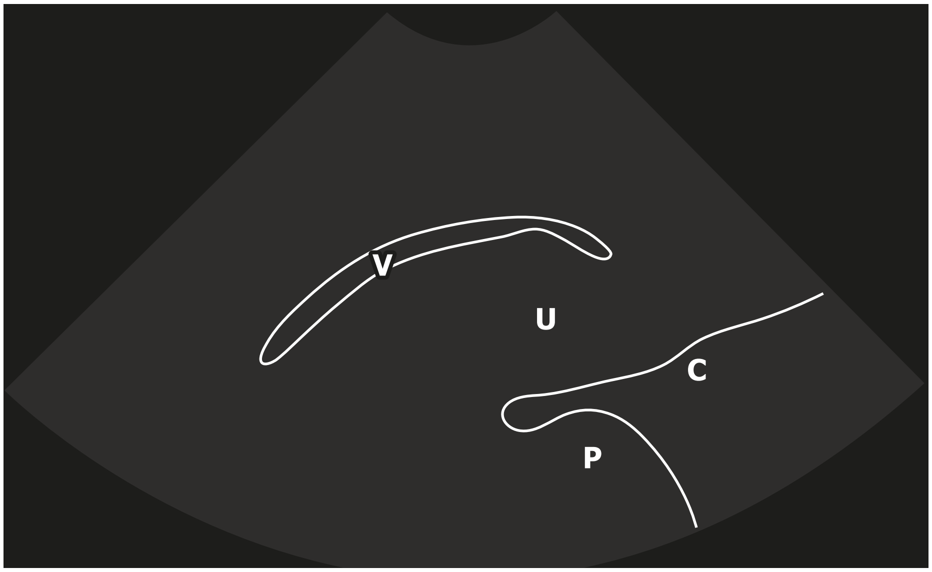
TEMPORAL REGION

- TEMPORAL LOBE
- TEMPORAL LOBE,
  CORTICAL DYSPLASIA
- TEMPORAL LOBE
  GLIOBLASTOMA MULTIFORME
- TEMPORAL LOBE,
  HEMATOMA PRODUCED BY CAVERNOMA

TEMPORAL LOBE

Intraoperative ultrasound image with correlation of MRI in a case of epilepsy surgery. Ultrasound in this case was particularly useful in order to locate the temporal horn of the ventricle, fundamental anatomic landmark to locate the most mesial regions of temporal lobe.

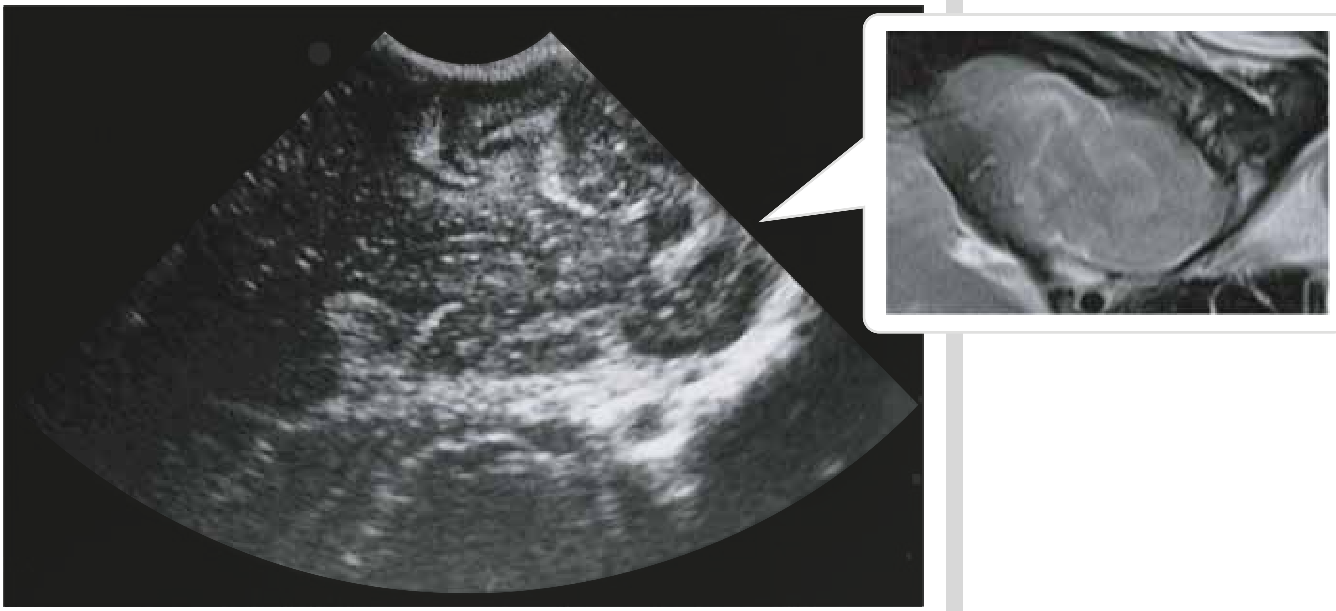


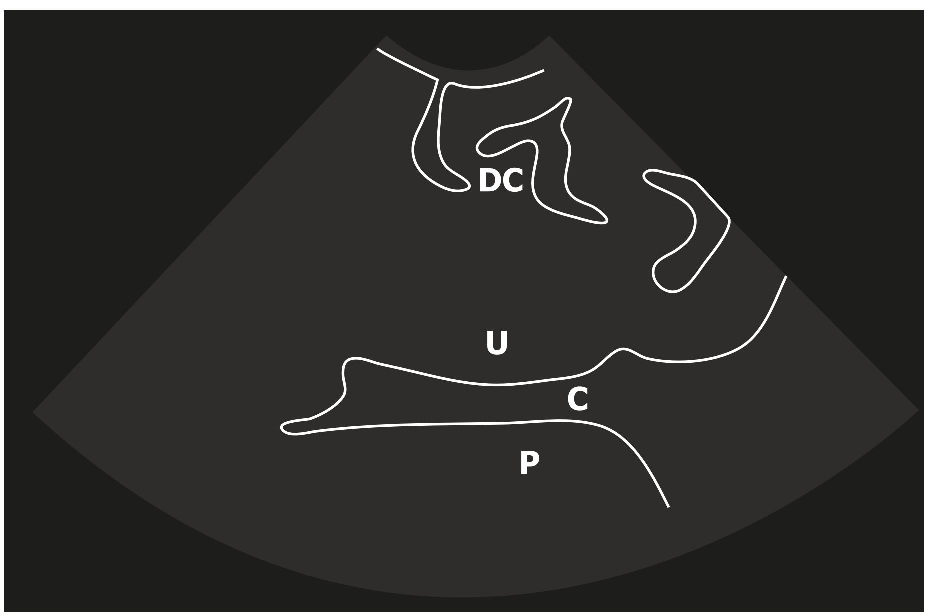


V Ventrículo, **U** Uncus, **P** Peduncle, **C** Cistern

TEMPORAL LOBE,
CORTICAL DYSPLASIA

Intraoperative ultrasound image with correlation of MRI in a case of epilepsy surgery. Notice that intraoperative ultrasound clearly shows the cortical dysplasia.

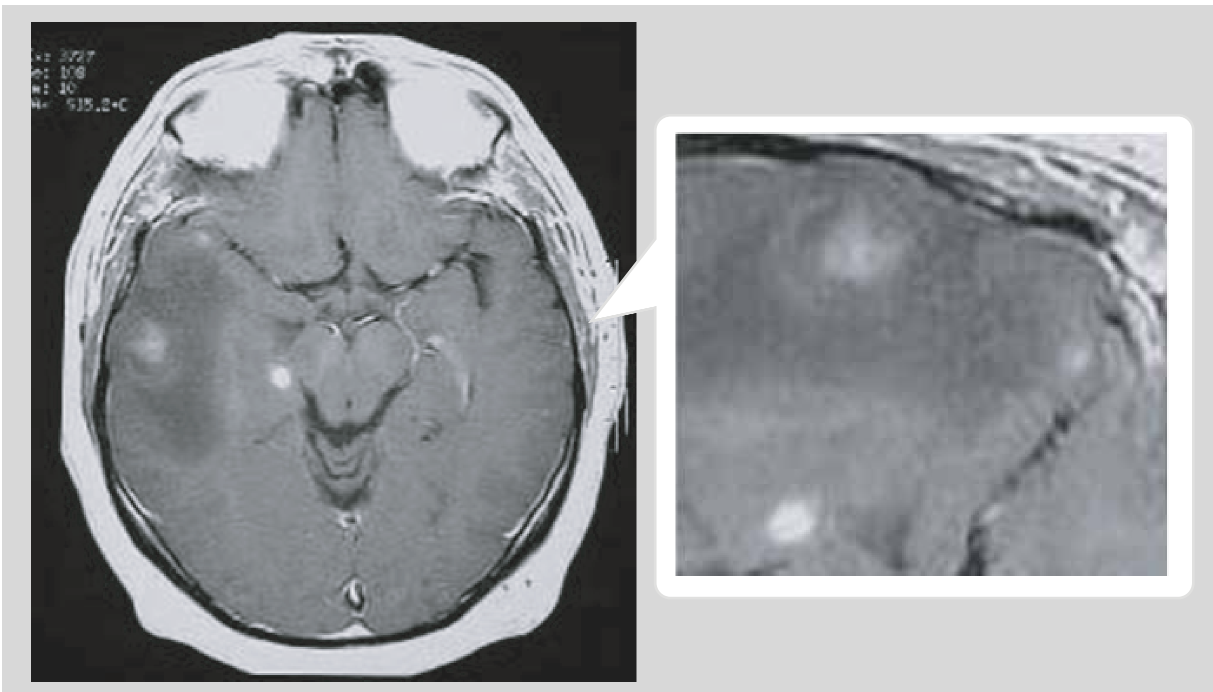


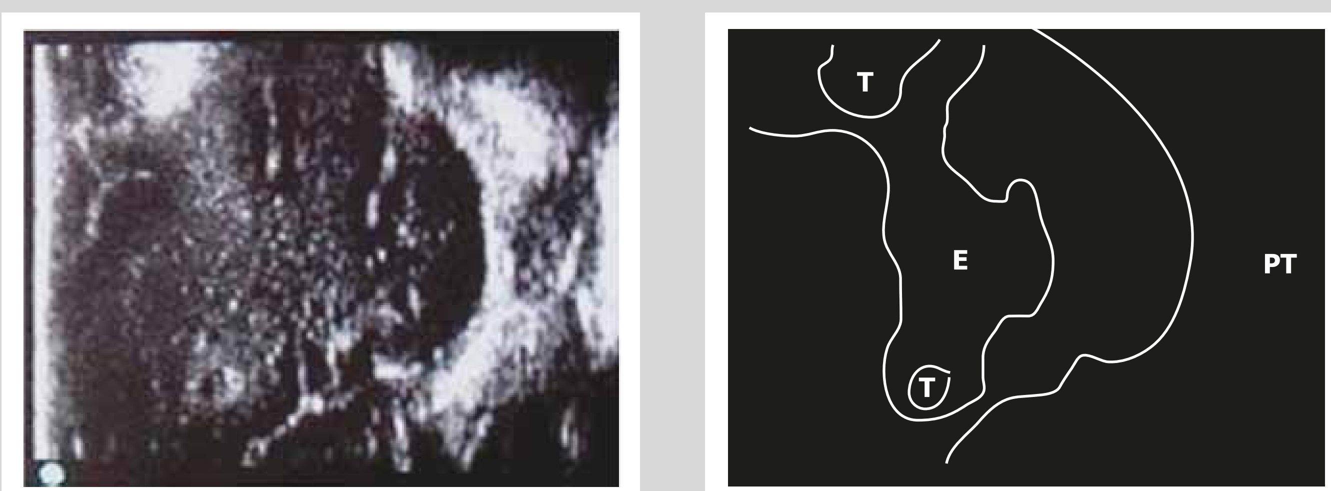


DC Cortical Displasia, **U** Uncus, **P** Peduncle, **C** Cistern

TEMPORAL LOBE
GLIOBLASTOMA MULTIFORME

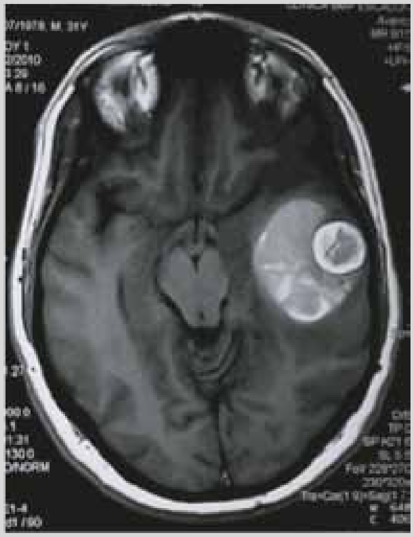
Axial MRI with gadolinium where the area of interest has been angled with the intention of matching the image of intraoperative ultrasonography. Below, intraoperative ultrasonography, which allows to distinguish small lesions less than 1 cm (mesial lesion).





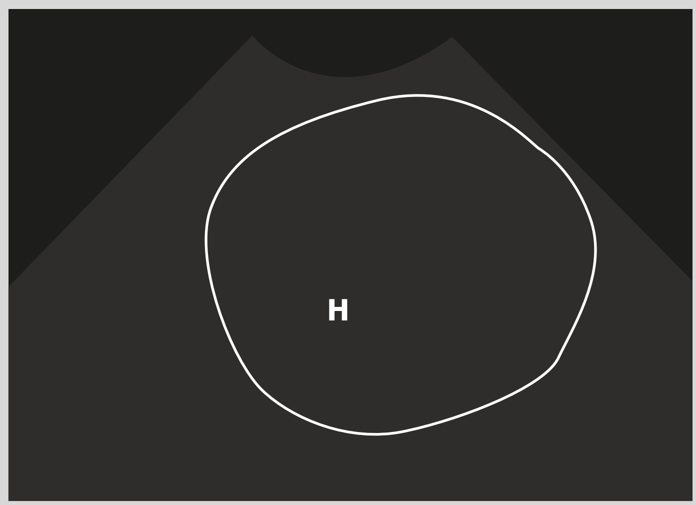
T Tumor, **E** Edema, **PT** Tempral pole

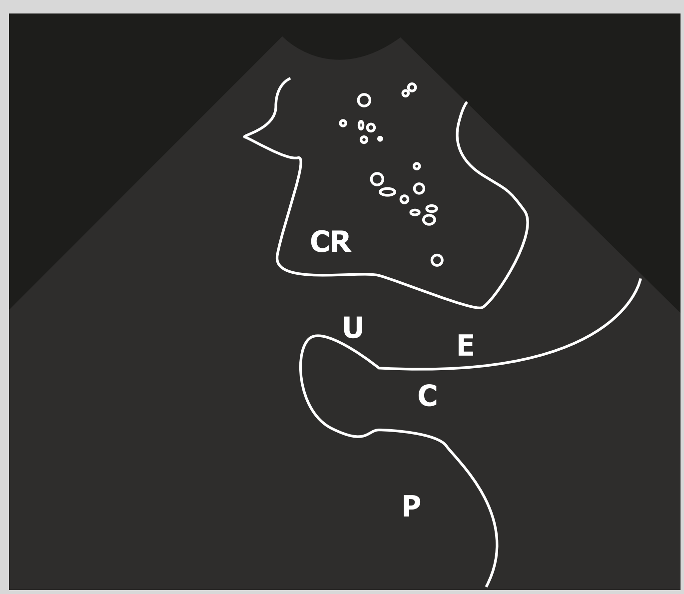
TEMPORAL LOBE,
HEMATOMA PRODUCED BY CAVERNOMA



Axial MRI which shows the presence of a large hematoma at the left temporal lobe. Below, intraoperative ultrasonography, note in the first ultrasound image is significant mass effect caused by the hematoma and does not allow visualization of the midbrain structures at that depth. The second ultrasound image shows the resection cavity and visualization of the pontine cisterns and midbrain structures.

H Hematoma, **CR** Cavidad de Resección, **U** Uncus, **E** Edema, **P** Pedúnculo



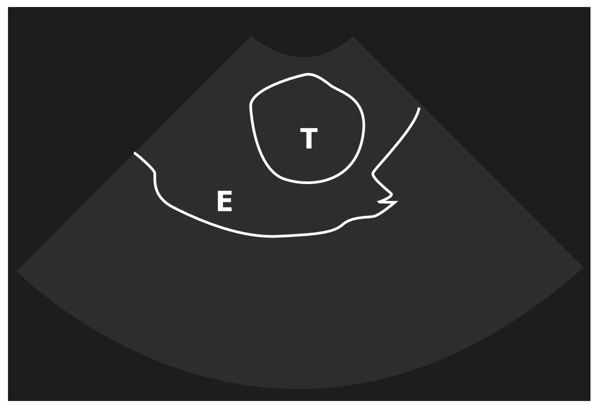


HIGH GRADE TUMORS AND OTHER MALIGNANT LESIONS

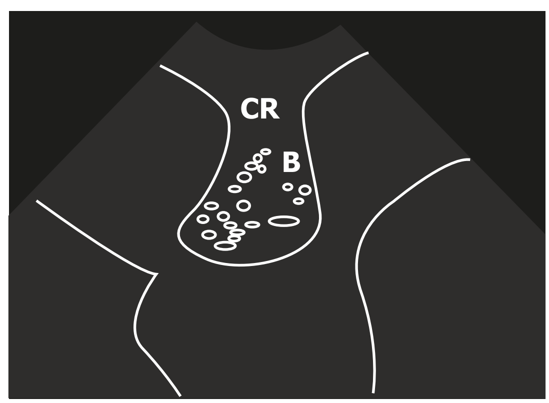
- **RIGHT TEMPORAL**
  GLIOBLASTOMA MULTIFORME
- **RIGHT FRONT**
  GLIOBLASTOMA MULTIFORME
- **GLIOBLASTOMA,**
  PARIETOOCCIPITAL, LEFT
- **GLIOBLASTOMA**
  MULTIFORME, FRONTAL, LEFT
- **GLIOBLASTOMA**
  MULTIFORME, TEMPORAL REGION BACK, LEFT
- **PRIMARY LYMPHOMA**
  OF THE CENTRAL NERVOUS SYSTEM, SUPPLEMENTARY MOTOR AREA
- **CYSTIC METASTASIS,**
  FRONTOPARIETAL, LEFT
- **NEUROESTESIOBLASTOMA**
  WITH PENETRATION IN THE BRAIN

RIGHT TEMPORAL
GLIOBLASTOMA MULTIFORME

Axial MRI with gadolinium which has been angleded on the basis of ultrasound. Intraoperative ultrasound showing the precise demarcation of the lesion (more hyperechogenic signal) and peritumoral edema. Lower images, ultrasound shows the resection cavity and brain edema is still present. Postoperative axial MRI with gadolinium, showing complete resection of the lesion.



T Tumor, **E** Edema

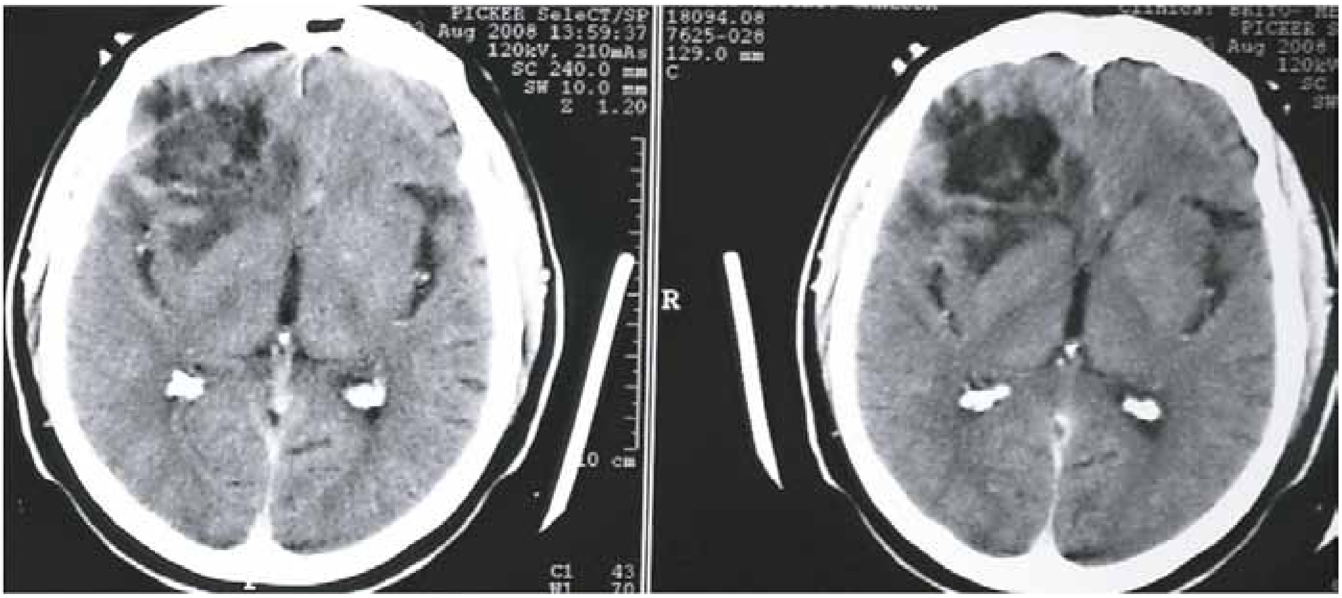


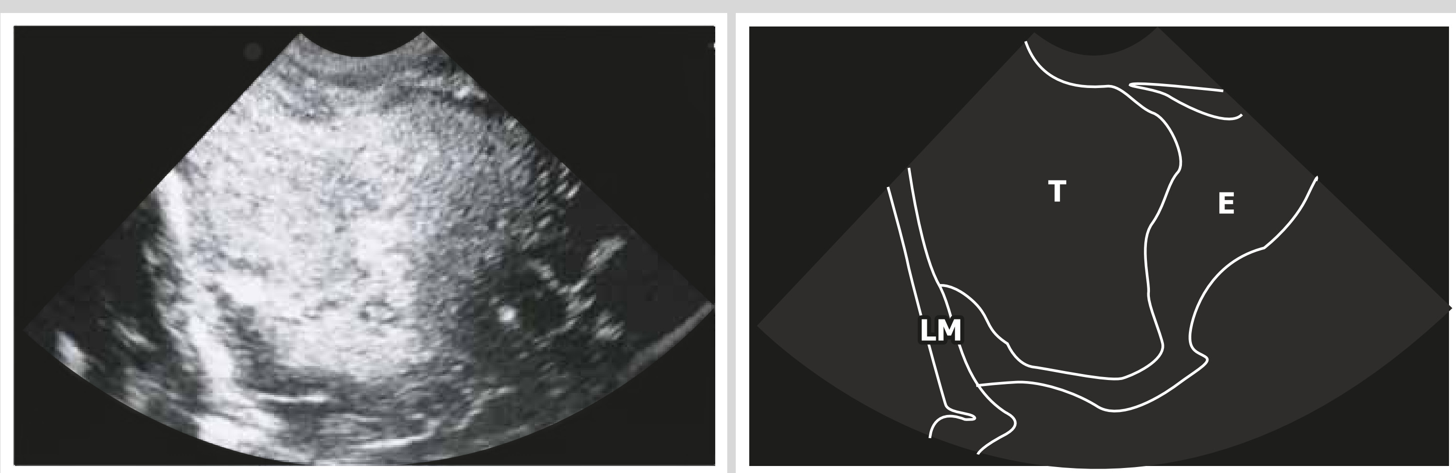
CR Cavidad de Resección, **B** Burbujas,

RM control

RIGHT FRONT
GLIOBLASTOMA MULTIFORME

Axial CT with contrast showing the infiltrative lesion occupying the right frontal lobe, lower intraoperative ultrasound images of the tumor which shows the demarcation between the lesion and edema.

