AMERICAN BRAIN TUMOR ASSOCIATION

Surgery

American Brain Tumor Association®

Providing and pursuing answers™

ABOUT THE AMERICAN BRAIN TUMOR ASSOCIATION

Founded in 1973, the American Brain Tumor Association (ABTA) was the first national nonprofit organization dedicated solely to brain tumor research. The ABTA has since expanded our mission and now provides comprehensive resources to support the complex needs of brain tumor patients and caregivers, across all ages and tumor types, as well as the critical funding of research in the pursuit of breakthroughs in brain tumor diagnoses, treatments and care.

To learn more, visit abta.org.

The ABTA gratefully acknowledges the following for their review of this brochure edition: Gabriel Zada, MD, MS, FAANS, FACS (Professor of Neurological Surgery, Otolaryngology, and Internal Medicine; Director, USC Brain Tumor Center; USC Keck School of Medicine, University of Southern California); Eric Holland, MD, PhD (Senior Vice President and Director, Human Biology Division, Fred Hutch; Director, Seattle Translational Tumor Research, Fred Hutch and UW Medicine); Chris Ferry (patient reviewer) and Morgan Mosky (patient reviewer).

ABTA1223

Surgery

INTRODUCTION

This brochure is about **surgery** for treating patients with primary, metastatic (secondary) and other central nervous system (CNS) tumors. Primary brain tumors start in the brain or spine[1] and rarely spread outside the CNS to other organs.[2] Metastatic brain tumors form when cancer from another part of the body spreads to the brain. There are more than 130 different types of brain tumors.[3,4]

About 70% of primary brain tumors and other CNS tumors are not cancerous (benign), but they are still serious medical conditions and often require treatment.[5] The remaining 30% of primary brain tumors are cancerous (malignant). Metastatic or secondary brain tumors are all considered cancerous (malignant). Both primary and metastatic brain tumors generally grow faster and behave more aggressively than benign tumors. They commonly invade other areas of the brain and spinal cord and can be deadly. Categories of brain tumor treatments include surgery, radiation therapy, and chemotherapy, and one or more may be recommended depending on the tumor type.

A doctor who specializes in doing surgery of the brain, spine, and other parts of the CNS is called a neurological surgeon or ***neurosurgeon.***[6,7] The neurosurgeon works with a team of clinicians, such as neuro-oncologists and radiation oncologists, as well as other healthcare professionals including physician assistants, nurse practitioners, rehabilitation specialists, and nurses.[6,7]

BOARD CERTIFICATION

Board certification is an advanced credential that indicates a high degree of competence and training in a certain medical specialty. A neurosurgeon seeking board certification from the American Board of Neurological Surgery must submit to a rigorous evaluation process governed by the American Board of Medical Specialties. Before board certification is granted, a neurosurgeon must:

- Validate appropriate education and training
- Demonstrate professional skills, judgment, and knowledge
- Pass both a written and oral examination
- Engage in lifelong learning

Board certification is considered the ***gold standard*** that can help patients assess the neurosurgeon's qualifications. To find out if a neurosurgeon is board certified, visit the American Board of Medical Specialties' website (www.certificationmatters.org) or call the Physician Referral Service at the hospital where the surgeon is on staff.

ABOUT SURGERY

Surgery remains the first step in the treatment of many brain tumors.[7,8,9] It is considered the standard of care, meaning that it is the best treatment known, for several types of brain tumors.

As an example, surgery may be the only treatment needed for non-malignant (benign) growths and low-grade (less aggressive) gliomas, especially if the entire tumor is removed.[7] For other brain tumors, including high-grade (more aggressive) gliomas and other malignant tumors, surgery may be performed in combination with radiation therapy and/or chemotherapy.[8,9]

Surgery is often considered as a first option for treating brain metastases if there is one large tumor causing symptoms, the number of tumors is limited, all or most of the tumor(s) can be safely removed, there is diagnostic uncertainty, the cancer is controlled, and the patient is in good overall health. Surgery also may be recommended if there is a single tumor and the cancer has not spread to other parts of the body. Some tumors can be removed completely, while others may be reduced in size.

The goals of surgery are generally to:[7,8,9]

- Obtain tumor tissue to make a diagnosis (if a biopsy was not already done)
- Remove as much tumor as possible (maximal safe resection)
- Reduce symptoms caused by the tumor and prevent future neurological issues
- Prolong survival
- Reduce the need for corticosteroids

Just as there are different types of brain tumors, there are different kinds of operations that can be used to treat brain tumors. The neurosurgeon will discuss options with the different specialists and providers who are part of the healthcare team, as well as the patient. Among the factors they will consider are:[6,7]

- The tumor size and perceived grade
- Location of the tumor and function of neighboring brain regions
- Possible side effects and risks of surgery
- The patient's overall health, age, and preference

A tumor that cannot be operated on is referred to as being ***inoperable***. If the tumor is inoperable, the surgeon may still be able to perform a biopsy to obtain a tissue sample to confirm the diagnosis and guide future treatment, or remove a portion of the tumor (subtotal resection).[6,7]

Surgery may not be a good option for people who have a tumor located in parts of the brain that control critical functions, such as movement, speech, and senses, or individuals who have other health problems.[8]

TYPES OF SURGERY

Biopsy

Although imaging tests such as computed tomography (CT) and magnetic resonance imaging (MRI) scans may give the doctor an educated idea of the tumor type, **a biopsy is usually recommended to be sure of the diagnosis**.[6,10]

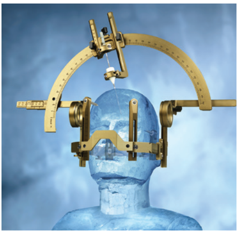
A biopsy is a surgical procedure that involves removing a small piece of tumor and sending it to the pathologist for testing.[6,11,12] In general, the neurosurgeon makes a small cut in the scalp and drills a tiny hole into the skull. The surgeon then removes one or several small pieces of suspected tissue using a needle or similar instrument.[11]

The surgeon sends the sample to a pathologist, who is trained in identifying diseases of the CNS. The pathologist will examine the tissue under a microscope[6,10] and will usually test it for certain molecular and genetic markers, all of which will help determine what type of tumor it is and whether it is benign or malignant.[6,8]

A biopsy may be performed as a separate procedure to obtain a tissue sample, or as part of the operation to remove the tumor. When undergoing a biopsy, the patient is usually given general anesthesia, which keeps the patient from feeling any pain. Depending on the type of biopsy done, the operation may take up to two hours.[14]

There are two types of biopsies:

Stereotactic Biopsy. A stereotactic biopsy uses a computer and three-dimensional scanning device based on CT or MR imaging to accurately guide the biopsy needle to remove the target tissue.[12,13] A ***framed stereotactic biopsy*** uses a frame fixed to the patient's head to keep it still, while a ***frameless stereotactic biopsy*** uses pins to fix the stereotactic equipment to the patient's head with small metal disks placed on the scalp that are used to guide the needle.[11,14] Stereotactic biopsies are typically used when a tumor cannot be removed surgically or a need for re-grading or resampling the tumor exists.[12,13]



Sample of a head frame used during stereotactic biopsy.

Open Biopsy. When imaging tests show that the tumor can be removed surgically or the location is unfavorable for a needle biopsy, an open biopsy may be done.[12] An open biopsy is considered major surgery. Sometimes, the tissue sample is taken directly to the pathologist, who will examine it right away and send the results to the neurosurgeon while the patient is still in the operating room.[6] With the preliminary results in hand, the surgeon may then decide how much of the tumor can be safely removed.

Craniotomy

A craniotomy is the most common type of operation used to remove brain tumors.[11,15] ***Crani*** means skull and ***otomy*** means cutting into.

When having a craniotomy, the patient is given general anesthesia, which keeps the patient from feeling any pain. The patient may be awake for at least some of the procedure if the surgeon recommends an awake craniotomy.[15] An awake craniotomy may be recommended if the patient's brain function must be assessed during the operation. ***(Read more about awake craniotomy later in this brochure.)***

Before surgery starts, a small part of the patient's head is usually shaved.[6,11,15] The neurosurgeon makes an incision in the scalp, uses a special drill to remove a piece of the skull called a bone flap, and then carefully removes the tumor. The scalp opening is usually just large enough for the surgeon to insert several instruments and see the parts of the brain needed to operate safely.[15] The surgeon may need to cut into the brain itself to reach the tumor, or work through natural spaces within the brain. The tumor can be either cut out with a scalpel or special scissors, removed with suction devices if it is soft enough, or broken up and suctioned out using a handheld ultrasonic aspirator. ***(Read more about ultrasonic aspiration later in this brochure.)*** After the tumor is removed, the surgeon replaces the bone flap, seals it in place with titanium plates and screws, and then stitches the scalp closed with sutures and/or staples.[6,16]

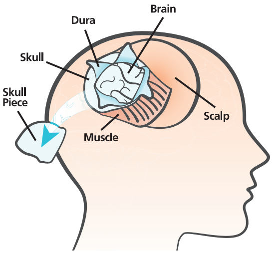


Illustration of craniotomy.

There are different types of craniotomies based on the technique used or tumor location. For example, a ***stereotactic craniotomy*** uses an MRI or CT scan to create three-dimensional images of the brain and guide the approach. An ***endoscopic craniotomy*** uses a tube with a light and camera on the end of it called an endoscope to access the brain through small openings, sometimes called keyholes. In general, operations that are based on the principle of using smaller incisions and openings and/or natural corridors in the body are called ***minimally invasive surgeries***.

Depending on the type of craniotomy done and the complexity of the tumor, it may take between 2-12 hours.

Craniectomy

A craniectomy is similar to a craniotomy in almost all ways except one. While ***otomy*** means cutting into, ***ectomy*** means removal. In a craniectomy, the bone flap removed to reach the brain is not replaced following surgery.[16,17]

The neurosurgeon may perform a craniectomy because it can be challenging to replace the bone flap in certain regions or may require extensive bony drilling. In other instances of an infection or brain edema (swelling), it may not be advisable to replace the bone flap. If the bone flap is reusable, the medical facility will sometimes store it until the surgeon determines if and when it can be replaced. If the bone is not reusable, for example, due to infection, an artificial bony prosthesis or implant will be made, often based on the patient's anatomy derived from CT imaging.

When a craniectomy is done, the healthcare team provides instructions to the patient for protecting the soft spot created by the missing bone, or it may be covered with a titanium plate or other bony substitute instead.

Debulking

Debulking means to surgically reduce the size of a tumor by removing as much of it as possible.[11,18] Following debulking, the surgeon may recommend chemotherapy and/or radiation therapy to treat the remaining tumor cells.[18] Debulking also may be done to relieve symptoms or help the patient live longer.

Partial Removal

Partial removal, also known as a ***subtotal resection***, refers to removing only part of the tumor.[6]

The neurosurgeon can perform a subtotal resection as part of major surgery or minimally invasive surgery, depending on the tumor's location and other factors.

Some tumors cannot be fully removed because of their location and proximity to critical surrounding regions or structures. The tumor could be hard to reach or near a vital area in the brain that, if damaged, could affect the patient's movement, speech, vision, or hearing.[6,7,8] In other instances, the tumor may be adherent to structures such as arteries or nerves that may prevent a complete removal.