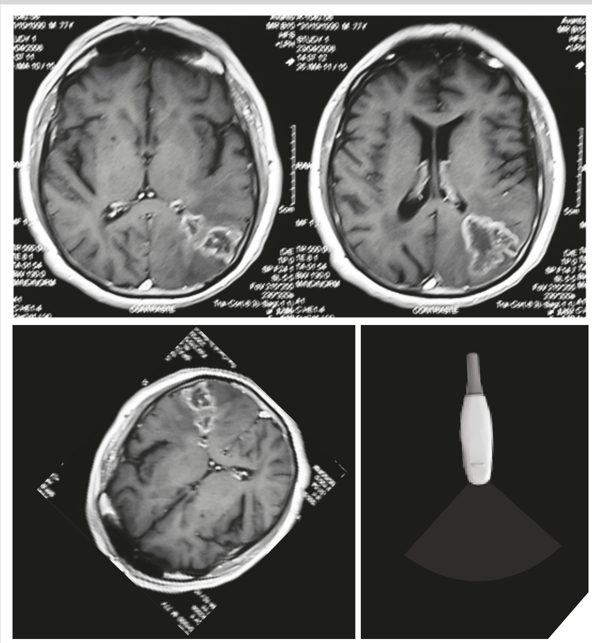


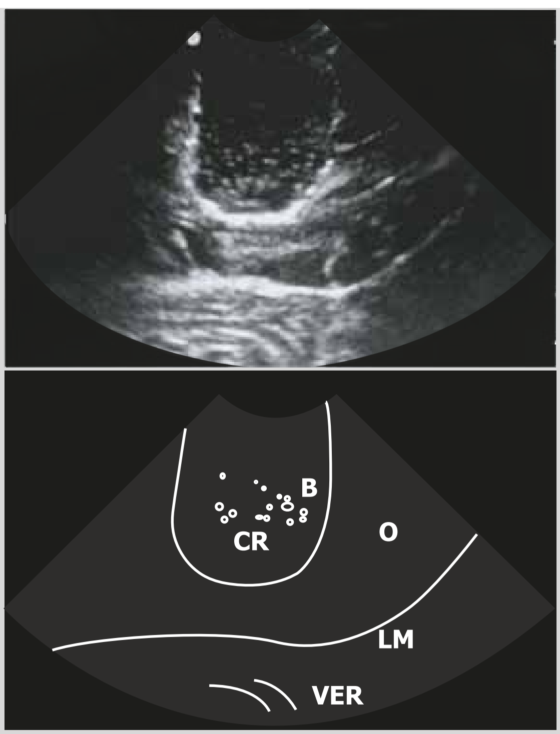


T Tumor, **E** Edema, **LM** Línea Media

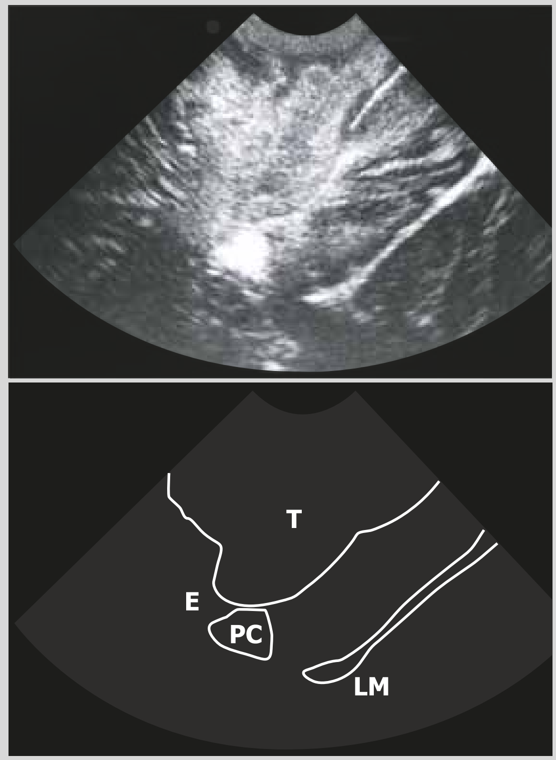
GLIOBLASTOMA,
PARIETOOCCIPITAL, LEFT

Axial MRI with gadolinium showing the lesion, together with the reorientation of the MRI to match the ultrasound image. Ultrasonographic image preoperative and post-removal of the lesion showing the resection cavity.





LM Línea Media, **CR** Cavidad de Resección, **B** Burbujas, **O** Occipital, **Ver** Vermis

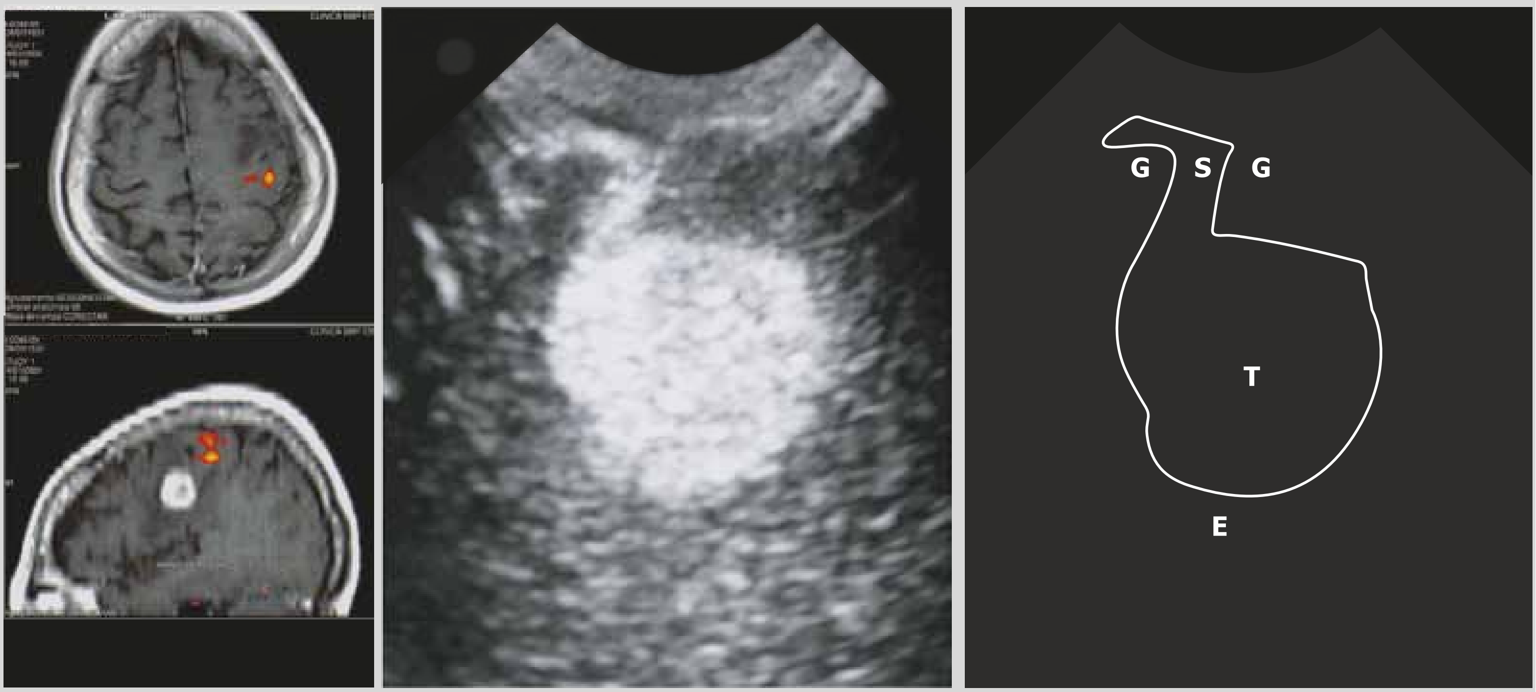


T Tumor, **E** Edema, **PC** Plexo Coroideo, **LM** Línea Media

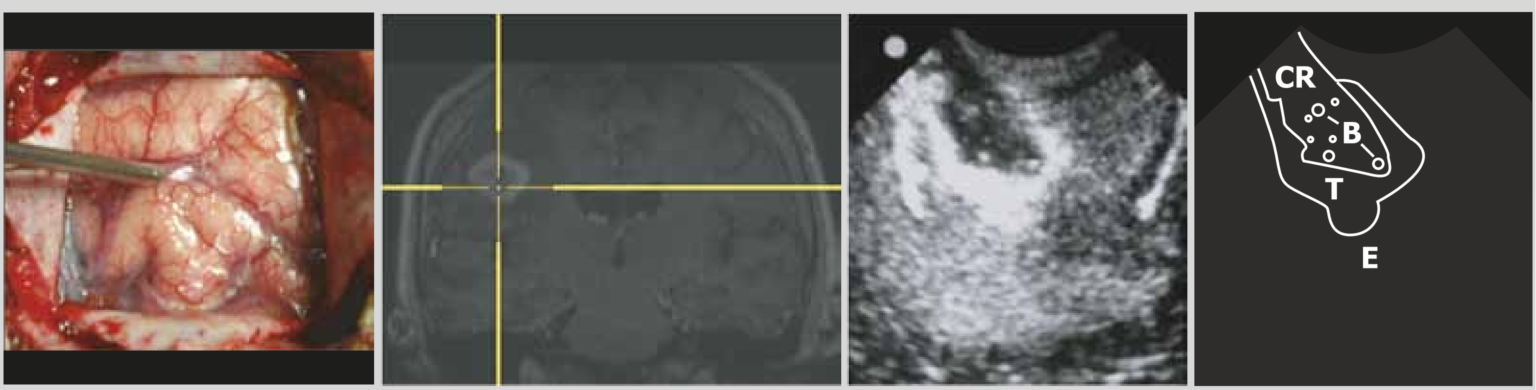
RM control

GLIOBLASTOMA
MULTIFORME, FRONTAL, LEFT

Functional MRI shows the lesion and its relationship with the motor strip. Intraoperative ultrasound in which the lesion is delineated with the associated brain edema, the path towards it via transsulcus aproach. Intraoperative photograph of the brain showing the sulcus of interest. Neuronavigation image shows the tool being tracked within the lesion and intraoperative ultrasound image of the real time progression of the removal of the lesion.



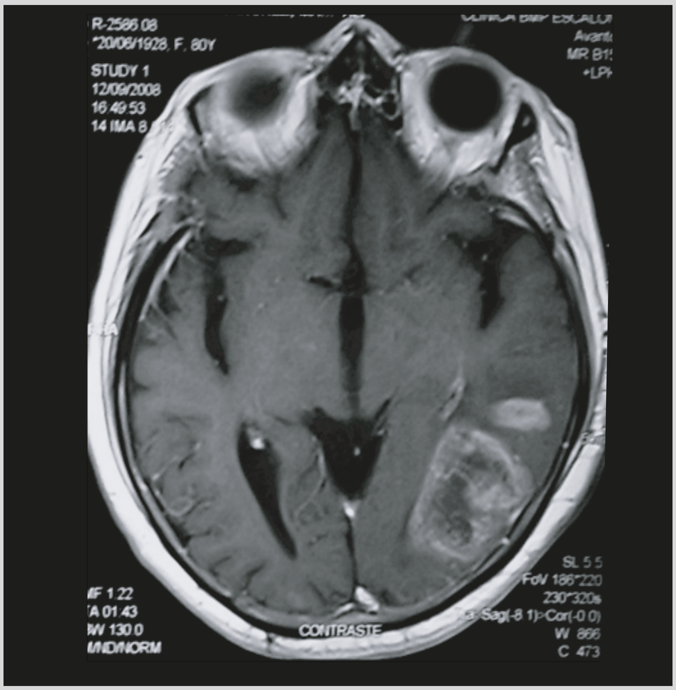
S Sulcy, **G** Girus, **T** Tumor, **E** Edema,

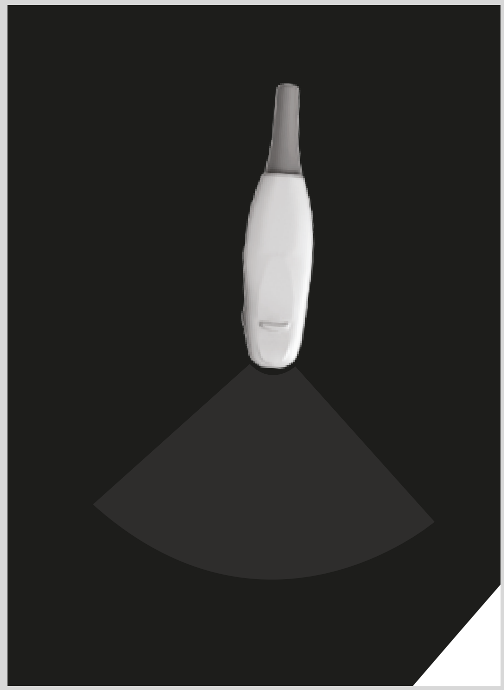


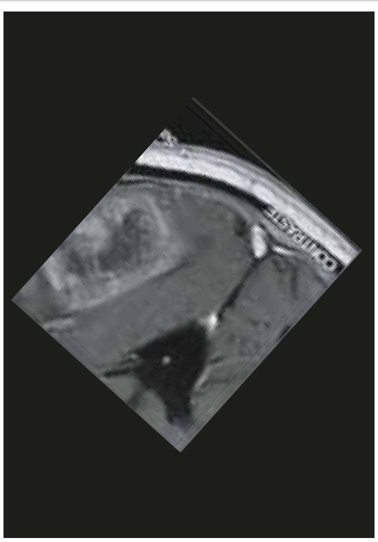
T Tumor, **E** Edema, **CR** Cavidad de Resección, **B** Burbujas

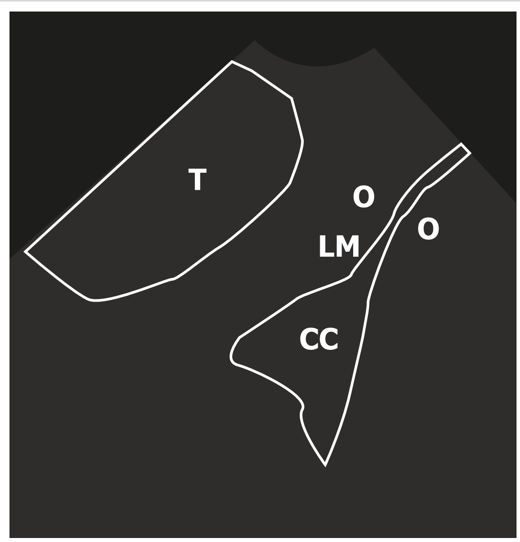
GLIOBLASTOMA
MULTIFORME, TEMPORAL REGION BACK, LEFT

Axial MRI with gadolinium showing infiltrative lesions, on the side schematization of the orientation of the ultrasound with regard to the lesion. Below, close-up of the MRI (area of interest) in relation to the intraoperative ultrasound image of the lesion.





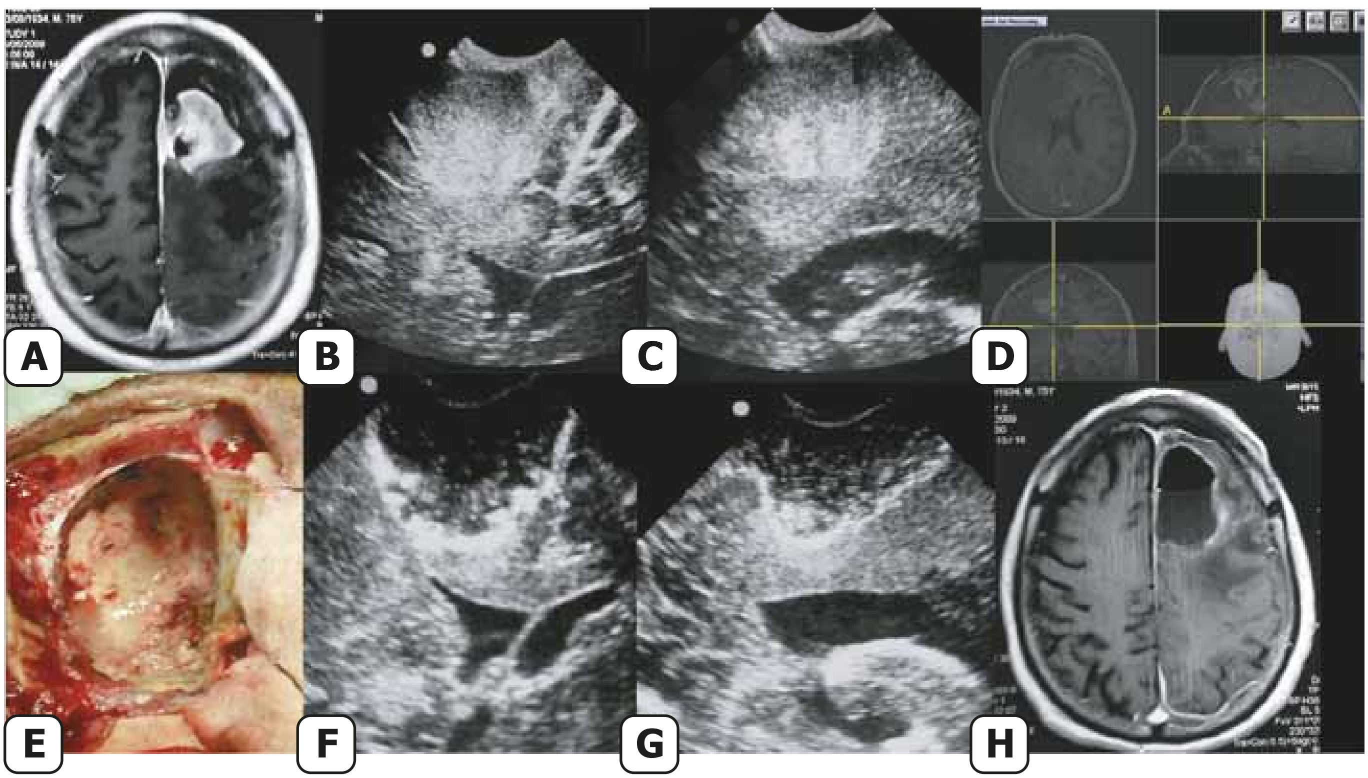


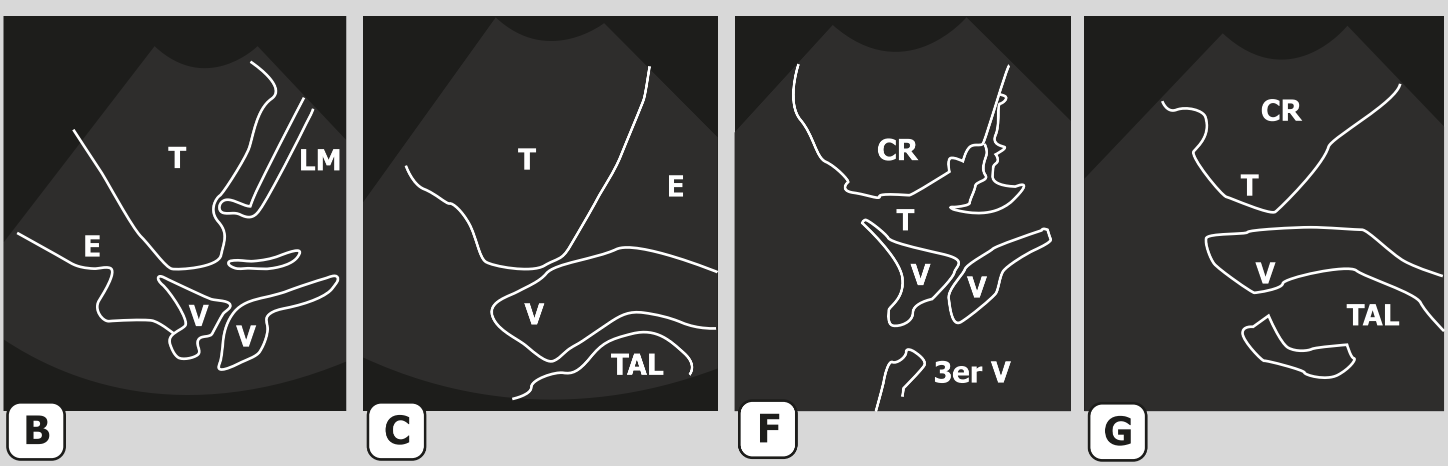


T Tumor, **CC** Cuadrigeminal Cistern, **LM** Línea Media

PRIMARY LYMPHOMA
OF THE CENTRAL NERVOUS SYSTEM, SUPPLEMENTARY MOTOR AREA

The first image shows axial MRI with gadolinium, with the presence of the lesion. Subsequent ultrasound images show coronal and sagittal cut of the tumor causing mass effect on left ventricle. Neuronavigation image showing the localization of the instrument being tracked in the basal part of the lesion. The images below show the resection cavity during the procedure, intraoperative ultrasonography images (coronal and sagittal) showing the resection cavity; at the bottom of the cavity there is still a remnant of tumor at the close to the corpus callosum (which was removed). Postoperative axial MRI.