When partial removal is performed, the patient is usually given additional treatment, such as radiation therapy or chemotherapy, to treat the remaining tumor cells. This is often the case with high-grade gliomas.[6,7]

Complete Removal

Complete removal, also known as a ***gross total resection***, refers to removing the whole tumor seen during the operation and on subsequent imaging.[6,11] However, it is possible that some microscopic tumor cells may remain in the surgical cavity or surrounding regions that cannot be seen by the human eye, are not detected using a surgical microscope, and are not visible on MRI after surgery. Following complete removal, the surgeon will discuss with the patient the likelihood that the tumor will return, based on the type of tumor, and if additional treatment (e.g., radiation and/or chemotherapy) is needed to destroy any remaining cells.

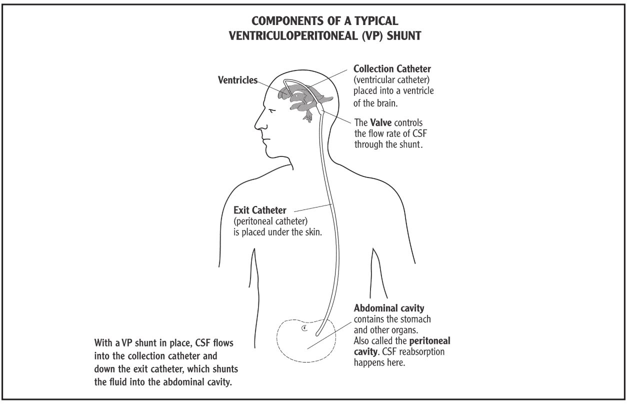
Shunt

When there is excess cerebrospinal fluid (CSF) in the brain or the CSF pathways are blocked by the tumor or edema (swelling), the patient may have a build-up of pressure and fluid inside the brain and skull. The build-up of CSF is called ***hydrocephalus*** and the pressure inside the brain is known as ***intracranial pressure,*** which can cause headaches, nausea, and drowsiness, and may even be life-threatening.[11,15]

Pressure caused by hydrocephalus can be relieved using a temporary drain called a ventriculostomy or external ventricular drain (EVD), or a permanent implant called a shunt.

An EVD is a catheter-like tube that drains CSF into an external drainage system. The amount of CSF being drained is monitored very closely and the tube is removed once the pressure has resolved.

A shunt is a long catheter-like tube that drains the CSF from the brain and diverts it to other parts of the body. Most commonly, the CSF is drained to the abdomen (belly), where it is absorbed. Sometimes, it is placed in the chest area. When the shunt goes into the abdomen it is referred to as a ***ventriculoperitoneal shunt***, and when it goes into the chest area it is called a ***ventriculo-pleural or ventriculo-atrial shunt***.[15]



Components of a typical ventriculoperitoneal shunt. Courtesy of McGill University Health Centre, Montreal, Canada.

To place a shunt, an area on the patient's head is shaved. The neurosurgeon cuts a small flap in the scalp and drills a small hole in the skull.[19,20] The surgeon makes another small cut in the belly. Next, a sterile catheter is passed into a ventricle of the brain (an area filled with CSF) on one end, and the belly or other destination site at the other end. A valve that controls the flow of CSF is located between both catheter ends and helps to regulate the drainage, often to an adjustable setting. When extra pressure builds up around the brain, the valve opens, and the excess CSF drains through the catheter into the belly or other part of the body.

Operations for insertions of shunts often take less than one hour. Occasionally, shunts may become blocked and may require revision, or become infected and require removal.

Ommaya Reservoir

An Ommaya reservoir is a small, dome-shaped container that is surgically implanted under the scalp. The container (reservoir) is connected to a catheter (tube) that is placed in a ventricle and resembles the tube used for a shunt.[21,22] Connecting the Ommaya reservoir to a ventricle gives it direct access to the CSF space.

An Ommaya reservoir can be used to:[11,21,22]

- Deliver chemotherapy into the brain and the CSF surrounding it
- Remove samples of CSF to check for abnormal cells or infection without doing a spinal tap
- Remove excess cystic fluid without surgery

To place the Ommaya reservoir, the patient's head will be shaved near the implant site.[15,21,22] The neurosurgeon makes a small cut in the scalp to insert the Ommaya reservoir, which is about the size of a quarter. The surgeon drills another small hole in the skull where the catheter will be threaded through and placed into a ventricle. The incision will be closed with staples or stitches. The patient will be able to feel the Ommaya reservoir under the skin, which will be slightly raised in that area.[21] A CT or MRI scan of the patient's head will ensure that the Ommaya reservoir was placed properly.

An Ommaya reservoir can be built into the catheter as part of a shunt or as a stand-alone device.[11] It can be removed when it is no longer needed. Inserting an Ommaya reservoir is an operation that takes about an hour.[21]

Skull Base Surgery

The skull base is the delicate bony area located beneath the brain and is generally considered to be a complex region for tumors and surgery.[11] Tumors located in this area are often surrounded by nerves and blood vessels that control critical functions, such as speech, senses, and facial movements.[11,23] Skull base surgery is performed to remove tumors on the skull base, underside of the brain, or top of the spinal cord.[24]

Skull base surgery is best performed by a team of specialists including a neurosurgeon; an ear, nose, and throat specialist or otolaryngologist; a maxillofacial surgeon or plastic surgeon; and a radiologist, among others.[23,24]

The surgeon commonly uses microsurgery or endoscopic techniques to remove as much tumor as possible (maximal safe resection) while preserving critical functions.[24,25] (***Read more about microsurgery techniques later in this brochure.***) Using microsurgery techniques enables the surgeon to make fewer and smaller incisions, or to place an endoscope in the skull and insert tiny instruments through natural openings in the skull. These include the nose, mouth, eyelid, and forehead as well as above and behind the ear or from the neck.[23,24,25] An MRI may be used to take images of the skull base in real time to help guide the surgeon in removing as much of the tumor as possible through the endoscope.[24]

Due to the challenging nature of the operation, skull base surgery may be lengthy. A routine case may take around 2-8 hours. Patients may need additional treatment, such as chemotherapy or radiation therapy, following skull base surgery depending on the tumor type and extent of removal.[24]

Endonasal and Transsphenoidal Surgery

Endonasal surgery is performed through the nostrils to access the sinuses and skull base and is the major surgery used for pituitary and other selected skull base tumors. The most common subtype of endonasal skull base surgery is transsphenoidal surgery. This type of operation is performed through the nose and sphenoid sinus, which is the gateway to the pituitary region.[11,26] ***Trans*** means through, and ***sphenoid*** refers to the sphenoid bone and sinus.[11] Transsphenoidal surgery requires specialists including a neurosurgeon and possibly an otolaryngologist.[27]

This approach limits the chances of causing damage to the brain because the brain is often not moved or touched during the surgery.[28] However, if leakage of CSF occurs during the operation, it must be repaired to achieve a water-tight closure. Additionally, these operations may result in fewer side effects and without a visible scar. Transsphenoidal operations often take between 1-4 hours.[27]

An endoscope is commonly used for this type of surgery and is inserted through the nostrils with no external incisions on the outside of the body. Depending on the tumor type and location, the surgeon will remove some of the bone of the skull base to access the tumor.

Laser Interstitial Thermal Therapy

Laser interstitial thermal therapy (LITT), also known as stereotactic laser ablation, is a minimally invasive surgical technique that uses a laser to heat and destroy a brain tumor or necrosis (dead tissue) of the brain following radiation treatment.29,30,31

The neurosurgeon makes a small cut in the scalp and drills a tiny hole in the skull.[32,33] A thin, flexible laser fiber is inserted in the hole and guided toward the tumor by a special type of MRI. Once the laser is in the proper location, it transmits energy toward the tumor, which in turn, heats up and destroys the tumor. During the procedure, an MRI is used in ***real time*** to monitor the temperature in the part of the brain being treated, ensuring that the laser stays focused on the tumor and avoids damaging nearby healthy tissue.[29] When the tumor has been ablated, the surgeon removes the flexible laser fiber and closes the incision.

Although LITT is still a fairly new technique,[11,31] it has been used successfully to treat brain tumors that are in hard-to-reach areas or have not responded to other treatment options, and in patients who are poor candidates for surgery.[29,30] Among the types of tumors that have been treated with LITT are glioblastomas, metastatic brain tumors, and recurrent tumors[29,30] as well as other types of tumors that are smaller than 3 cm (the size of a grape).[32,33] Because LITT is less invasive than a craniotomy, it may reduce pain after surgery and shorten recovery time.

LITT can take as little as one hour and as long as 3 to 4 hours, depending on the size, location, and shape of the tumor. [32,33]

SPECIALIZED TOOLS AND TECHNIQUES

Brain Mapping

Thanks to recent medical advances, many tools are available to help the neurosurgeon surgically remove brain tumors safely. One of them—brain mapping—helps the surgeon identify the areas of the brain that control critical functions, such as movement and speech.[34] The goal is to avoid damaging these sensitive areas during surgery. While brain mapping techniques are constantly evolving, the following are some common methods currently being used.

Computer technology is an aid in tumor removal. Courtesy of Gene Barnett, MD, The Cleveland Clinic Brain Tumor and Neuro-Oncology Center.

Awake Craniotomy

An awake craniotomy is the same as a craniotomy, except that the patient is awake for critical portions of mapping and/or the tumor removal so they can be monitored for neurological preservation and safety.[6] The patient is given extensive local anesthesia on the scalp to help reduce possible pain. The brain itself does not have pain receptors, and most patients tolerate this technique well.

During an awake craniotomy, the neurosurgeon uses small electrodes to stimulate the specific part of the brain close to where the tumor is located, usually while asking the patient questions. If the surgeon is trying to find the areas that control movement, the doctor may ask the patient to wave a finger or wiggle toes.

The surgeon uses MRI scans of the brain taken before and during the procedure, along with the patient's responses, to create a map of the functional areas of the brain. This helps the surgeon know which tissue should be removed and which should remain, minimizing potential damage to these sensitive (eloquent) areas of the brain that control important functions.[6,7,9]

Direct Cortical Stimulation

Direct cortical stimulation, also known as cortical mapping, allows the neurosurgeon to identify sensitive areas of the brain around the tumor by using a tiny probe with a low dose of electrical current.[7,15,35] The surgeon attaches the electrodes to the surface of the patient's brain and the patient's face, arm, and leg.[36] When the probe touches an area of the brain, the electric current causes a visible movement of the related body part or a response picked up using electrical monitoring. By monitoring this response, the surgeon can see the sensitive areas that should be avoided. A patient who is awake during this procedure can respond verbally to the surgeon about the electrical stimulation.

Somatosensory- and Motor-Evoked Potentials

Somatosensory-evoked potentials, also known as ***evoked potential*** or ***evoked response***, measure sensory responses from electrical stimulation to the patient's nerves that ultimately reach the brain.[37] For this technique, the neurosurgeon attaches electrodes to the patient's scalp and the patient's arms, legs, and back. The electrodes measure the weak electrical impulses as they travel along the nerves to the brain. A machine records how long it takes for these impulses, which are called ***evoked potentials***, to reach the brain. Similarly, motor-evoked potentials test the integrity of regions and tracts that control movement or motor function.