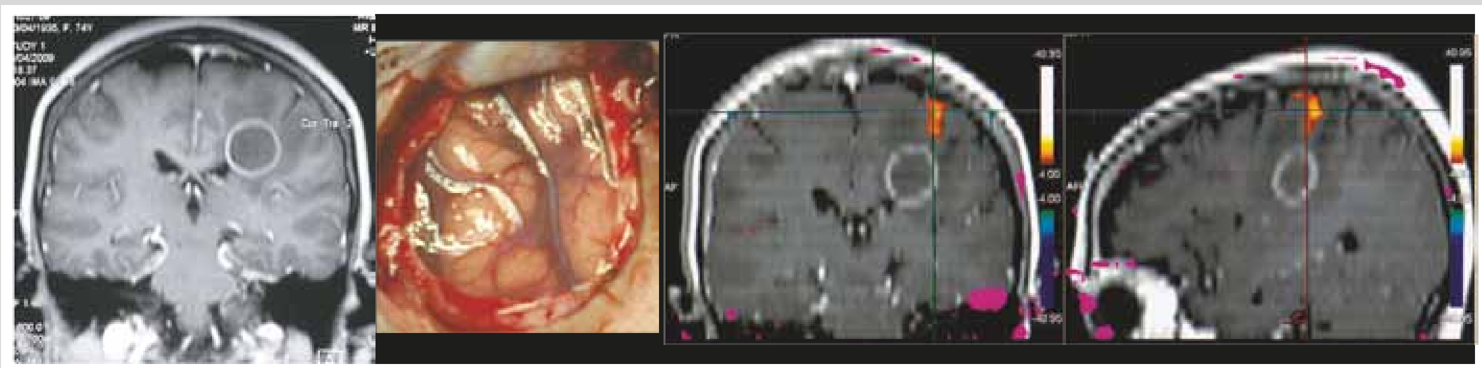


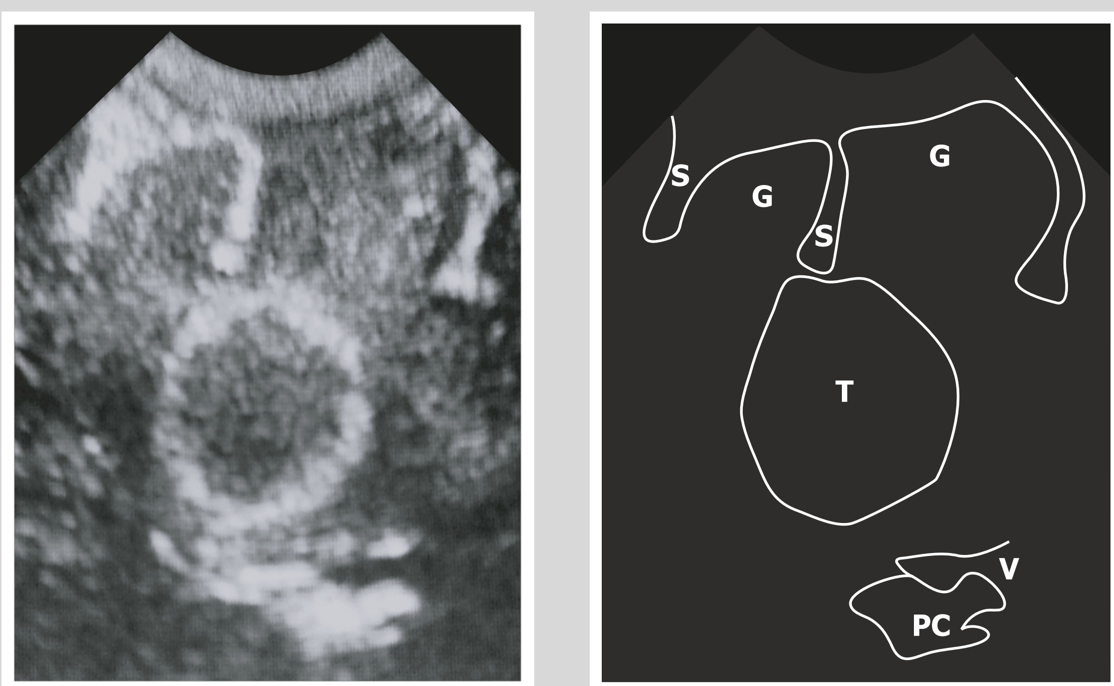


T Tumor, **E** Edema, **V** Ventrículo, **TAL** Thalamus, **LM** Línea Media, **CR** Cavidad de Resección, **3rd** Ventricle

CYSTIC METASTASIS,
FRONTOPARIETAL, LEFT

Coronal MRI showing a solitary cystic metastases with mass effect on the ventricle, Intraoperative photograph showing the orientation of the motor strip as functional MRI predicts it. The images below show the intraoperative ultrasound image of the cystic lesion, the path leading to it and its proximity to the ventricle and choroid plexus.

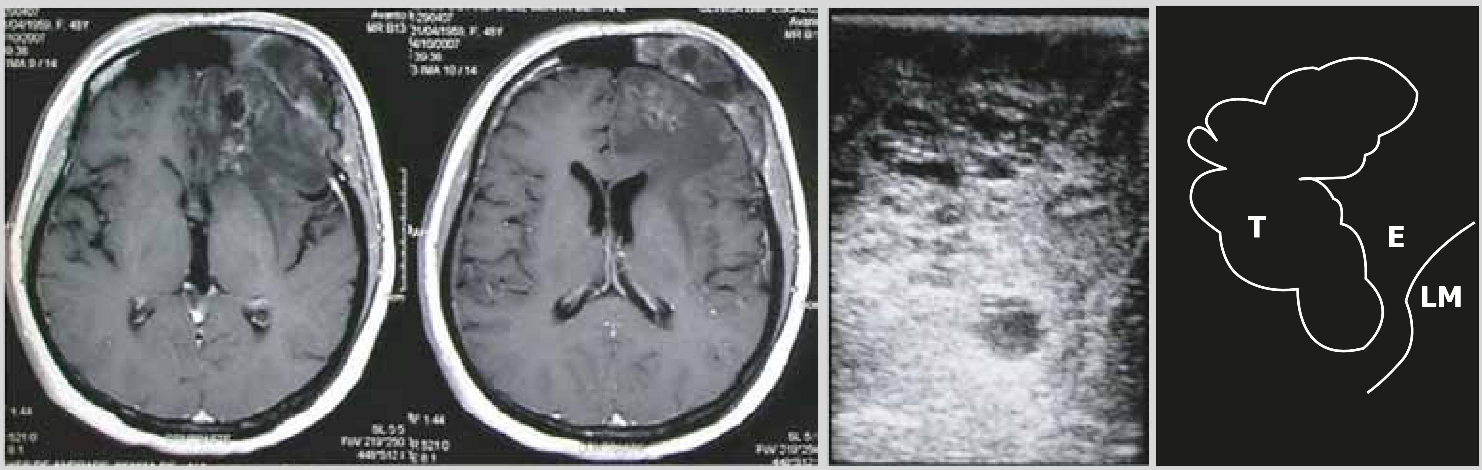




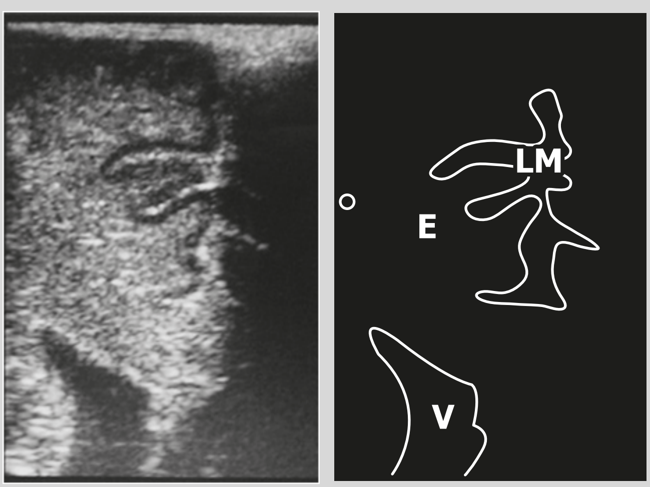
S Surcos, **G** Giros, **T** Tumor, **V** Ventrículo, **PC** Plexo Coroideo

NEUROESTESIOBLASTOMA
WITH PENETRATION IN THE BRAIN

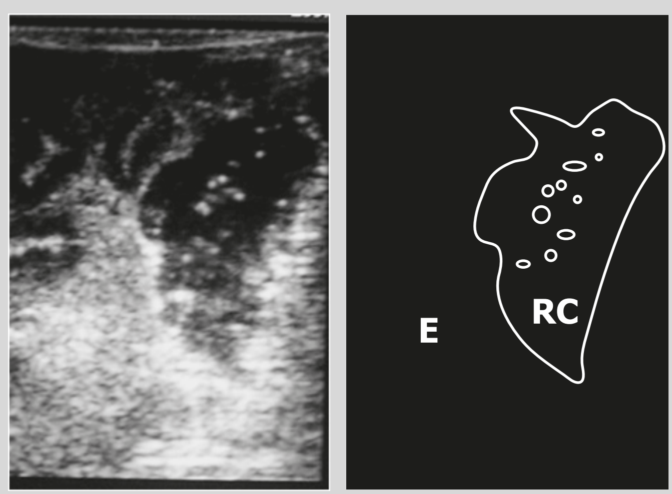
Axial MRI shows brain tumor infiltration. Ultrasound image shows irregular multi-cystic of intra-axial tumor and edema associated. Coronal ultrasonographic image from a top view with ultrasound showing the abundant periventricular edema in the frontal lobe. The following image shows the resection cavity where the tumor was.



T Tumor, **E** Edema, **LM** Línea Media



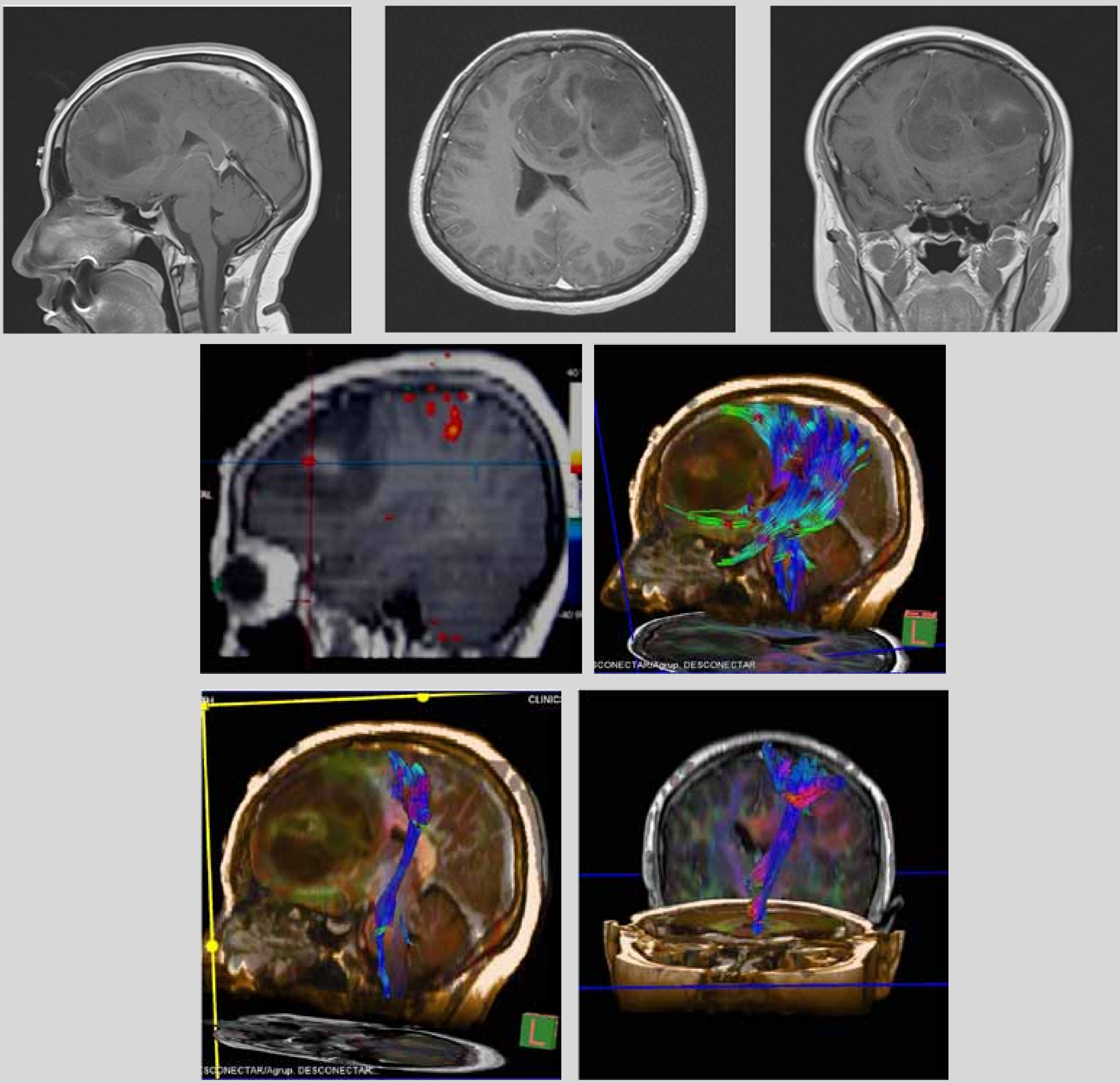
E Edema, **V** Ventrículo, **LM** Línea Media

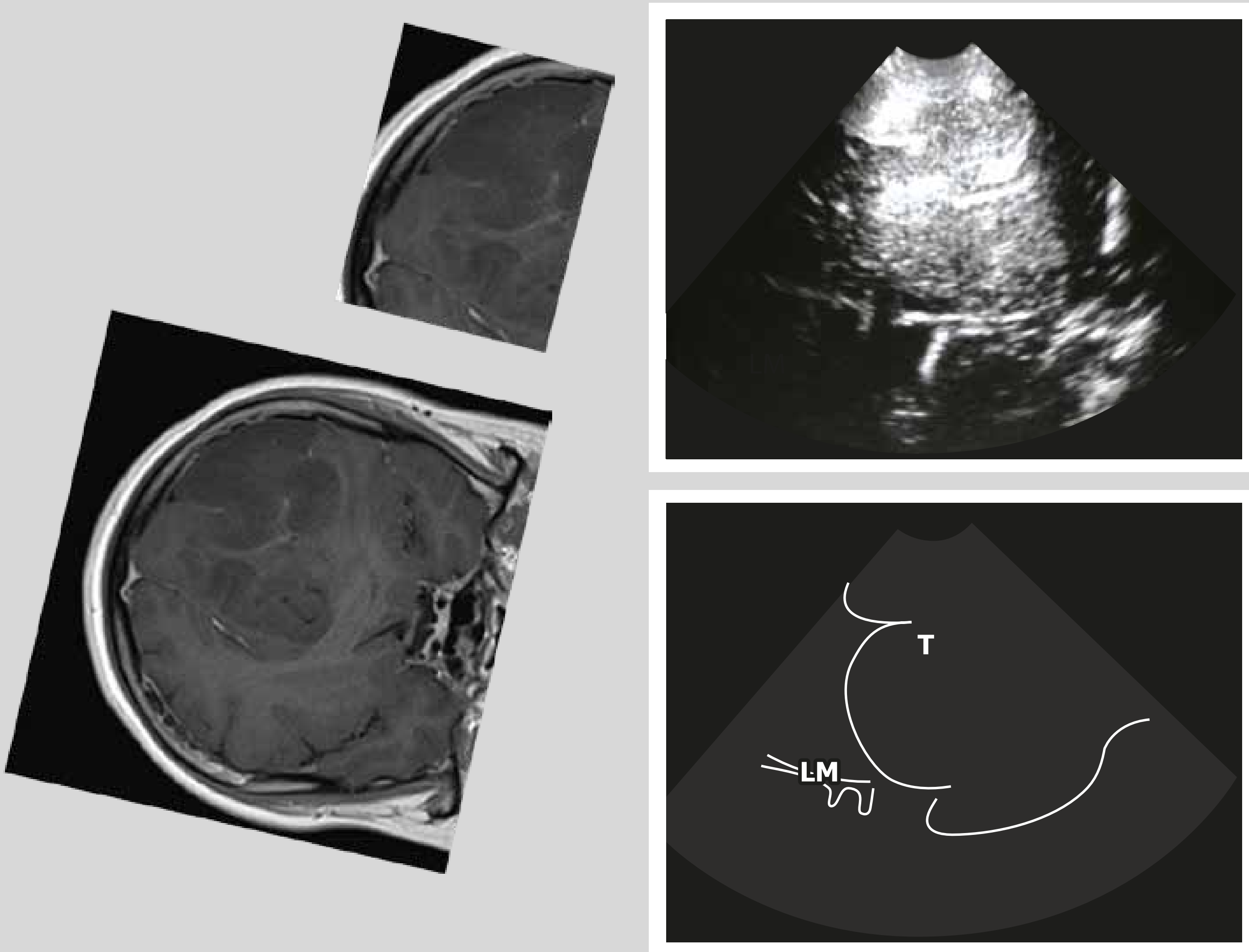


E Edema, **CR** Cavidad de Resección, **B** Burbujas

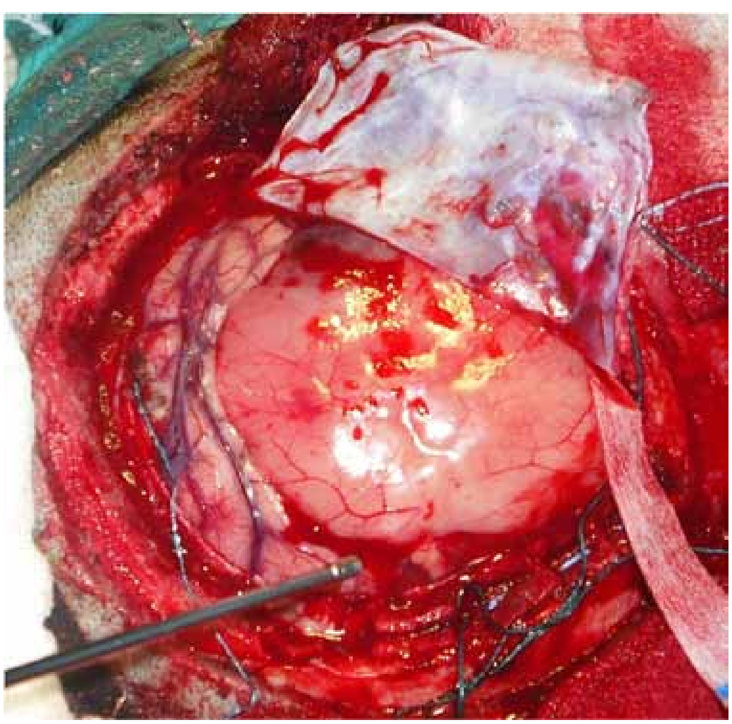
EPENDIMOMA
ANAPLASICO FRONTAL IZQUIERDO

Images from top to bottom and from left to right: RM T1 GAD in the 3 planes that show a left frontal expansive tumor. The images in the middle show a RMf with neuroactivation of the right hand, to note is the displacement of the motor cortex to the caudal plane. Next to the RMf is a DTI sequence (Diffusion Tensor Image) tractography shows displacement of the tracts in the neighboring parts of the tumor. The inferior images of DTI just show the pyramidal tract that is respected all along its path.