Functional MRI

Functional MRI (fMRI) measures the small changes in blood flow that occur when the brain is active.[31,34] This ***activity*** occurs when the brain is using oxygen.[35] The high-speed MRI creates pictures of the brain's use of oxygen. This helps the neurosurgeon tell the difference between normal brain activity, which uses oxygen, and a tumor that contains dead tissue, which does not use oxygen. This technique is often used prior to surgery to help guide the craniotomy.

Intraoperative Ultrasound Imaging

During surgery, the neurosurgeon may use ultrasound to help determine the depth, size, and shape of the tumor as well as define the borders of the tumor.[35,38] It also can help distinguish the tumor from dead tumor cells (necrosis), cysts, edema, and normal brain tissue.[35] The procedure uses ultrasound, which are high-energy sound waves that bounce off tissues and organs.[18] When the waves bounce back, they are made into images that the neurosurgeon can view on a computer. A benefit of ultrasound is real-time imaging.

Intraoperative MRI

Intraoperative MRI (iMRI) uses a special type of MRI that provides the neurosurgeon with high-quality images in ***near-real time*** instead of relying on MRI scans taken prior to the surgery.[9,39] By constantly updating the images, iMRI helps the surgeon see how much tumor remains after the initial resection, helping guide further surgery to remove even more tumor.[39] This method also helps the surgeon determine the size and shape of a tumor, define the tumor's border, and distinguish between a tumor and nearby normal tissue.[40,41] It is often used to see whether a tumor has been removed entirely, and whether any residual tumor remains and where it may be located.

An iMRI scanner in the operative suite, is seen on the right. Courtesy of Linda Liau, MD, UCLA Health.

Embolization

Embolization is a technique that is used to block the blood flow to a tumor prior to removing it.[18,42] Operating on a tumor that has a lot of blood vessels can be difficult because they can cause heavy bleeding during surgery. The purpose of embolization is to cut off the blood supply to the tumor and reduce the risk of the blood vessels breaking open.[42]

During an embolization, the neurosurgeon makes a small cut in the patient's groin area, creating a hole in a large blood vessel known as the femoral artery that travels down the leg, and inserts a tiny tube (catheter) into the artery.[42] Next, the neurosurgeon gently moves the catheter through the blood vessel closer to the tumor. Then a dye is injected through the catheter, enabling the blood vessel to be seen on x-ray images called an ***angiogram***. It is used to examine the blood supply to the tumor and make sure that it is safe to get rid of the blood vessel in question.

With the catheter in place, the surgeon inserts either a small ***plug*** made of tiny plastic particles or metal coils glued together, or a balloon to seal off the bad blood vessel. This stops the blood flow to the tumor, but not to normal parts of the brain. Within a couple of days after the embolization, the tumor is removed during a follow-up procedure.[43]

This technique might be used with tumors that contain a lot of blood vessels, such as meningiomas, hemangiopericytomas, and glomus jugulare tumors. Embolization can take several hours, and the operation for resection is often performed soon thereafter.[42]

Convection-Enhanced Delivery

Convection-enhanced delivery (CED) is a newer method used to deliver chemotherapy drugs or biologic therapies to the brain tumor.[44,46] This technique uses the principles of constant pressure to ***infuse*** these drugs directly into the tumor.

To perform CED, the neurosurgeon makes a small hole in the patient's skull and inserts a catheter (or many catheters, depending on the tumor size) near the tumor.[44,46]

The surgeon then connects a pump-like device to the catheter, filling it with a liquid form of the drug that is pumped directly into the tumor tissue.

By creating this direct route to the tumor, CED bypasses the blood brain barrier, which prevents many of these treatment drugs from entering the brain to treat the tumor.[44,45,46] As this technique evolves, it could be used to monitor the drug infusion in ***real time*** to help the surgeon make sure the proper amount of the drug is delivered.[46]

Lasers

Laser is an acronym that stands for ***Light Amplification by Stimulated Emission of Radiation***. Unlike light from the sun or a light bulb that has many different wavelengths spreading in every direction, laser light has a single, high-energy wavelength that is focused in a very narrow beam.[47] This narrow beam of intense light, which is both powerful and precise, can heat and destroy a brain tumor.[48] A laser also can be used to activate light-sensitive drugs that destroy cancer cells in a procedure known as ***photodynamic therapy***. (***Read more about photodynamic therapy later in this brochure.***) Different types of lasers are used depending on the procedure.

Lasers are frequently used for minimally invasive surgery, such as microsurgery and LITT,[48] as lasers can be more precise than scalpels.[47] The heat from the laser seals the blood vessels, resulting in less bleeding, swelling, pain, or scarring. The laser heat also helps clean the edges of the tissue as it cuts through it, reducing the risk of infection. Laser surgery may cut down on operating time, damage to healthy tissue, and healing time.

When a laser is used in surgery, the neurosurgeon makes a tiny cut in the scalp, drills a small hole in the skull, and inserts a thin, flexible laser fiber in the hole.[48] The laser is guided by a computer-assisted or stereotactic device to the proper location so precisely that it comes within 1 mm or less of the target. A special type of MRI, known as ***MR thermometry***, is used to monitor the temperature in the part of the brain being treated during the procedure. This ensures that the laser stays focused on the tumor and avoids damaging nearby healthy tissue. Once the tumor has been destroyed, the surgeon removes the fiber and closes the incision.

Lasers have been used to treat brain tumors that are located deep in the brain or in hard-to-reach areas, and in patients who are poor candidates for surgery.[48] Among the types of brain tumors that have been treated with lasers are glioblastomas, brain metastases, ependymomas, gliomas, and recurrent tumors.

Microsurgery

Microsurgery refers to the use of a high-powered microscope to magnify the surgical area during the procedure, along with tiny surgical tools that enable the neurosurgeon to operate on small or delicate structures in the brain.[49,50,51]

These microscopes produce bright light that can magnify the area up to 40 times greater, allowing the surgeon to see arteries, veins, thin nerves, and tiny blood vessels. Often, the microscope can display an image of the surgical area on a monitor. This enables the surgeon to have an assistant help during surgery as both can see the surgical area. This technique helps the surgeon navigate with precise movements around the finest nerve endings and tiniest blood vessels to remove the tumor and examine the brain for any remaining tumor.

Microsurgery enables surgeons to perform minimally invasive procedures, which typically result in smaller incisions, fewer complications, and a quicker recovery.[50]

Among the types of brain tumors that microsurgery has been used to treat are astrocytomas, brainstem glioma, ependymoma, glioblastoma, glioma, glomus jugulare tumors, hemangioblastoma, medulloblastoma, meningioma, metastatic brain tumors, mixed gliomas, and pediatric brain tumors.

An operative microscope aids the neurosurgeon's view of the tumor. Courtesy of John Sampson, MD, PhD, MBA, MHSc, Duke Health.

Some microscopes allow surgeons to share the same view. Courtesy of Carl Zeiss Surgical, Inc. NC33 Microscope.

Endoscopic Surgery

For endoscopic surgery, a type of microsurgery, the neurosurgeon makes a small hole in the skull and inserts an endoscope, which is a long, thin, flexible tube with a light and camera on the end.[52] The surgeon uses tiny surgical tools placed through the endoscope to perform the operation. An MRI or CT scan may be used to help guide the surgeon to the appropriate place in the brain. The endoscope is often used for various types of skull base surgery, or as an adjunct during an open craniotomy.

Neuro-Endoscopy

For neuro-endoscopy, the neurosurgeon uses an endoscope and tiny surgical tools to remove a tumor in areas that are difficult to reach using other surgical techniques. However, instead of making a small cut in the skull, the surgeon may reach the tumor by funneling the endoscope through the mouth or nose.[53,54,55]

This technique can be used to perform a biopsy or partial or complete removal of a brain tumor, or sometimes to treat hydrocephalus.[55] Among the types of brain tumors that have been treated with neuro-endoscopy are skull base tumors, acoustic neuromas, ventricular tumors, pituitary tumors, pineal region tumors, and meningiomas.

Photodynamic Therapy

Photodynamic therapy (PDT) is a procedure that involves the use of both a laser and a special drug called a ***photosensitizing agent*** to destroy a brain tumor.[47,56] For PDT, an argon laser is typically used, and the drug has a special non-toxic chemical that makes it ***light up***—often described as ***glowing green***—when it is exposed to the laser light.

Just prior to surgery, the drug is injected into a vein or artery where it travels through the bloodstream and is absorbed by the tumor. During surgery, the neurosurgeon aims the laser at the tumor, which causes the drug to react and destroy the tumor cells.[47,56]

PDT can destroy tumor cells while limiting harm to nearby healthy brain tissue. It is very precise and can be repeated many times at the same site if needed. PDT is less invasive than surgery, takes less time, and usually results in little or no scarring once the site heals.[56,57]

This treatment is limited, however, in that it can only treat tumor cells that the surgeon can see and the light can reach, as well as tumors that are considered operable.[35,56,57] PDT cannot be used to treat tumors that are large and/or deep, have spread to many places, will not respond to the sensitizing drug, or are near the brain stem due to the risk of edema.

The PDT drugs may leave patients very sensitive to light for a while after surgery, so they must take special precautions after the drugs are used.[56] Researchers continue to evaluate different kinds of lasers and new photosensitizer drugs that might work even better.[47]

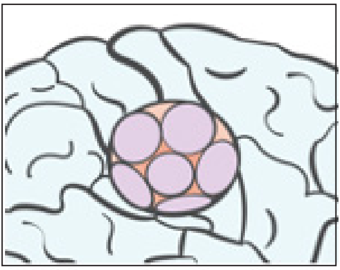
Radiation/Chemotherapy Implants

Following surgery to remove a brain tumor, radiation/chemotherapy implants may be placed to destroy any remaining cancer cells.

Polymer Wafer Implants

Polymer wafer implants use a chemotherapy drug, carmustine, that is placed in the brain to destroy any cancer cells that remain following surgery to remove a brain tumor.[6,7] Chemotherapy drugs destroy tumor cells by keeping them from growing, dividing, and making more cells.[7]

During surgery, the neurosurgeon places polymer wafer implants, which are about the size of a dime, in the area where the tumor was removed.[6,7] Depending on the size of the tumor, up to eight wafers may be left behind. During the following two to three weeks, the wafers slowly dissolve, releasing the chemotherapy directly to the tumor site.[6,7,58]



Wafer placement in the cavity created by tumor removal.

Carmustine wafers have been used to treat high-grade gliomas[6,7,59] and glioblastomas that have returned.[59] Research has shown that the use of carmustine wafers helps prolong a person's life.[60,61] For brain tumors, this form of carmustine may work better than other forms and result in fewer side effects. However, there are risks associated with the use of carmustine wafers[9] that the patient should discuss with their healthcare team.