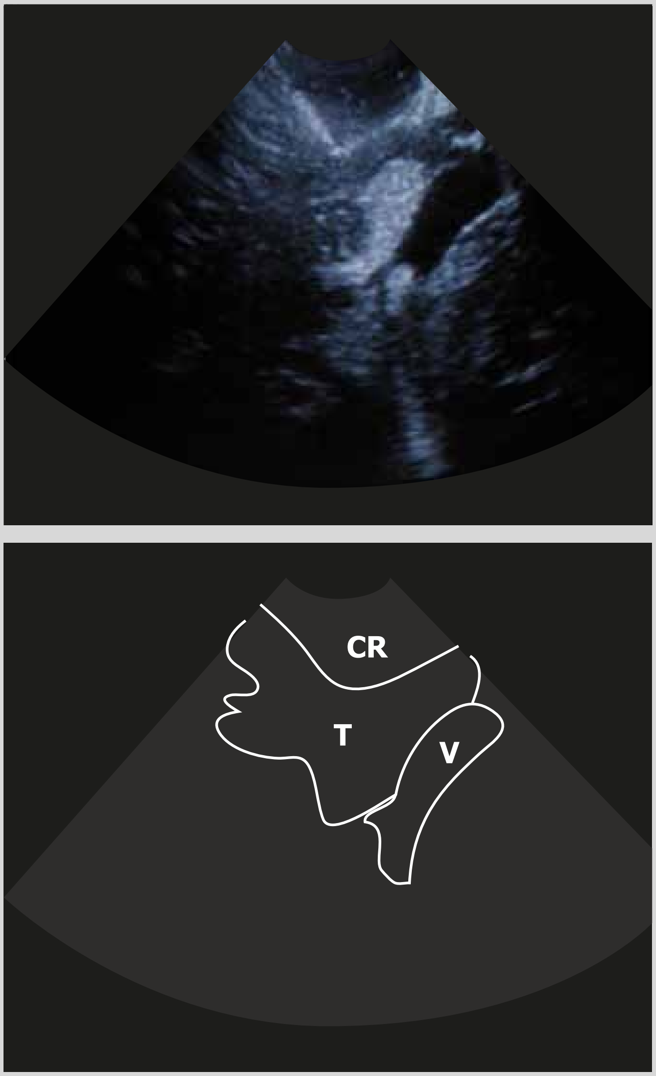




T Tumor, **LM** Línea Media

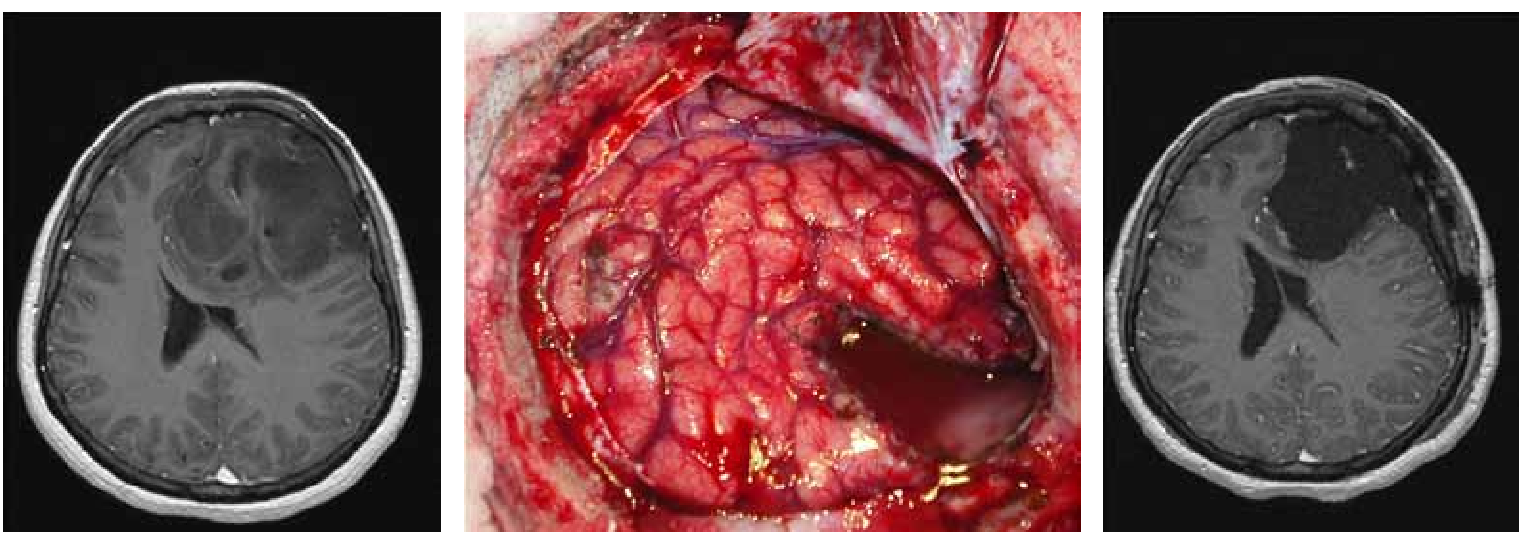


Images from top to bottom and from left to right: Close-up of the RM in coronal plane that has been angled for ultrasound correlation. At the bottom, intraoperative photograph showing the extra-axial lesion.



CR cavidad de resección, T Tumor, **V** Ventrículo, PC plexo coroideo

CR cavidad de resección, LM Línea media, **V** Ventrículo, S sangre

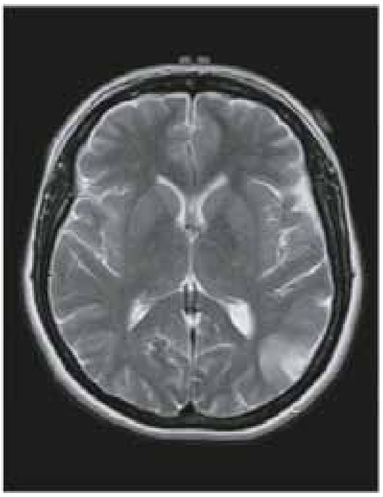
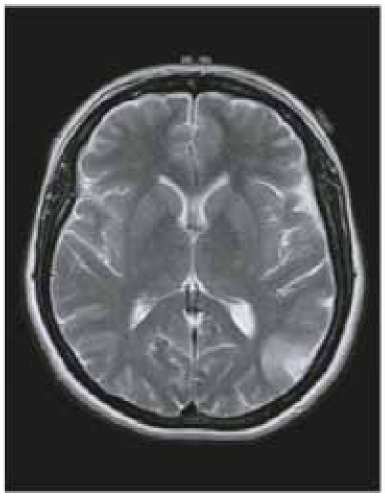
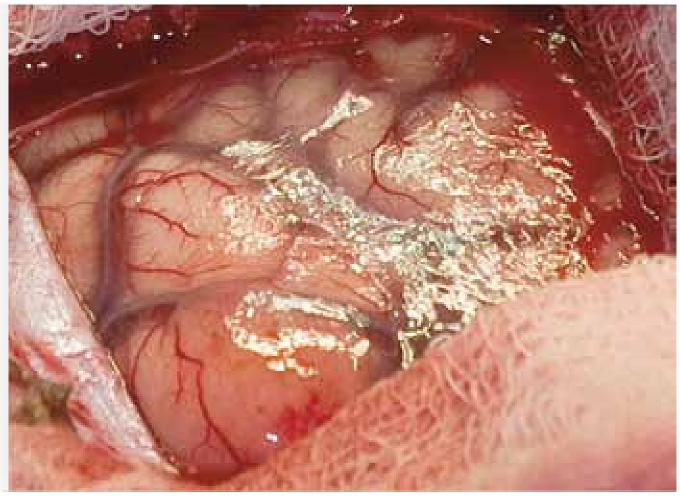


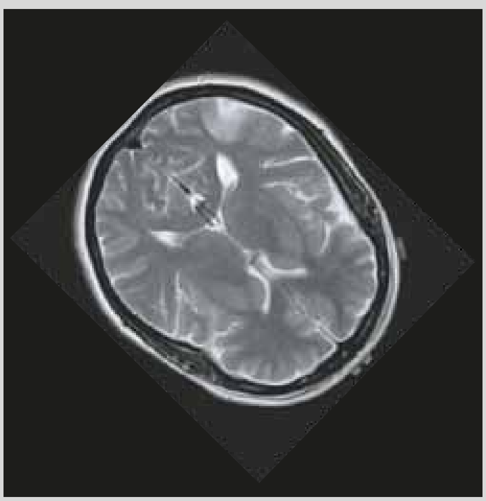
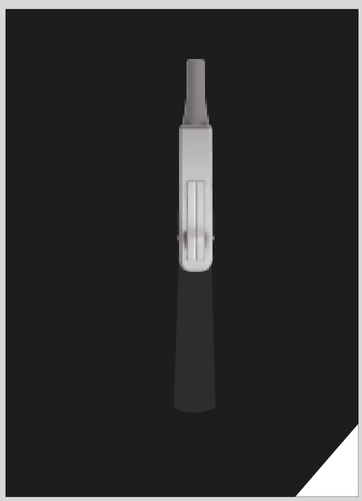
Images from top to bottom and from left to right: Intraoperative ultrasound that shows the left ventricle with residual tumor above it, in the corpus callosum region. The next ultrasound image shows the left ventricle that has been violated and it shows blood (S) inside it, this information was useful to correct this potential complication; the tumor is no longer visible. Bottom, preoperative RM that shows the lesion, middle an intraoperative photograph at the end of the procedure, and RM T1 GAD control.

LOW GRADE TUMORS AND OTHER BENIGN LESIONS

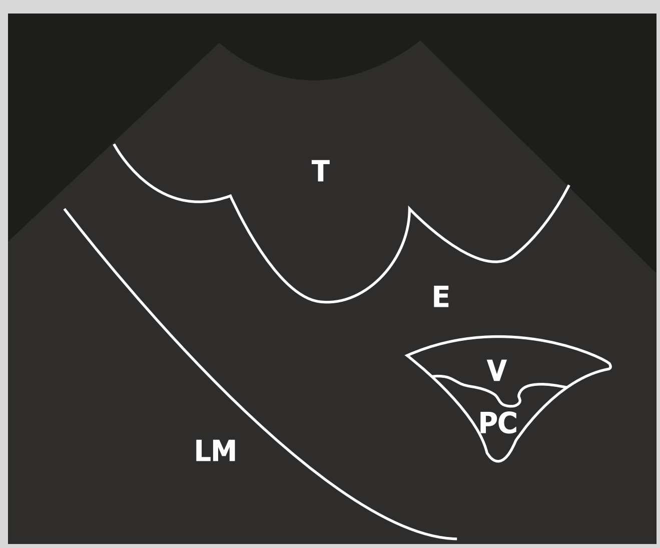
- **ASTROCYTOMA,** LEFT PARIETAL REGION
- **ASTROCYTOMA,** RIGHT PARIETAL PILOCYTIC
- **CHOROID PLEXUS** PAPILLOMA
- **OLIGODENDROGLIOMA** RIGHT FRONTAL
- **ASTROCITOMA**, RIGHT TEMPORAL
- **MENINGIOMA** RIGHT PARASAGITTAL
- **MENINGIOMA** RIGHT FRONTAL ON A LEFT HANDED PACIENT
- **MACROADENOMA OF** PITUITARY, BIFRONTAL APPROACH

ASTROCYTOMA,
LEFT PARIETAL REGION

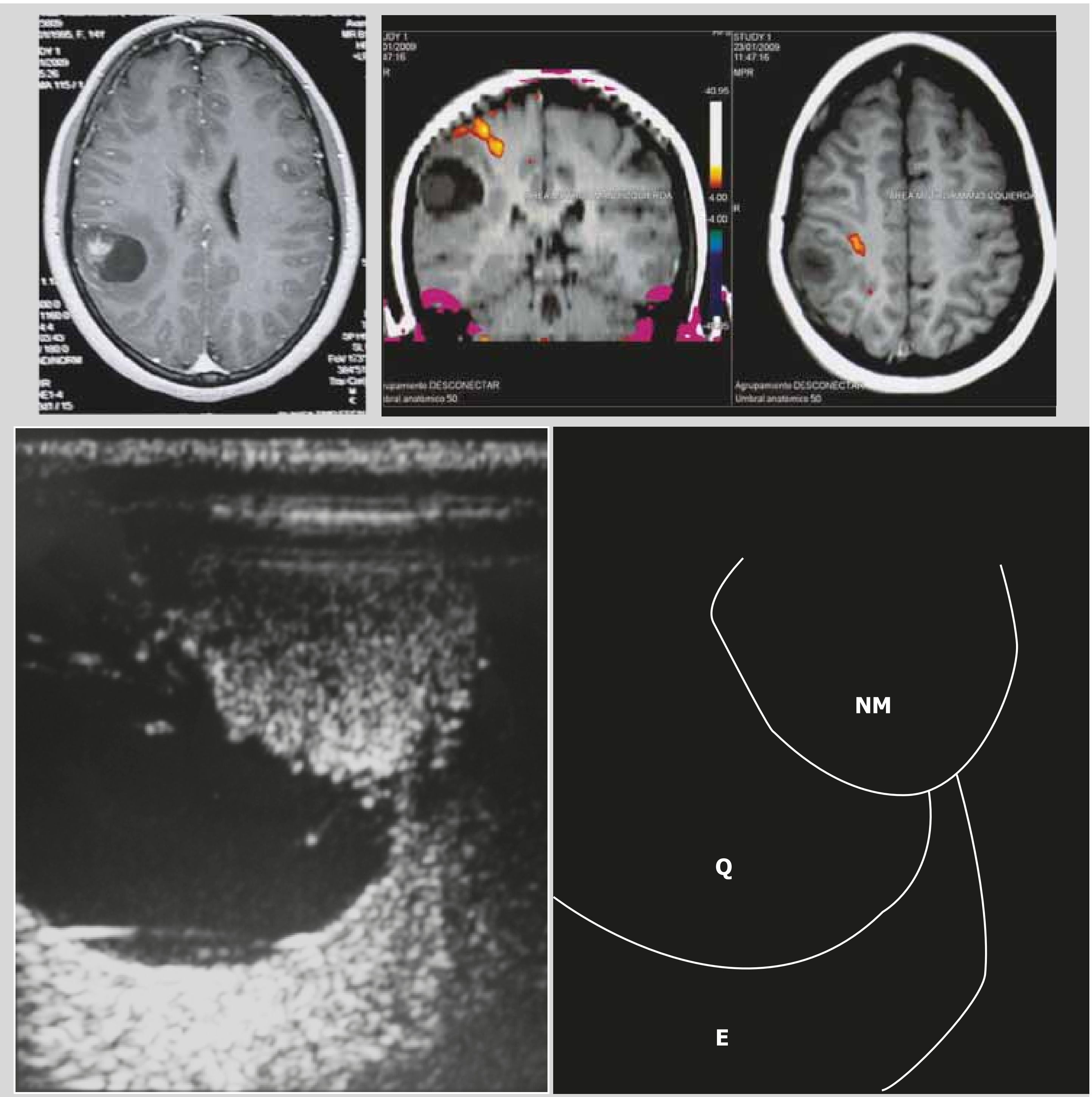
MRI axial T2 showing the infiltrative lesion. Tilting MRI image to match the ultrasound image. Intraoperative photograph showing cortical representation of the lesion on the most posterior gyrous. Ultrasonographic view of the tumor and three-lobed appearance with relation to the midline and ventricle.

T Tumor, **E** Edema, **V** Ventrículo, **PC** Plexo Coroideo, **LM** Línea Media

ASTROCYTOMA,
RIGHT PARIETAL PILOCYTIC

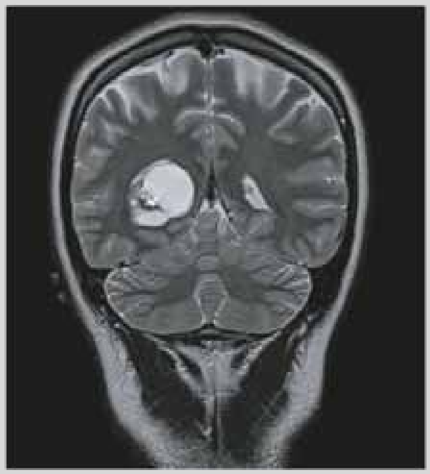
Axial MR sequences and functional MRI gadolinium showing the displacement of the motor strip in relation to the injury. Ultrasonographic view of the cyst with mural nodule inside. To notice is the edema associated with injury.

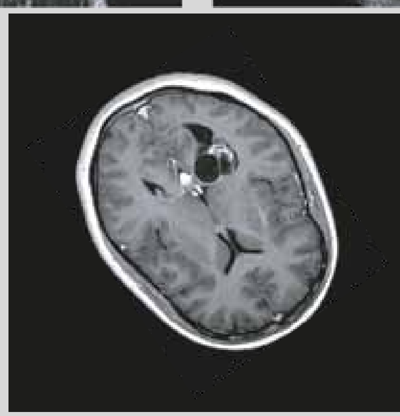


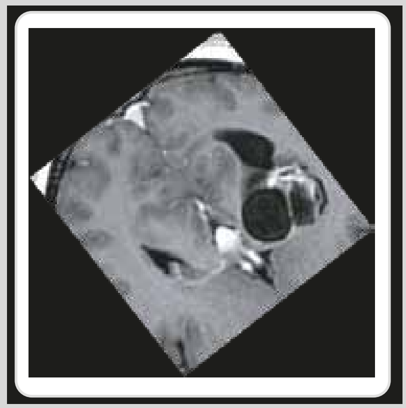
NM Mural Nodule, **Q** Quiste, **E** Edema

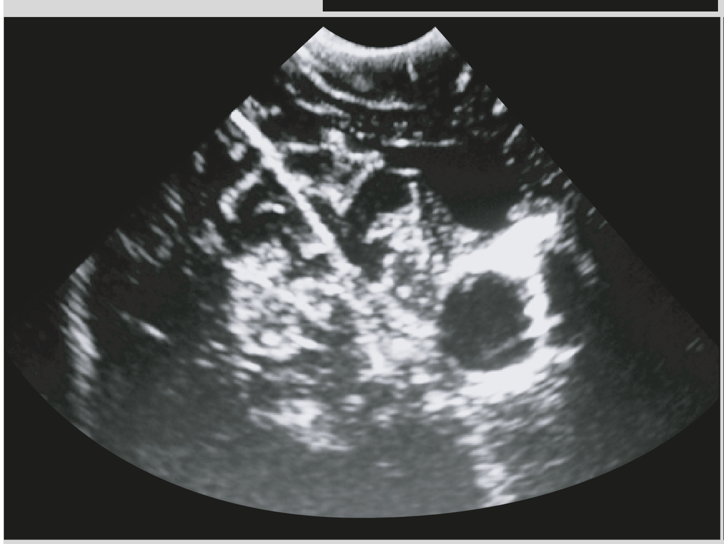
CHOROID PLEXUS
PAPILLOMA

Sagittal MRI sequences, axial T2 and T1 with gadolinium showing the intraventricular lesion. Down, Rotating the MRI findings and approach the area of interest to match the ultrasound image. Ultrasonographic image showing the calcified lesion within the ventricle. On the next page MRI is angled with measurement of lesion size, next to it the same image with ultrasound measuring the primary lesion. Below, diagram of the transducer in the resection cavity. Intraoperative ultrasound after complete resection of the lesion. Finally Neuronavegation image at the end of the procedure showing the tool being tracked in contact with the right thalamus.