Brachytherapy

Brachytherapy is a type of radiation therapy whereby a low dose of radioactive material is placed near the area where the brain tumor was removed.[62,63] This technique delivers radiation with great accuracy, minimizing the amount of radiation to nearby healthy tissue and structures. Sparing healthy tissue and organs helps reduce the side effects that patients may experience.

During surgery, the neurosurgeon and radiation oncologist carefully place the ***implants***, also called ***seeds***, that contain the radioactive material.

Brachytherapy has been used to treat newly diagnosed or recurrent brain tumors, including malignant meningiomas and brain metastases.[62,63]

The newest form of brachytherapy, known as targeted tile brachytherapy, uses a flexible collagen tile containing radioactive material instead of seeds. The tile delivers radiation until it is absorbed into the body. According to preliminary studies, this treatment improved local tumor control for patients with recurrent meningiomas and recurrent brain metastases[64,65] and could potentially improve overall survival in patients with recurrent glioblastoma.[66,67]

Robotic Surgery

Robotic surgery, also known as ***robot-assisted surgery***, is a method for performing surgery that uses a mechanical arm, three-dimensional imaging, and a computer.[68]

A few days before the surgery, the neurosurgeon uses robotic surgery software to perform three-dimensional imaging scans of the patient's brain. This helps the surgeon prepare, plan out, and pinpoint the exact location for the surgery.[69] As for any type of minimally invasive surgery, the surgeon makes a small hole in the skull and inserts an endoscope. During surgery, the surgeon controls the robotic arm, which has small surgical tools attached to it, from a computer workstation.[68,70]

Although a newer technology, robotic surgery is being used in select hospitals across the country to successfully remove brain tumors[70] and perform biopsies.[71,72]

Prototype of a surgical robot. Courtesy of Hunter Downs, PhD, NovaSol, Robotics Research 1607 test platform.

The benefits of robotic surgery include:[70]

- Allowing the surgeon to operate with more precision
- Viewing ***real time*** imaging scans without interrupting the surgery
- Operating with tiny surgical tools

Additional benefits for the patient may include a quicker recovery, less pain and bleeding, less risk for infection, shorter hospital stay, and smaller scars.[68]

Ultrasonic Aspiration

Ultrasonic aspiration uses the vibration created by ultrasonic waves to break apart tumors and then suction out, or aspirate, the pieces of tumor.[73] This handheld device enables the neurosurgeon to debulk large tumors inside the skull and avoid damaging nearby healthy brain tissue during the procedure. After the tumor is broken apart, suctioning the pieces minimizes the chances of spreading tumor cells to other parts of the brain.[74] In addition, this tool may reduce surgery time and decrease blood loss for patients.

Fluorescence-Guided Surgery

Fluorescence-guided surgery (FGS) is an imaging technique that uses a fluorescent dye and special microscope to light up the tumor cells, making it easier for the neurosurgeon to see the tumor and surgically remove as much of it as possible.[7,9,31]

A few hours before surgery, the patient is given the fluorescent dye to swallow.[7,9,31] Currently, 5-aminolevulinic acid (5-ALA) is a commonly used dye for FGS, although researchers are studying other dyes.[32] Once the dye is absorbed by the tumor cells, the surgeon uses a special blue light microscope that lights up the tumor cells.[7,9,31]

This technique enables the surgeon to see the tumor cells in a different wavelength of light that would otherwise not be visible to the human eye.[75] This type of light also allows the surgeon to see ***through*** the layers of tissue and organs. In addition, it uses ***real-time*** imaging. All these features help the surgeon better see the tumor and safely remove it while protecting normal brain regions.

A newer technique, FGS has been used to successfully treat gliomas, including glioblastoma, and is currently FDA approved for this indication.[76,77,78]

BENEFITS OF BRAIN TUMOR SURGERY

In general, the benefits of surgery for a brain tumor depend largely on the type of tumor and its location as well as the type of surgery performed. The potential benefits of brain tumor surgery include:[6,7,9]

- Establishing an accurate diagnosis
- Providing tissue for genetic analysis

- Safely removing as much of the tumor as possible
- Relieving pressure on the brain
- Eliminating or improving symptoms
- Improving functional status
- Possibly prolonging survival and preventing future neurological dysfunction

In general, the more tumor that is removed, the better a patient's prognosis.[2,6,9]

COMMON RISKS OF BRAIN TUMOR SURGERY

As with all treatments for brain tumors, there are risks associated with brain tumor surgery. The risks associated with brain tumor surgery depend largely on the type of tumor and its location as well as the type of surgery performed. **Different people experience different risks, and the risks of any given operation should be addressed with the treating neurosurgeon**.

This discussion with the treatment team is part of the informed consent process, during which the patient's written permission is obtained prior to surgery. It is very important that the patient read the informed consent document carefully and understand all that it says before signing it.

Brain tumor surgery poses both general and specific risks. General risks are for people having surgery for any reason and are not limited to brain tumor surgery. These may include:[15,52]

- Bleeding
- Blood clots
- Infections
- Reactions to anesthesia

Possible risks associated with brain tumor surgery include:[52]

- Speech or vision problems
- Memory or cognitive problems
- Balance or coordination problems
- Muscle weakness
- Blood clots or bleeding in the brain
- Infection in the brain, wound, or skull
- Edema (swelling)
- Seizures
- Stroke
- Coma

Many of the surgical techniques and tools described in this brochure were developed to reduce the risks associated with brain tumor surgery. They help neurosurgeons navigate the brain to reach tumors in hard-to-reach locations, remove as much tumor as possible while preserving critical functions, reduce damage to nearby healthy tissue, operate in small or delicate structures in the brain, and remove the tumor using less invasive techniques.