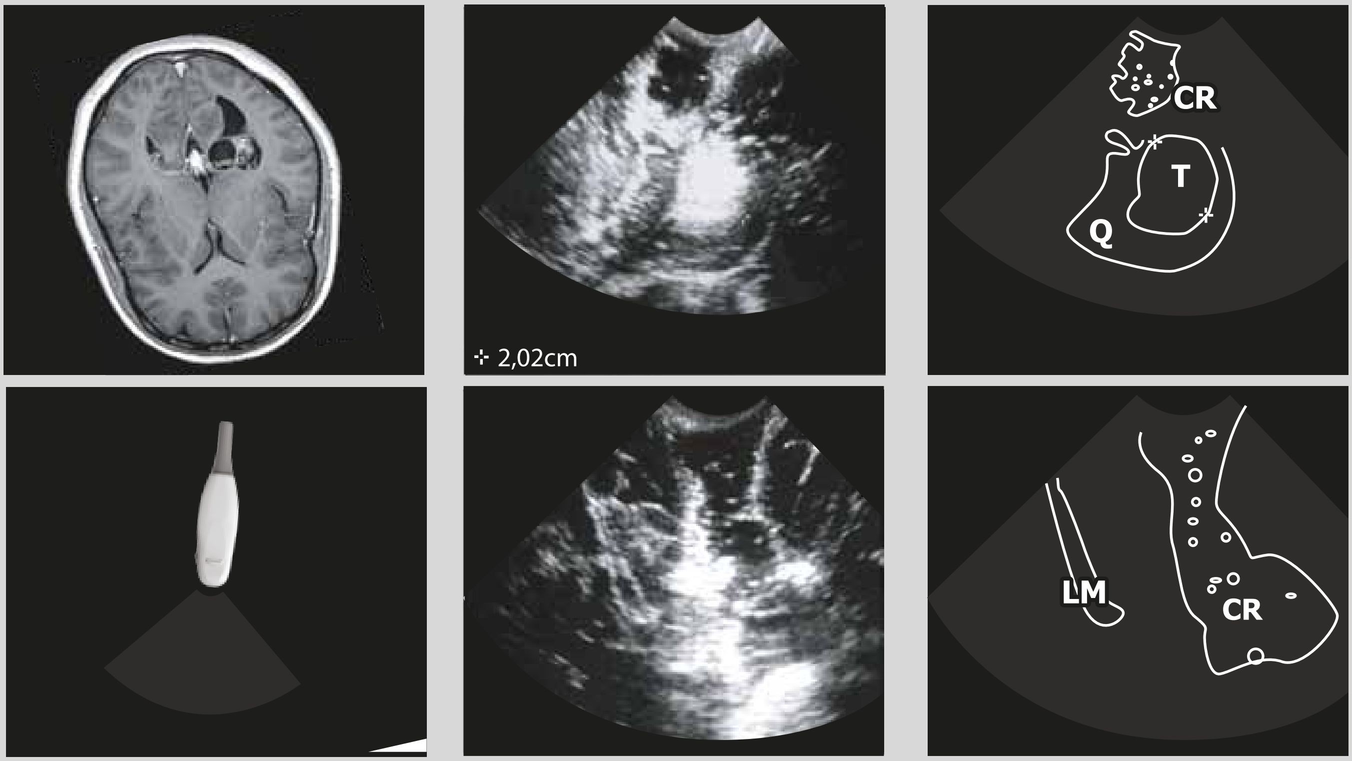




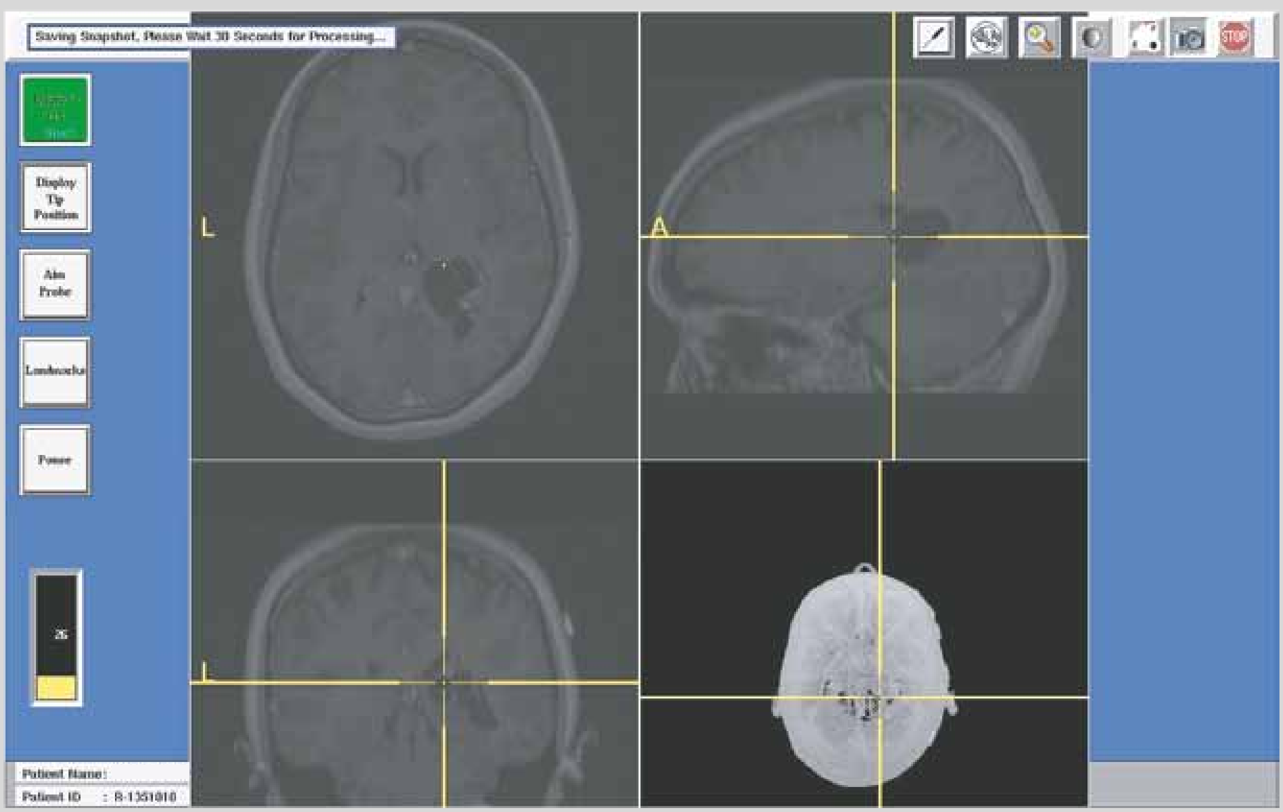




T Tumor, **V** Ventrículo, **LM** Línea Media, **Q** Quiste

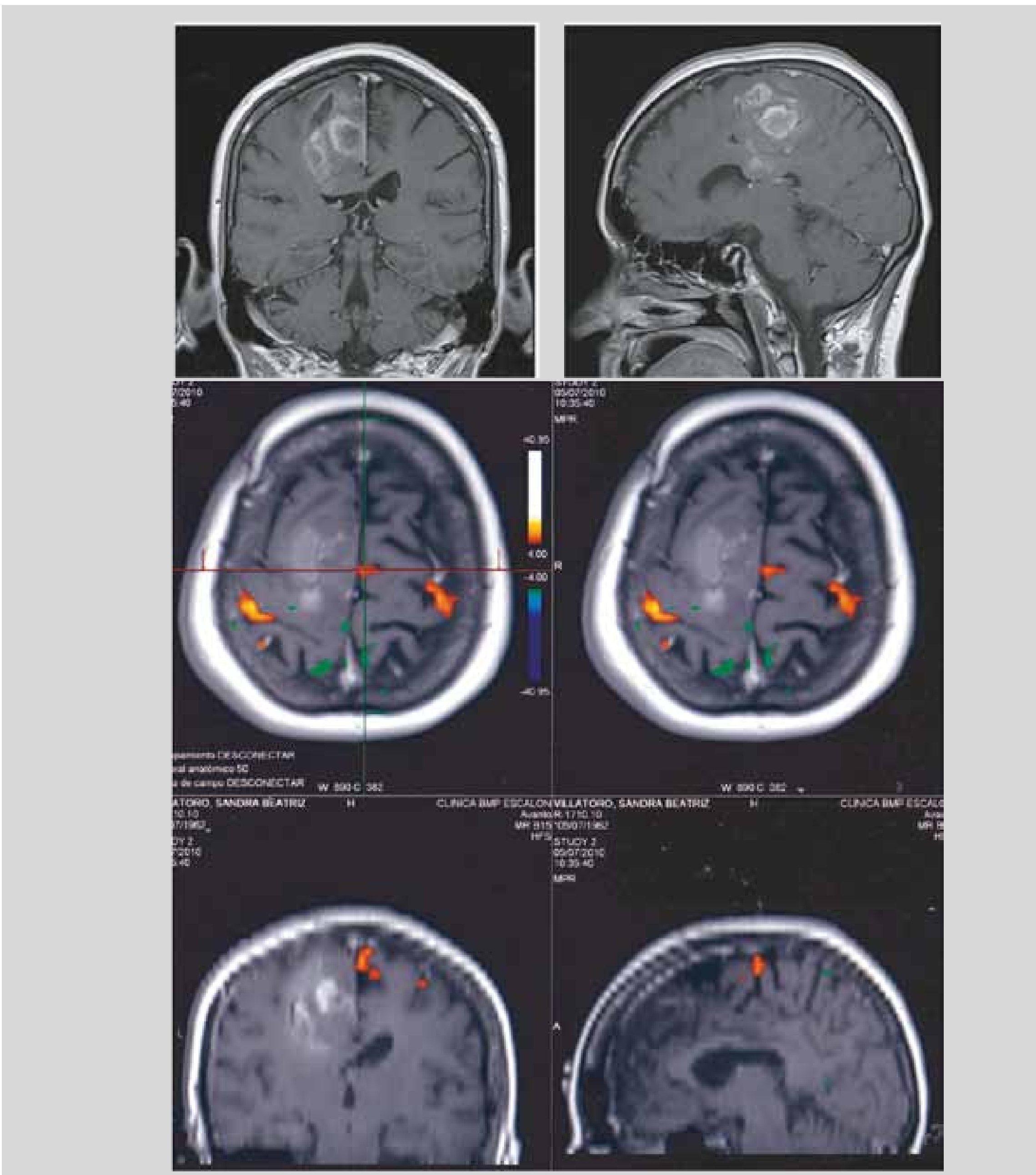


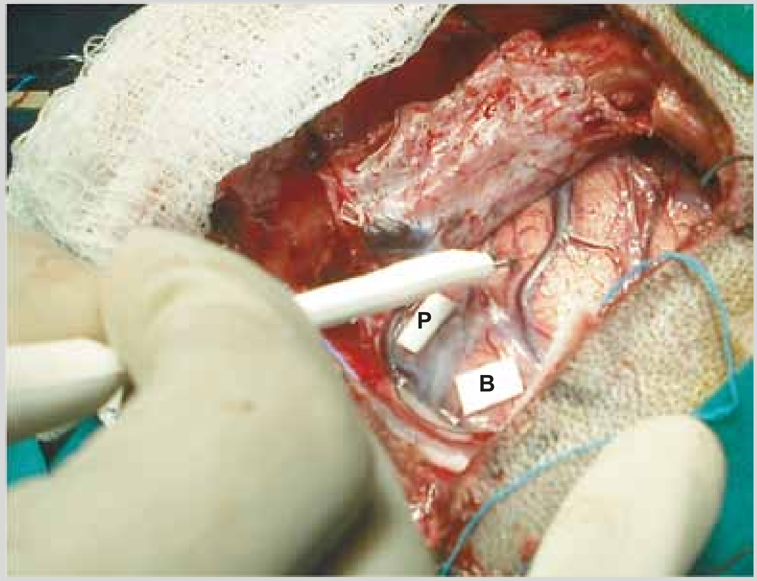
T Tumor, **V** Ventrículo, **LM** Línea Media, **Q** Quiste, **CR** Cavidad de Resección

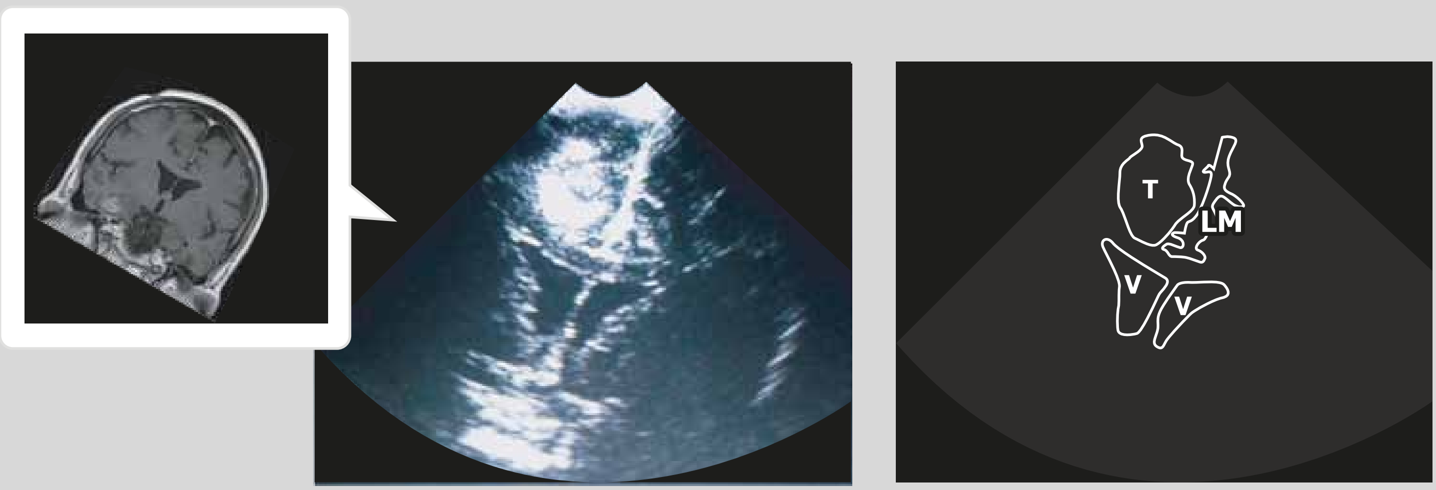


OLIGODENDROGLIOMA
RIGHT FRONTAL

MRI T1 with contrast in coronal and saggital slides that show a right frontal tumor producing mass effect over the ipsilateral ventricle. Functional MRI that shows the neuroactivation of the left hand (the foot does not illuminate du to a severe pre-operative paresis). Photographic sequence that shows pre-incision planification (based on Image Guided Surgery) where the close relation with regard to tumor-motor strip can be seen, next image shows corticostimulation process of motor strip identification intraoperatively right behind the tumor borders (P- represents Foot and B arm). MRI has been angled to match intraoperative ultrasound of the most anterior aspect of the tumor, the rest of the sequences show the same MRI correlation but of the most medial aspect of the tumor where its mass effect over the ventricle can be seen. Intraoperative photograph of the resection cavity and the Image Guided Surgery Probe in the most inferior part of the tumor which is verified in the 3 planes on the monitor, also the ultrsonographic correlation showing the resection cavity at this level. Finally, postoperative MRI that has been angled to match the intraoperative ultrasound image.

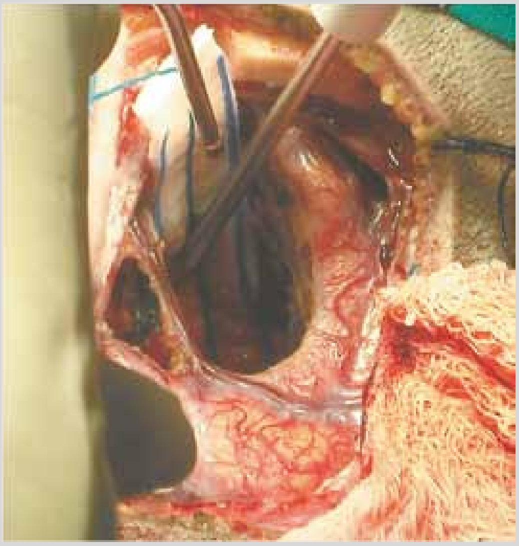


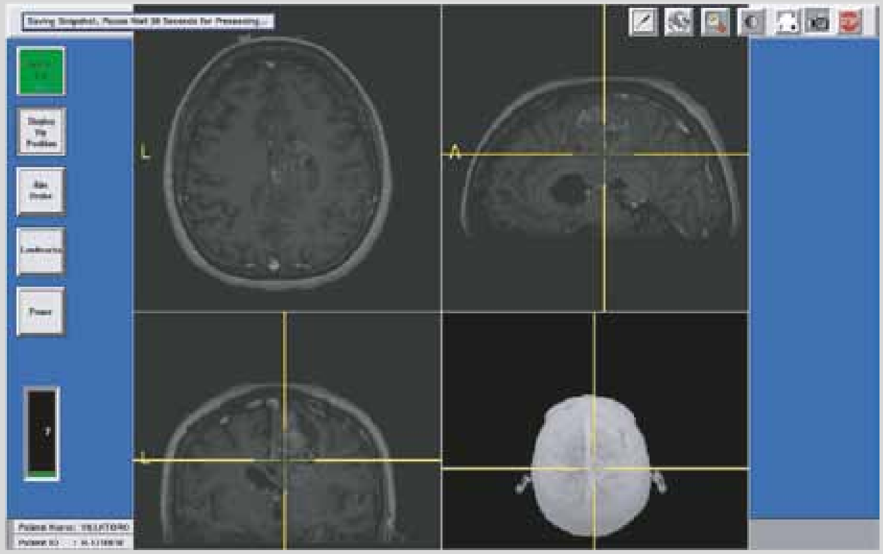




T Tumor, **V** Ventrículo, **LM** Línea Media

P peduncle, **T** tumor, **CF** cerebelar folia





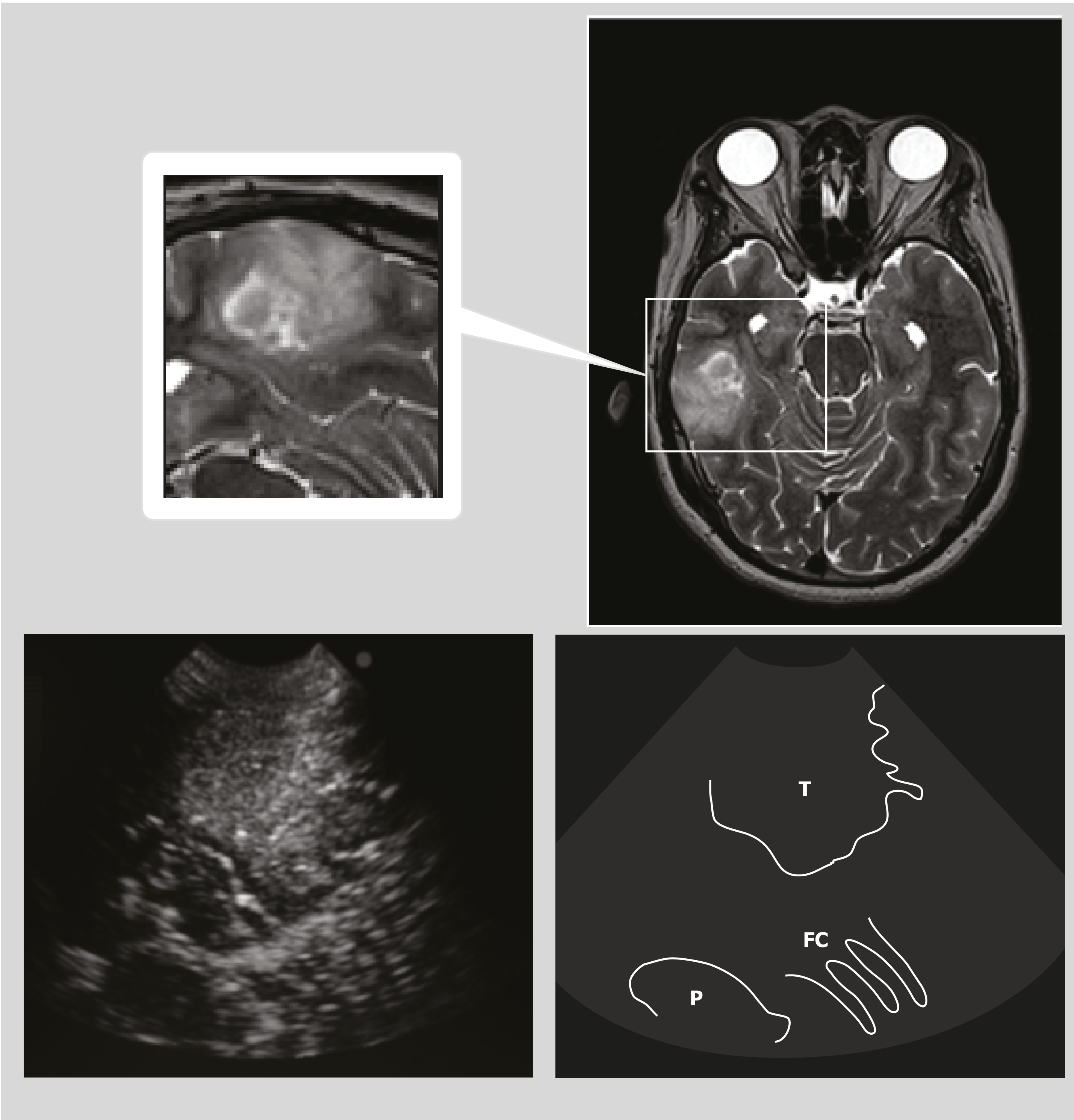
CR Cavidad de Resección, **V** Ventrículo

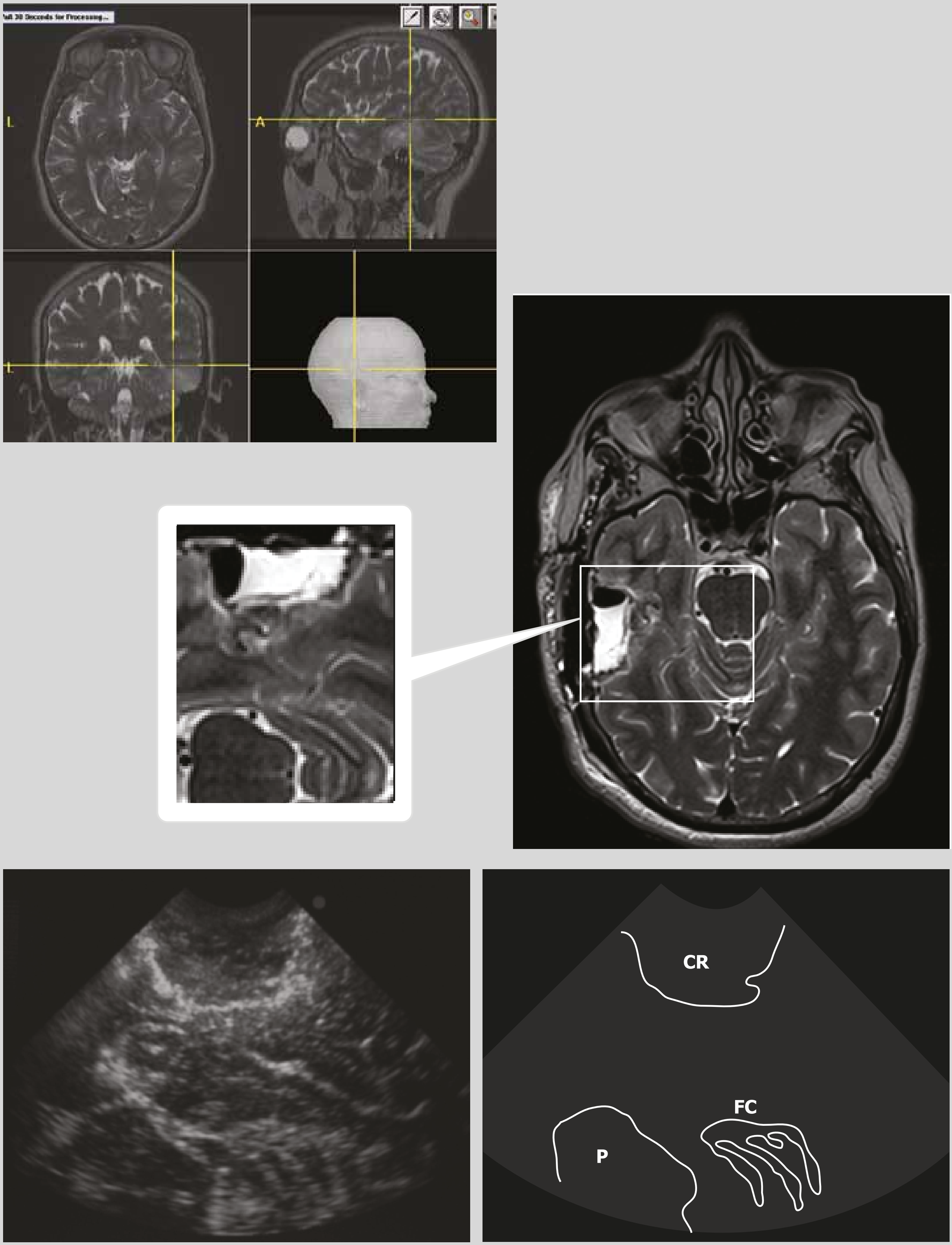
ASTROCITOMA, RIGHT TEMPORAL

T2 axial MRI showing the right temporal lesion with a close up of the lesion that has been angled to match the intraoperative ultrasound image ate the bottom.

Next page

Intraoperative Image Guided Surgery System displaying the deepest part of the resection, Transoperatory MRI showing cavity of resection with a close up of the lesion that has been angled to match the intraoperative ultrasound image at the bottom.

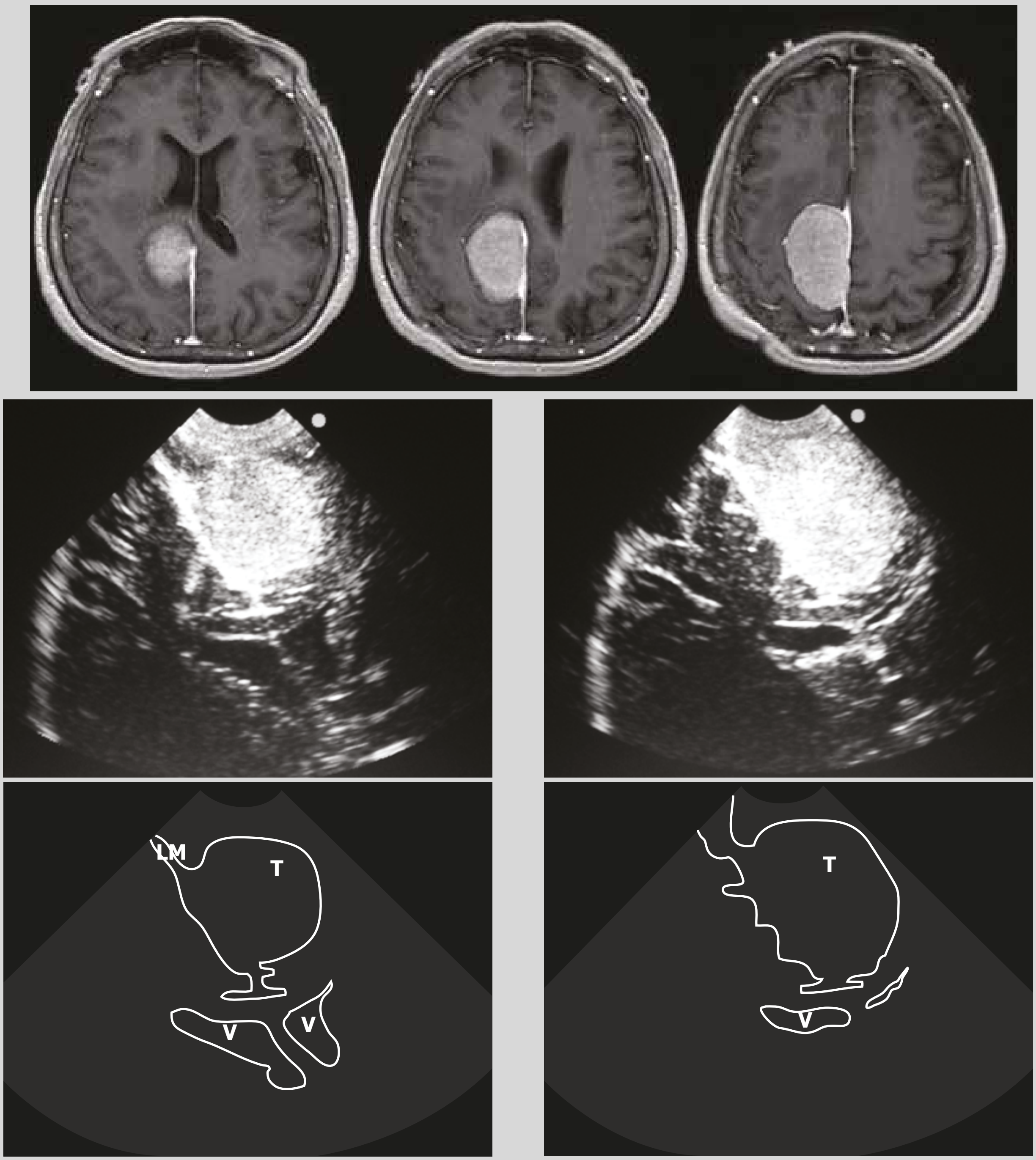




R resection cavity, **P** peduncle, **CF** cerebelar folia

MENINGIOMA
RIGHT PARASAGITTAL

Axial MRI with gadolinium showing the lesion and the mass effect on the right ventricle. Below, coronal ultrasonographic images from the most anterior to the most posterior part of the tumor where it exerts its greatest effect on the ventricular wall. The following page shows images of Neuronavegation at the end of the resection at the deepest point of the tumor. MRI control, which has been angled to match the ultrasound images. Below, a close-up (more superficial view) of the resection cavity, the second image shows a deeper image of ultrasound. To note is the ability of the ultrasound to see clearly distant structures of the contralateral hemisphere.



LM Línea media, **V** Ventrículos, **T** Tumor

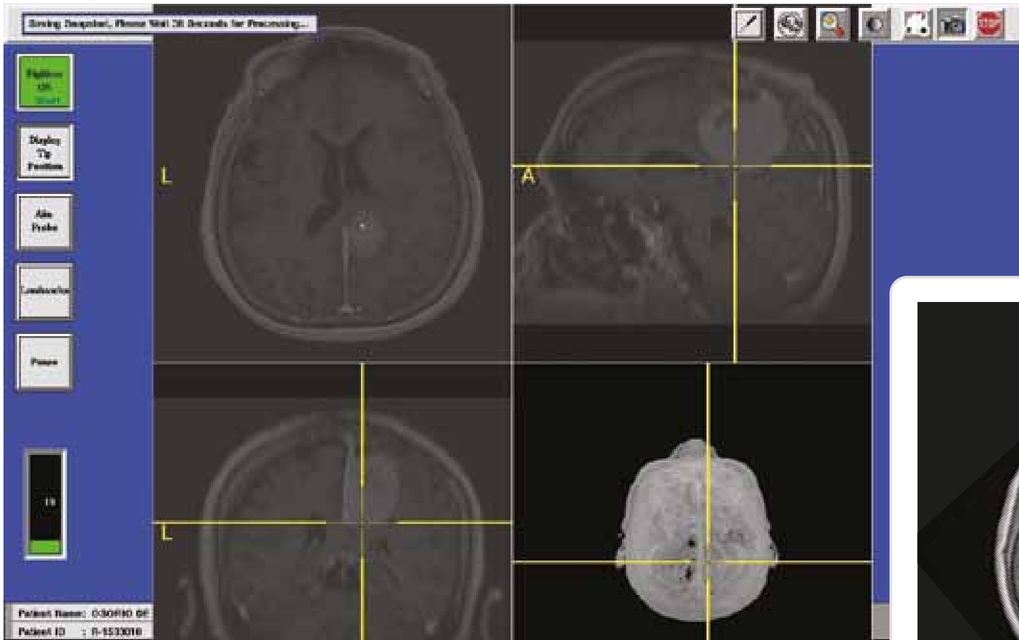
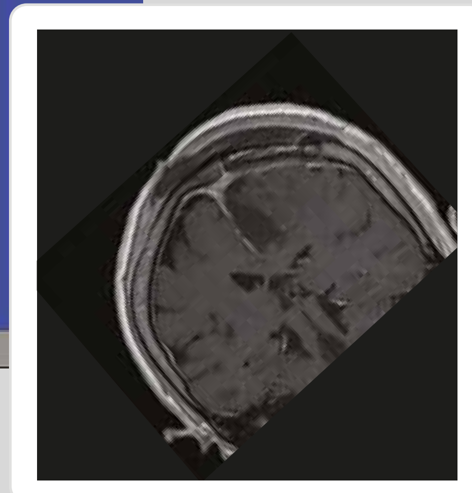
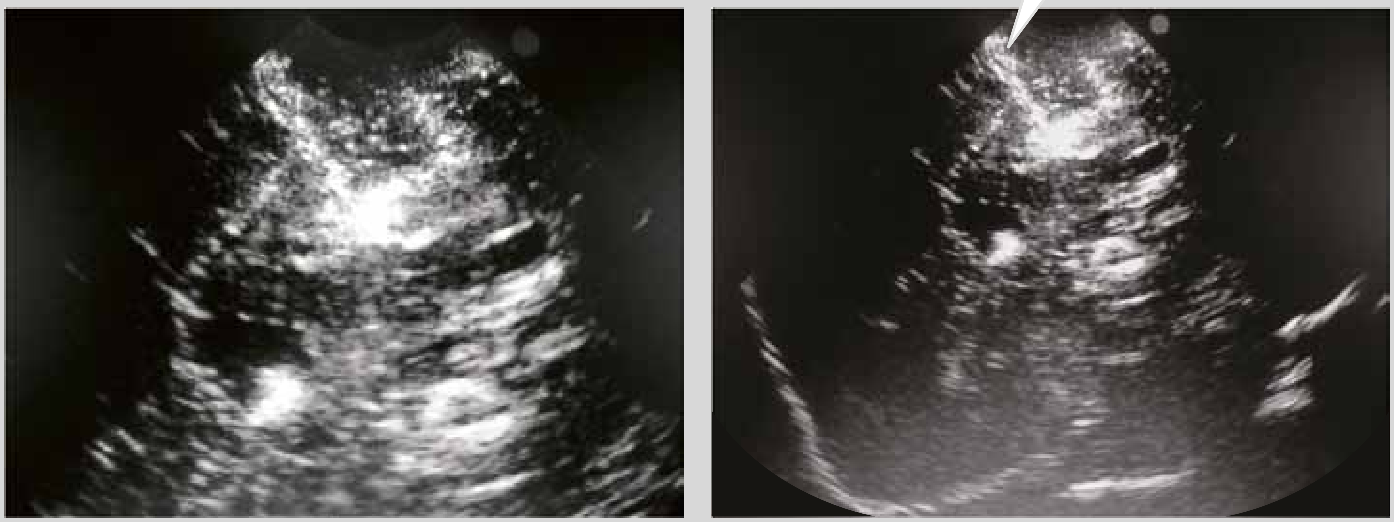


Imagen de neuronavegación al final del procedimiento



RM control



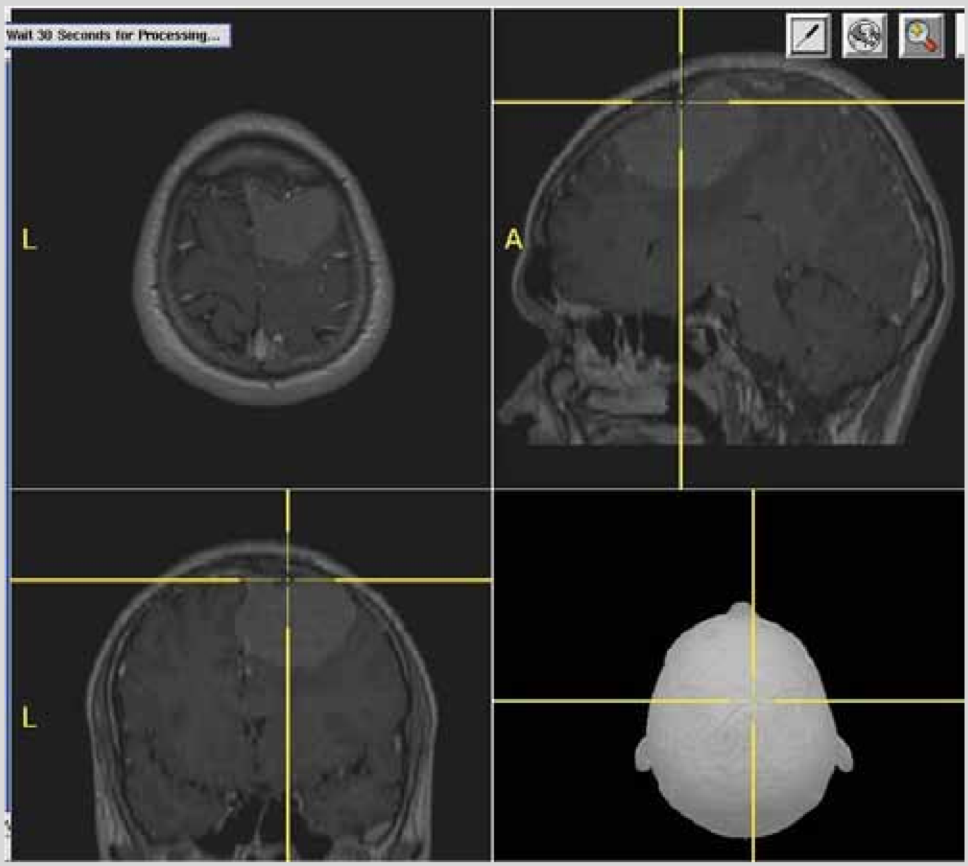
CR Cavidad de resección, **V** Ventrículos, **PC** Plexo coroideo, **LT** Lobulo temporal

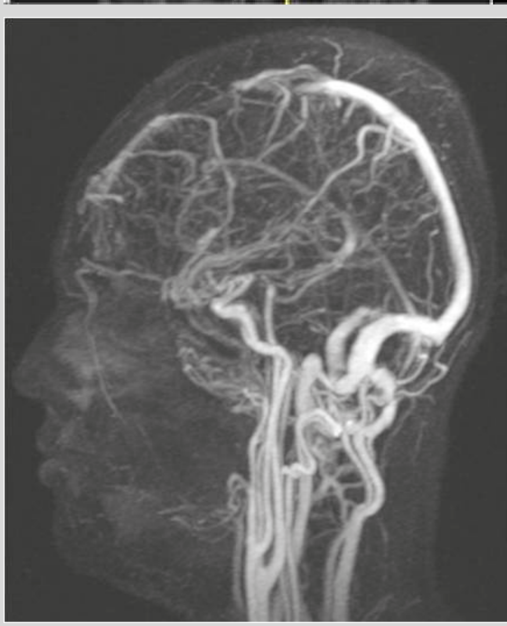
MENINGIOMA RIGHT FRONTAL ON A LEFT HANDED PACIENT

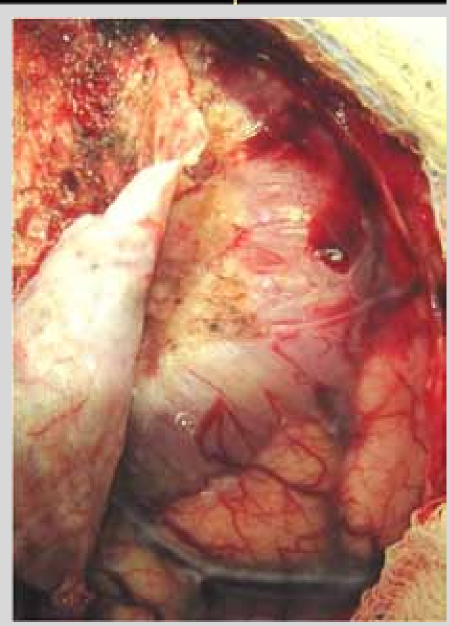
The first image shows the screen display of the Image Guided Surgery System showing a right frontal meningioma, Venous (TOF) MRI shows superior saggital sinous compromise. At the bottom right is an intraoperative picture of the lesion.

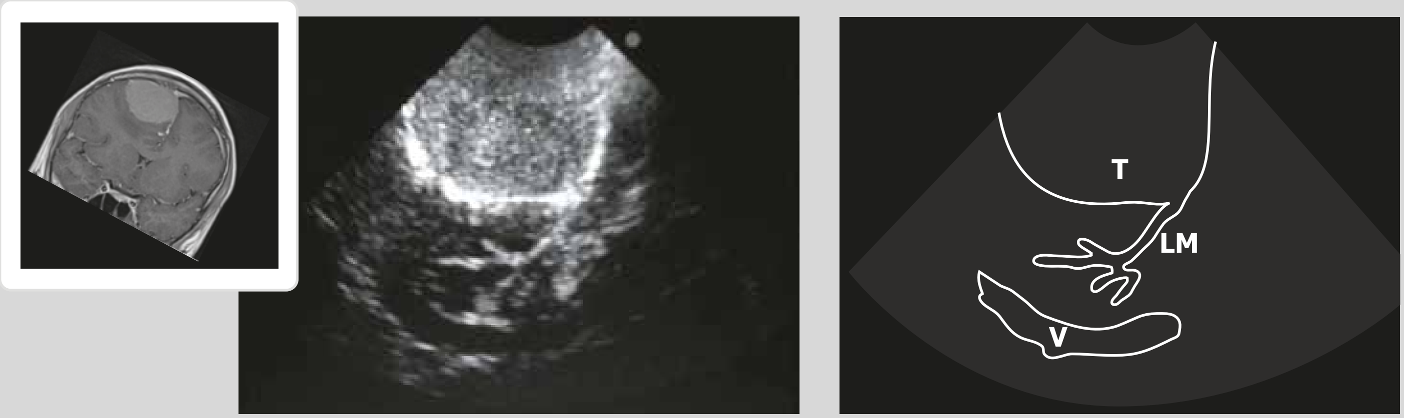
Next page

From the top, coronal MRI with ultrasonografic correlation before tumor removal. At the bottom, the tumor mass has been removed, to notice on both images is the significant edema surrounding both the lesion and the resection cavity.

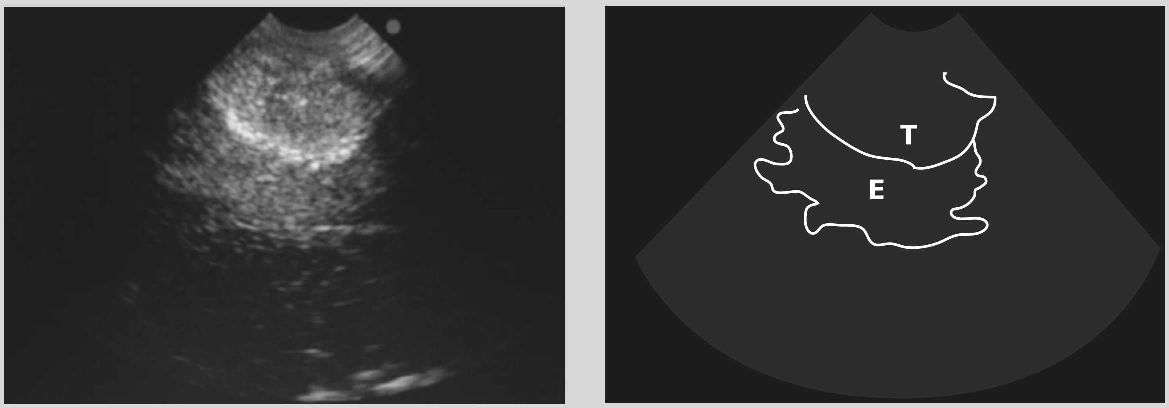






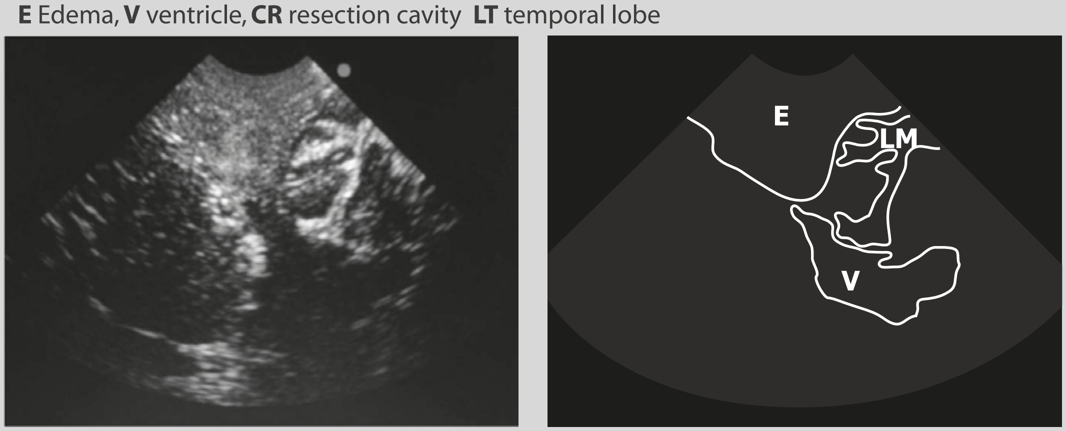


LM Mid line, **V** ventricle, **T** tumor



E edema**, T** tumor

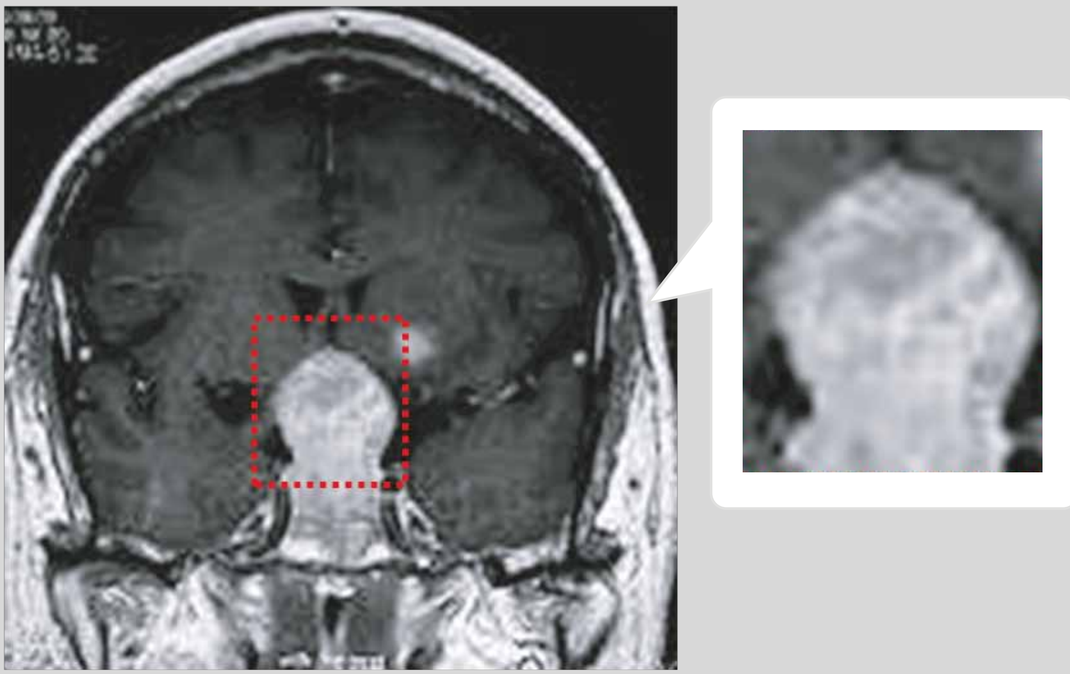
E Edema, **V** ventricle, **CR** resection cavity **LT** temporal lobe

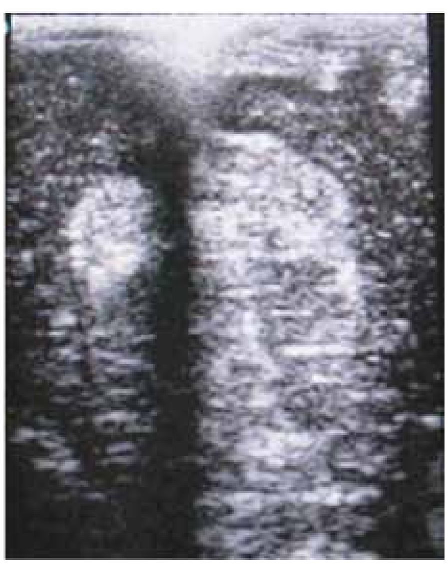


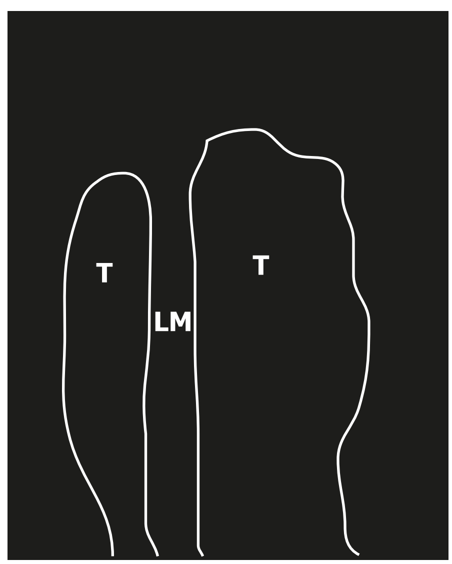
LM mid line

MACROADENOMA OF PITUITARY, BIFRONTAL APPROACH

Coronal MRI with gadolinium showing the suprasellar region. Ultrasound view of the lesion with acoustic shadow effect that is caused by the falx on the midline.