WHAT TO EXPECT

Prior to surgery, the patient will be given instructions on how to prepare for surgery. The neurosurgeon will perform a physical examination and order different laboratory tests and imaging scans and have a conversation with the patient and/or family discussing the risks, benefits, and alternatives of surgery.[52,79]

During the days before surgery:[52,54,79]

- Patients may be asked to start or temporarily stop taking certain medications. Some patients may be given steroids to reduce the risk of edema and/or anti-epileptic drugs to lower the risk of seizures. Some patients may need to stop taking blood-thinning medications for a while.

- Patients are asked to stop smoking. Smoking increases the risk of complications from surgery and can slow the healing process.
- Some patients may be asked to wash their hair with a special shampoo the night before surgery.

On the day of surgery:[52,79]

- Patients will likely be asked not to drink or eat anything for several hours before surgery.
- Patients on daily medications may be instructed by their treatment team to take specific ones with a small sip of water.
- Depending on the type of surgery, patients may be given local anesthesia (to numb the surgical area), regional anesthesia (to block pain in or near the surgical area), or general anesthesia (to keep from feeling any pain). Sedation is often administered immediately prior to the operation.
- Depending on the type of surgery, patients may have their head, or parts of it, shaved. For most minimally invasive surgeries, patients won't need to have their heads shaved.
- Depending on the type of surgery, it may be performed in the hospital or an outpatient setting.

Immediately after surgery, patients are closely monitored in a post-anesthesia care unit (PACU) until they are awake and stable enough to be transferred to a neuro intensive care unit (Neuro ICU).

In the neuro ICU, patients are closely monitored and assessed for neurological changes to help determine level of brain function. They may be asked questions, have their eyes checked with a light, or asked to do simple tasks.[52]

Recovery time will depend on the type of surgery, anesthesia given, and the patient's level of functioning prior to surgery. Patients may need medicines to relieve pain, nausea, and/or brain swelling (edema). They

Following surgery, you will be taken to a special care unit. Courtesy of Peter Black, MD, Brigham and Women's Hospital. ©BlueStar Media, LLP.

may require different types of therapy (e.g., physical, occupational, and speech therapy) to regain strength, movement, speech, and/or the ability to do daily tasks.

Depending on the type of surgery, patients may be sent home, or they may have to stay in the hospital for either a couple of days or several days. Shortly after surgery, patients will have an MRI to determine how much of the tumor was removed.[6,80]

Once at home, the patient should follow any self-care instructions they are given. These may include wound care, nutritional recommendations, and physical activity instructions or limitations. The healthcare team will explain the side effects to watch for and when to contact the doctor.[79] Depending on the type of surgery performed, making a full recovery from brain surgery could take weeks for a less invasive procedure or months following a craniotomy.

THE PATHOLOGY REPORT

At the time of surgery, the neurosurgeon sends a piece of the tumor tissue to the pathologist. The pathologist examines the tissue, determines the diagnosis, writes a report, and sends the report to the surgeon. This process usually takes several days to be completed. In complex cases or when the tissue is sent to a pathologist at another hospital for diagnosis, it may take a week or more for the surgeon to receive the final report. Additional tests for certain molecular and genetic markers may take even longer.

FOLLOW-UP CARE

A follow-up visit with the neurosurgeon and other team members will be scheduled to review test results; the next steps in the treatment if needed; and prognosis following surgery. ***Prognosis*** refers to the chance of recovery or survival from a disease. A follow-up visit may include having additional imaging scans and/or tests.

The neurosurgeon will want to discuss the pathology report results and the next part of the treatment plan. For some brain tumors, surgery may be the only treatment needed, leaving the patient to focus on healing. For others, surgery is the first step of the treatment plan. Be sure to keep follow-up doctor visits and have the necessary scans and tests. Regardless of the treatment phase, the patient's focus now is becoming well again.

NOTES

AMERICAN BRAIN TUMOR ASSOCIATION INFORMATION, RESOURCES AND SUPPORT

Educational brochures are available on our website or can be requested in hard copy format for free by calling the ABTA. Most brochures are available in Spanish, with exceptions marked with an asterisk.

General Information

About Brain Tumors: A Primer for Patients and Caregivers
Brain Tumor Dictionary*
Brain Tumors Handbook for the Newly Diagnosed*
Caregiver Handbook*

Tumor Types

Ependymoma
Glioblastoma and Anaplastic Astrocytoma
Medulloblastoma
Meningioma
Metastatic Brain Tumors
Oligodendroglioma and Oligoastrocytoma
Pituitary Tumors

Treatment

Chemotherapy
Clinical Trials
Conventional Radiation Therapy
Proton Therapy
Stereotactic Radiosurgery*
Steroids
Surgery

AMERICAN BRAIN TUMOR ASSOCIATION INFORMATION, RESOURCES AND SUPPORT

Information

ABTA WEBSITE | ABTA.ORG
Offers more than 200 pages of information, programs, support services and resources, including: brain tumor treatment center and support group locators, caregiver resources, research updates and tumor type and treatment information across all ages and tumor types.

Education & Support

- ABTA Educational Meetings & Webinars
  In-person and virtual educational meetings led by nationally-recognized medical professionals.

- ABTA Patient and Caregiver Mentor Support Program
  Connect with a trained patient or caregiver mentor to help navigate a brain tumor diagnosis.

- ABTA Connections Community
  An online support and discussion community of more than 25,000 members.

- ABTA CareLine
  For personalized information and resources, call 800-886-ABTA (2282) or email info@abta.org to connect with a CareLine staff member.

Get Involved

- Join an ABTA fundraising event.

- Donate by visiting abta.org/donate.

Contact The ABTA

CareLine: 800-886-ABTA (2282)
Email: info@abta.org
Website: abta.org

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