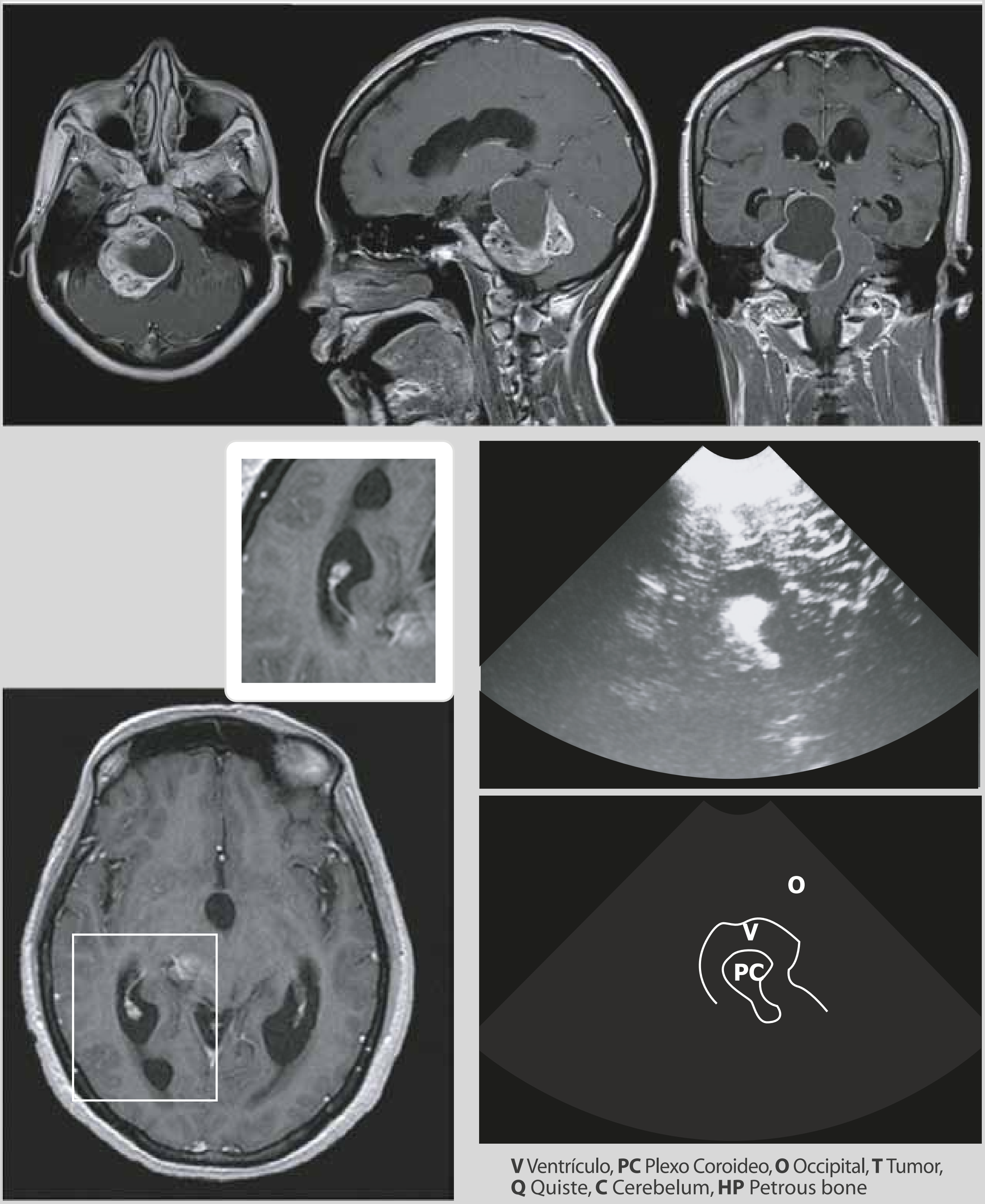
T Tumor, **LM** Línea Media

POSTERIOR FOSSA

- **POSTERIOR FOSSA,** SCHWANNOMA, KOS IV, CYSTIC
- **POSTERIOR FOSSA,** HEMANGIOBLASTOMA

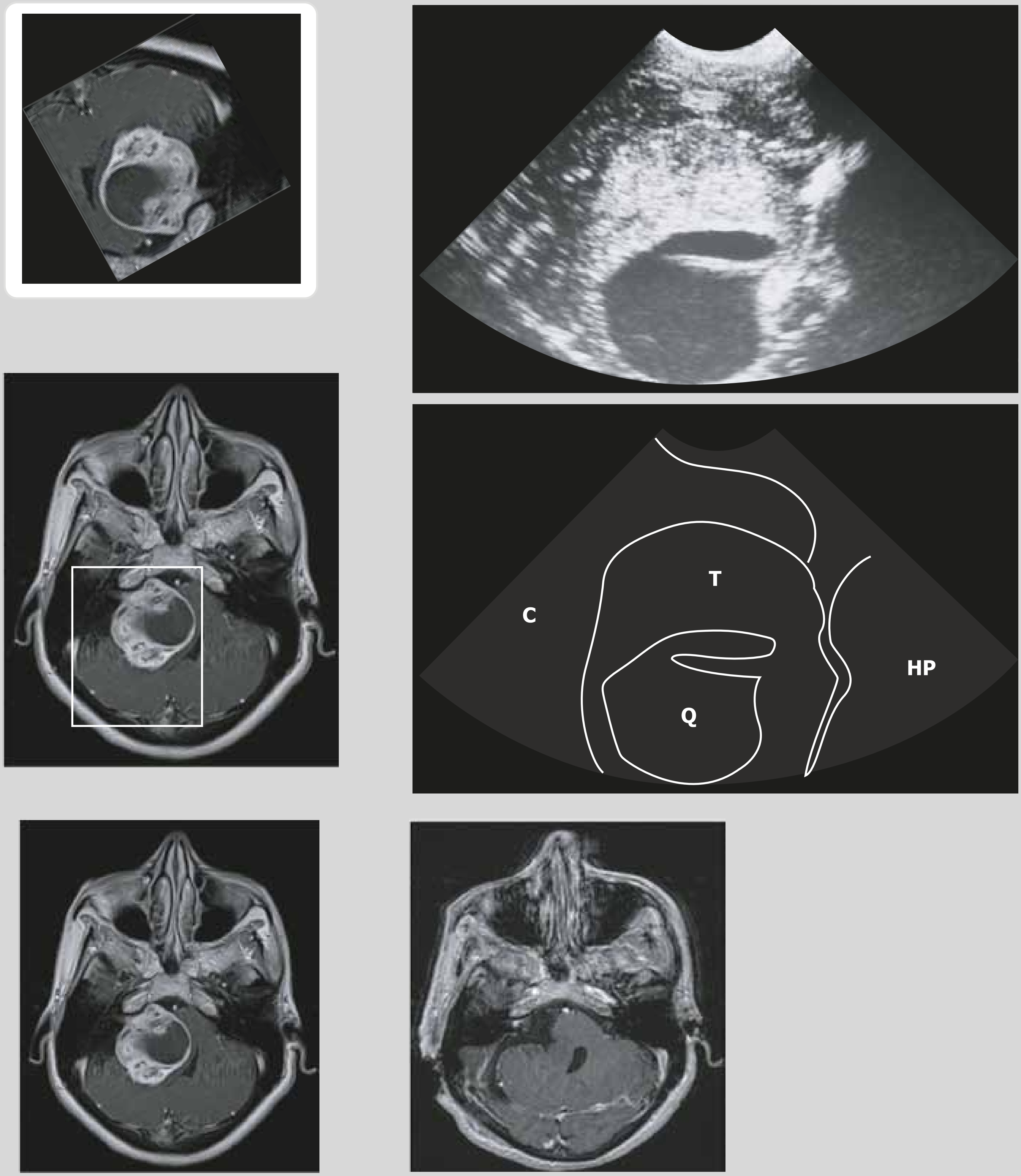
POSTERIOR FOSSA,
SCHWANNOMA, KOS IV, CYSTIC

Axial, sagittal and coronal cuts of MRI with gadolinium showing the tumor. Axial MRI above the lesion with close-up to right the ventricular horn (angle over the area of interest with the intention of matching the image with the one of intraoperative ultrasonography). Intraoperative ultrasound image of the same area (by tilting the transducer over the lesion) which distinguishes ventricular horn with the choroid plexus inside.



V Ventrículo, **PC** Plexo Coroideo, **O** Occipital, **T** Tumor, **Q** Quiste, **C** Cerebelum, **HP** Petrous bone

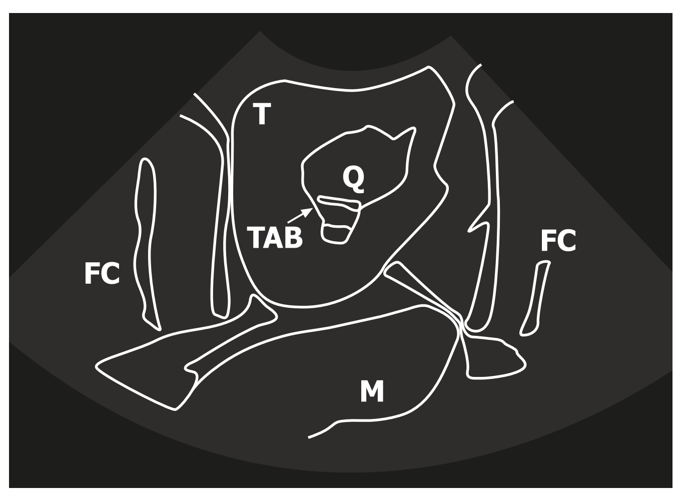
Approach and angulation of the tumor in relation to the ultrasonographic view which shows the tumor below the cerebellum. Control MRI showing complete resection of the lesion.



RM control

POSTERIOR FOSSA,
HEMANGIOBLASTOMA

Axial MRI with gadolinium where the area of interest has been angled with the intention of matching the image of intraoperative ultrasonography. Below, ultrasonographic image of the lesion, note the clear distinction of the septum within the lesion of millimetric size (same wall that is distinguishable on MRI).



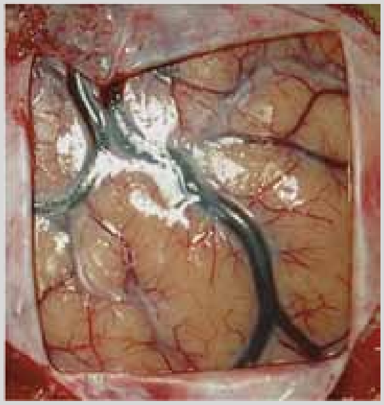
T Tumor, **Q** Quiste, **TAB** Tabications, **FC** Cerebelar Folia, **M** Spinal Cord (Bulbo-medullar junction)

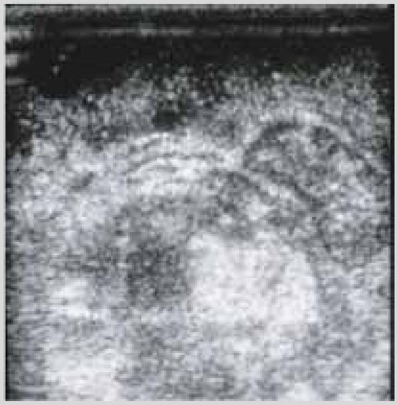
HEMATOMA

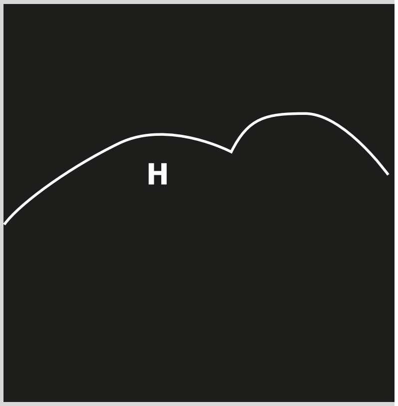
- **INTRACEREBRAL**
  HEMATOMA, FRONTAL, LEFT
- **LEFT FRONT CHRONIC**
  SUBDURAL HEMATOMA
- **LEFT PARIETAL**
  HEMATOMA

INTRACEREBRAL
HEMATOMA, FRONTAL, LEFT

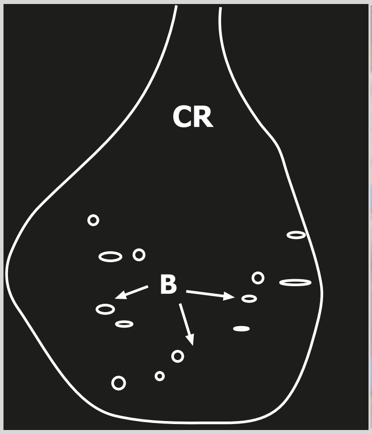
CT Image showing intracerebral hematoma. Intraoperative photograph in which the cortex is under tension, resulting from the mass effect of the hematoma. Intraoperative ultrasound image of the hematoma. Post evacuation intraoperative ultrasound showing the empty cavity. Intraoperative photograph at the end of the evacuation of the clot which shows the cerebral cortex more "relaxed" and the transsulcus access that was made for evacuation. Post-operative CT.

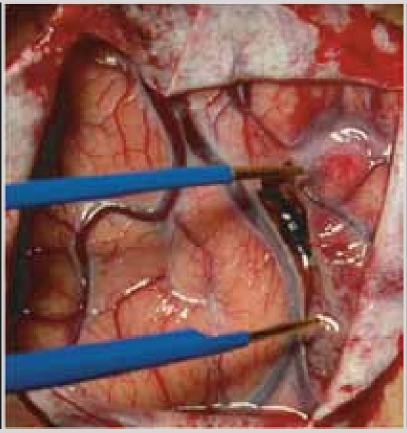






H Hematoma





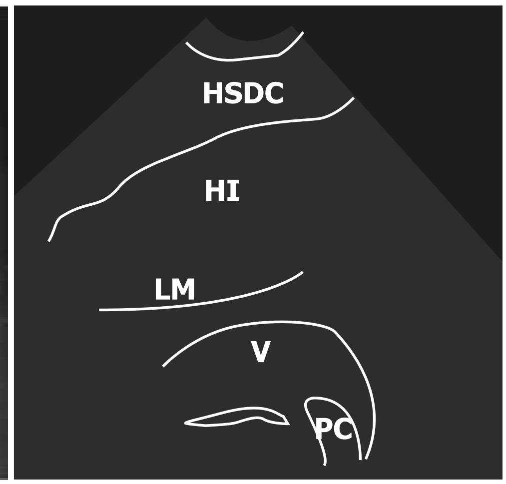
CR Cavidad de Resección, **B** Burbujas

End of surgery

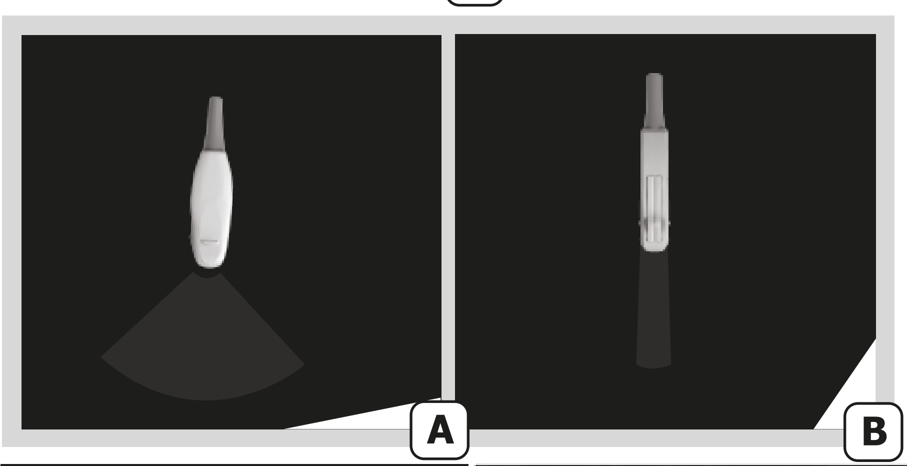
TAC control

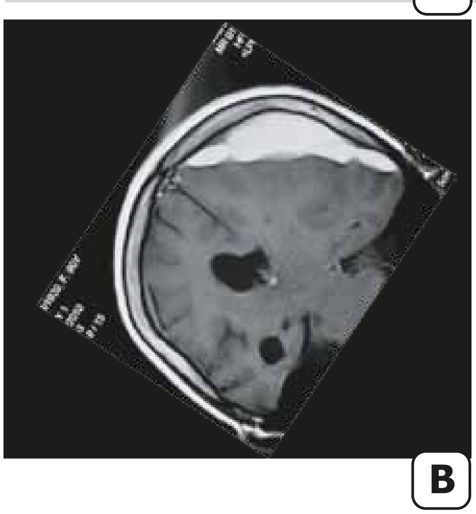
LEFT FRONT CHRONIC SUBDURAL HEMATOMA

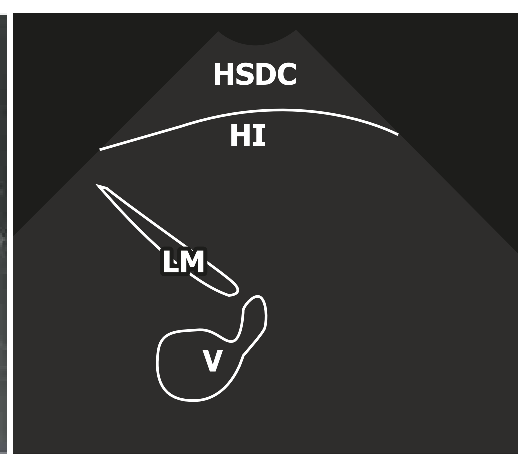
Image TC which has been angled to match the intraoperative ultrasound image. Ultrasonographic image showing the mass effect over the left hemisphere caused by the hematoma, it is possible to distinguish the midline and the contralateral ventricle. Below, Schematic angulation of the transducer based on radiological images A and B. Coronal MRI which has been angled to match the intraoperative ultrasound image. Intraoperative ultrasound image, note the subfalx herniation of the left ventricle.



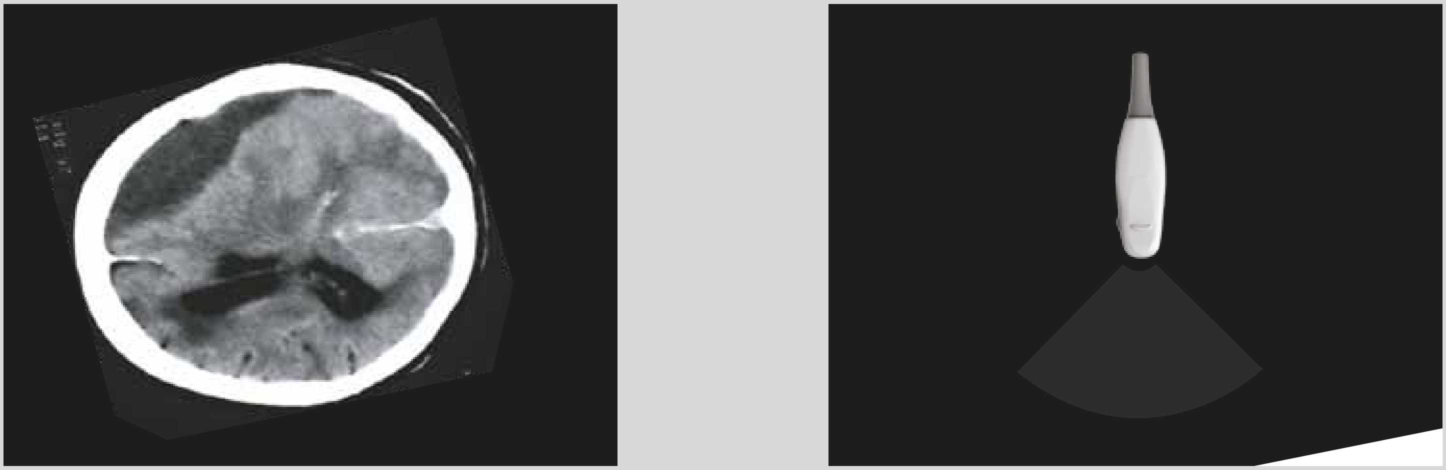
HSDC Cronic Sub-dural Hematoma, **HI** Left Hemisfere, **V** Ventrículo, **PC** Plexo Coroideo, **LM** Línea Media

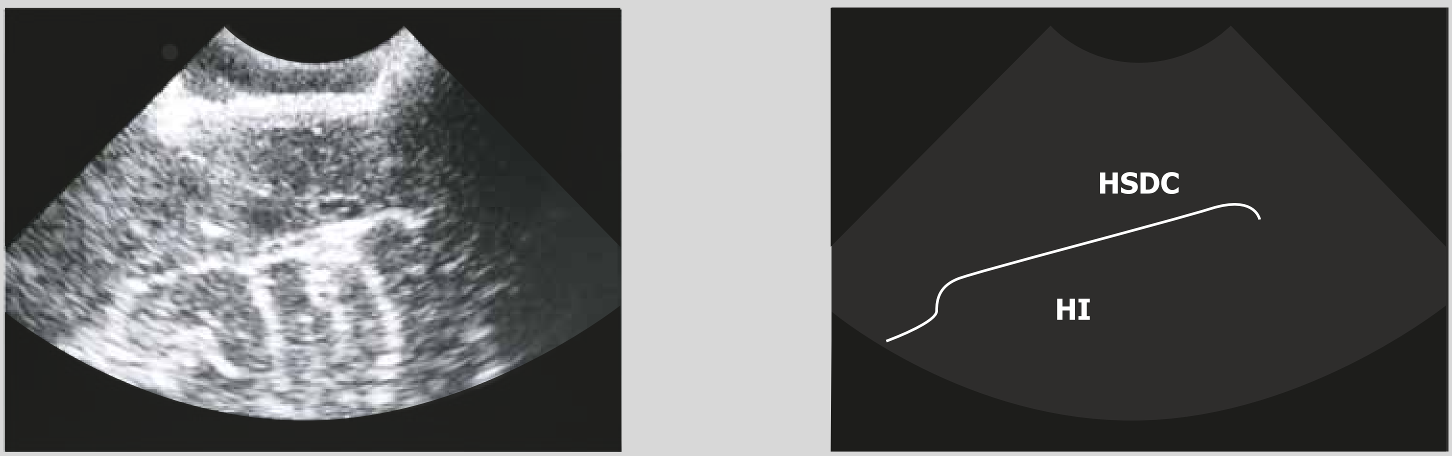




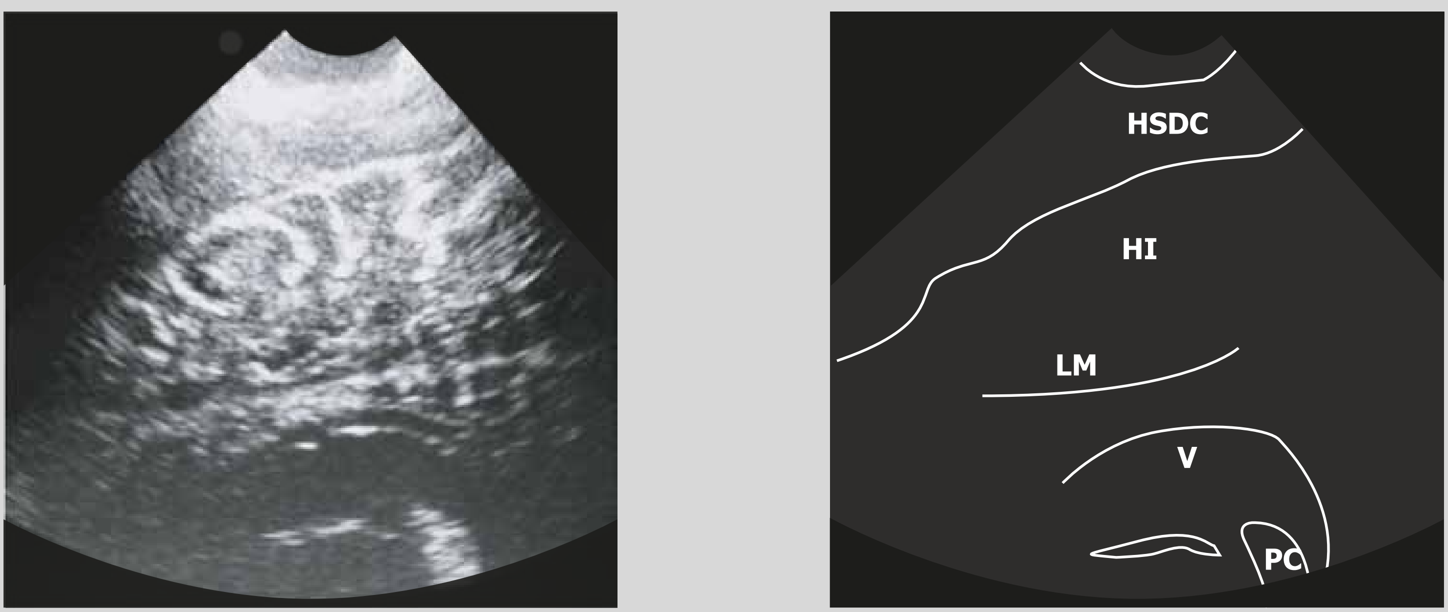


HSDC Cronic Sub-dural Hematoma, **HI** Left Hemisfere, **V** Ventrículo, **PC** Plexo Coroideo, **LM** Línea Media subsequent images are demonstrative of the depth effect that the transducer is capable of delivering.





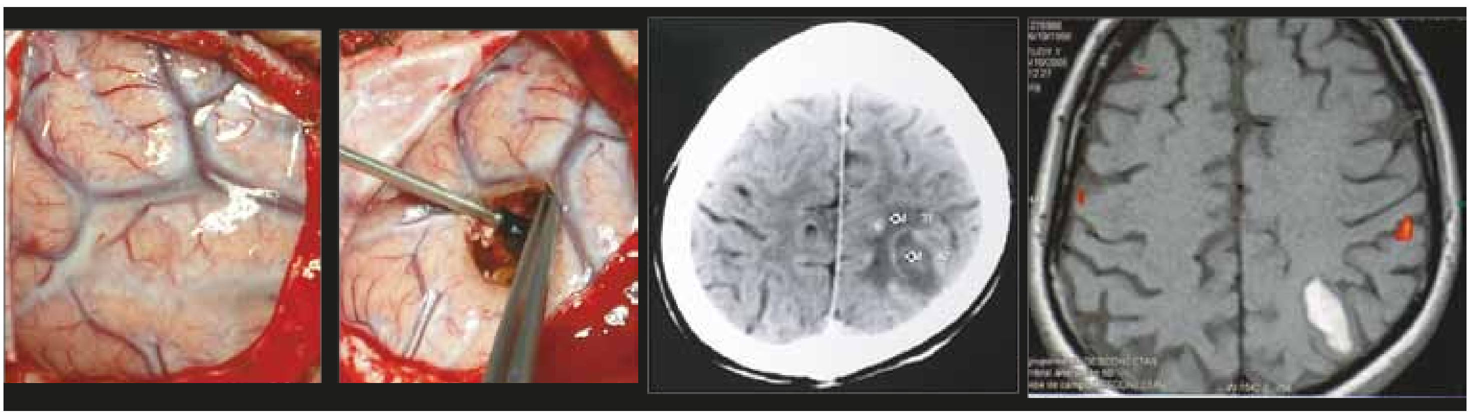
HSDC Cronic Sub-dural Hematoma, **HI** Left Hemisfere

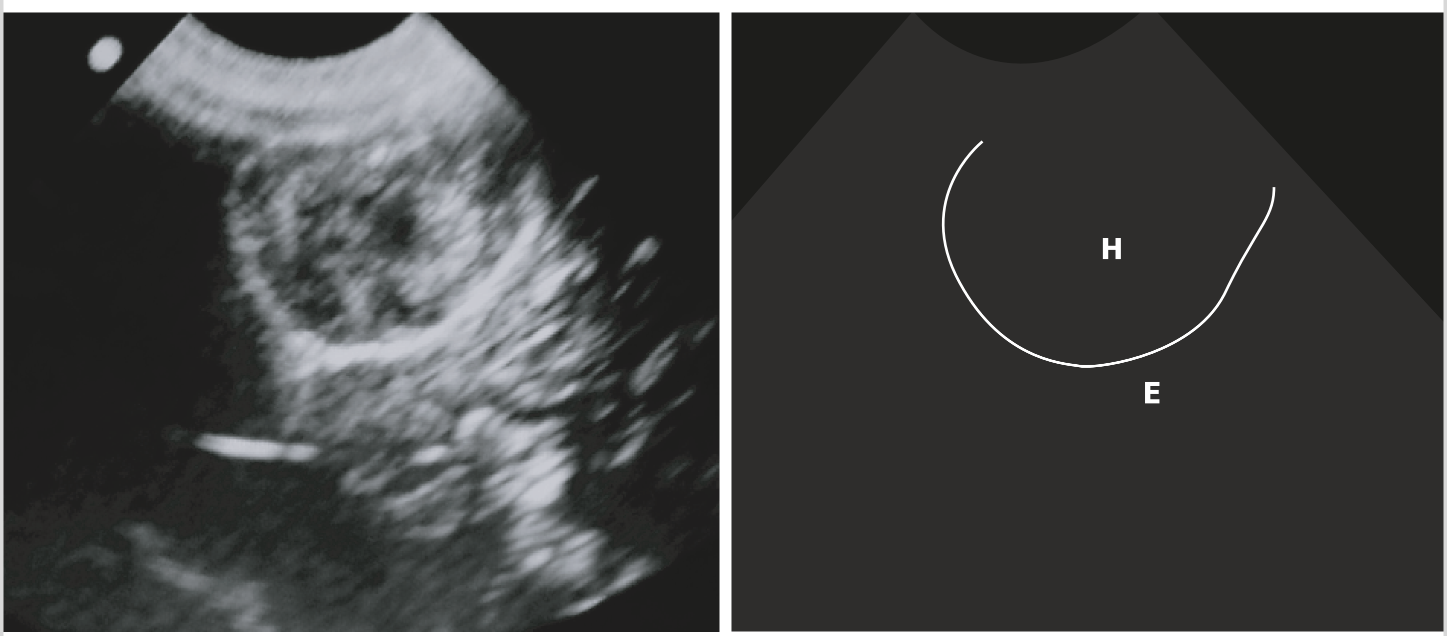


HSDC Cronic Sub-dural Hematoma, **HI** Left Hemisfere, **V** Ventrículo, **PC** Plexo Coroideo, **LM** Línea Media

LEFT PARIETAL
HEMATOMA

Intraoperative photographs of the cerebral cortex before transsulci incision and targeting of the hematoma, note the inflammatory reaction over the arachnoid. CT scan showing hematoma in subacute stage, functional MRI shows the relationship of the lesion with regards to the motor strip. Down, ultrasonographic view of the hematoma and associated brain edema.





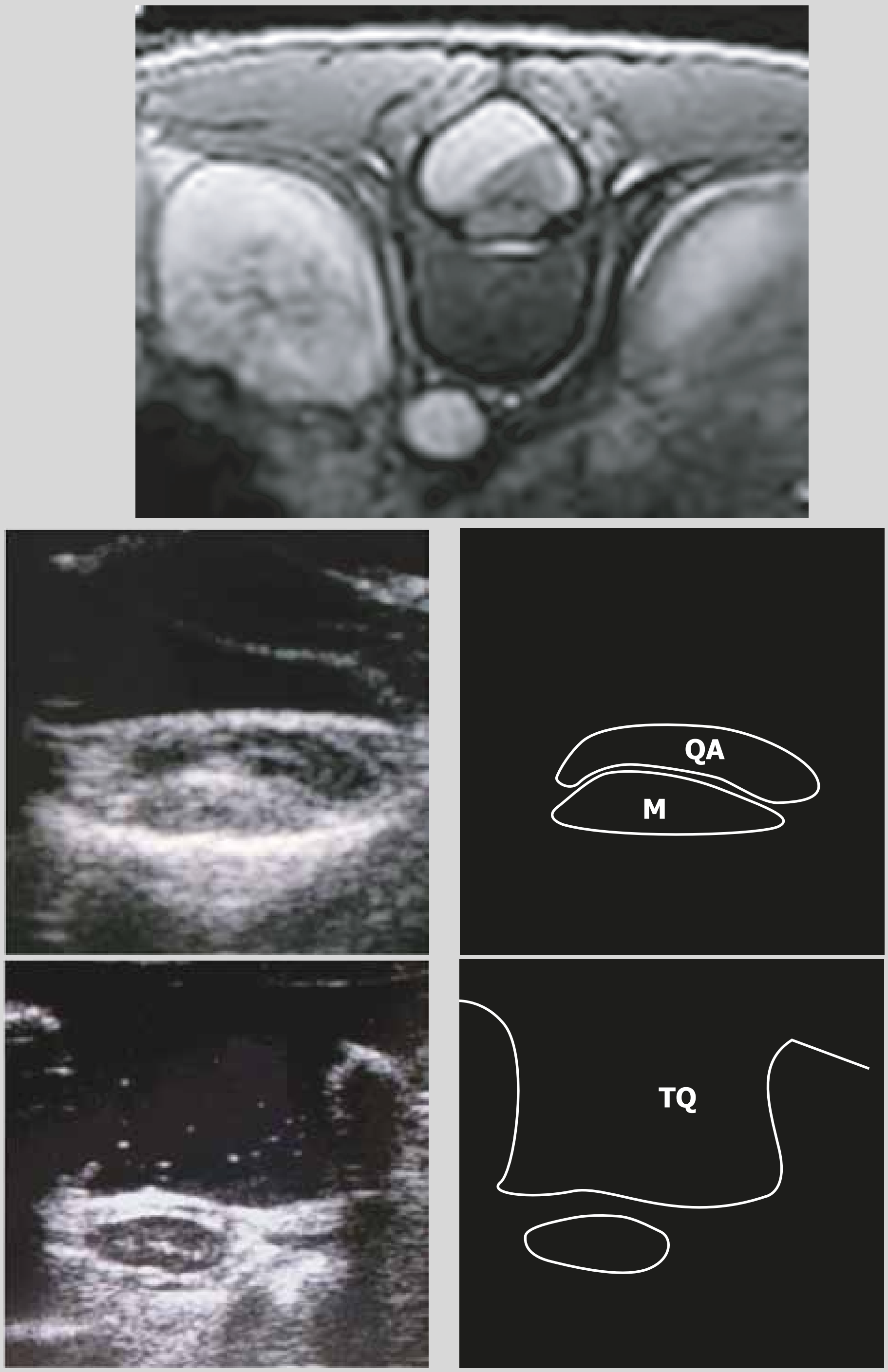
H Hematoma, **E** Edema

OTHER AREAS

- **ARACHNOID CYST**
  OF THE SPINAL CANAL
- **BULBOMEDULLARY**
  UNION

ARACHNOID CYST
OF THE SPINAL CANAL

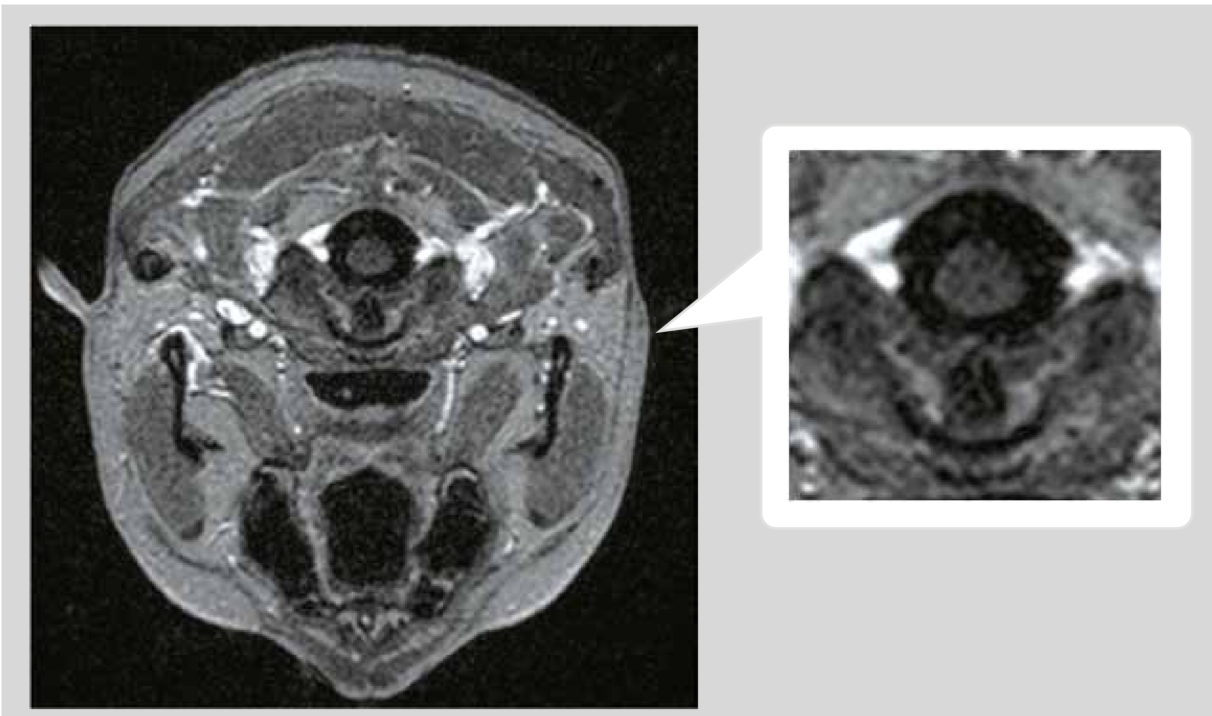
MRI and their respective close-up and angulation to match the intraoperative ultrasound image. Ultrasonographic image showing the spinal cord, below the bulbo-medullary junction. Note the ependymal canal, emerging roots and acoustic shadow that is causing the odontoid.

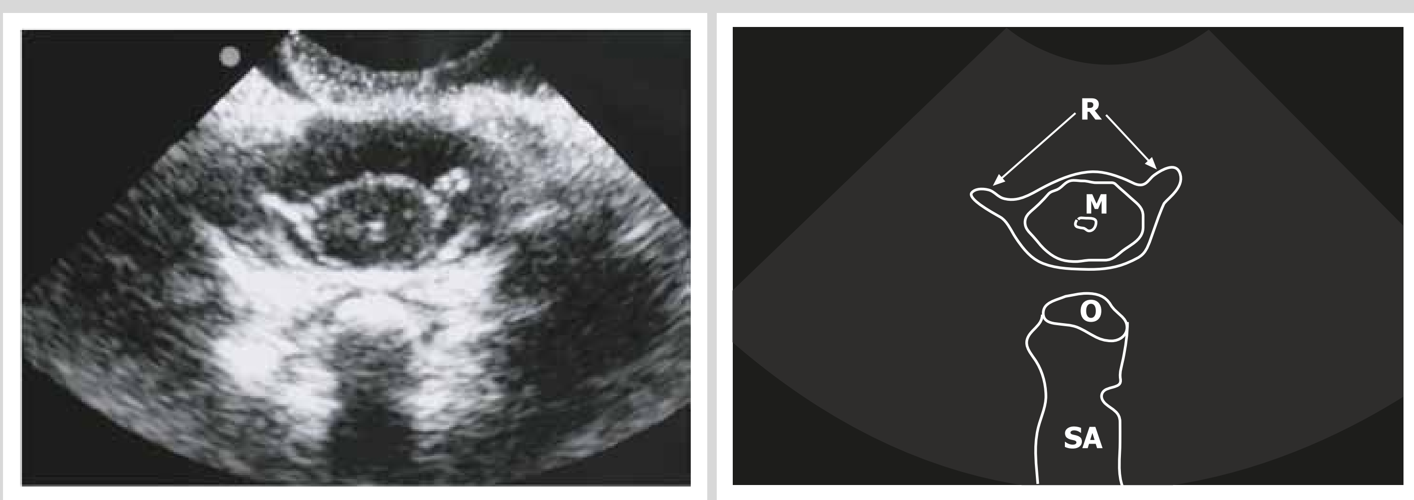


M Medula, **QA** AracnoidalCyst, **TQ** Surgical Trayectory

BULBOMEDULLARY
UNION

MRI and their respective close-up and angulation to match the intraoperative ultrasound image. Ultrasonographic image showing the spinal cord, below the bulbo-medullary junction. Note the ependymal canal, emerging roots and acoustic shadow that is causing the odontoid.





R Roots, **M** Spinal Cord, **O** Odontoid, **SA** Acustic Shadow

This page intentionally left blank

Todos los Derechos Reservados. Queda prohibida su
reproducción total o parcial sin la autorización del
Hospital de Diagóstico
......   www.hdiagnostico.com.sv ......

This page intentionally left blank

INTRAOPERATIVE ULTRASOUND OF THE CENTRAL NERVOUS SYSTEM