# The Neurosurgical Referral: What, When, Why, Where, How

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Treatment options for neurological diseases include medical and/or surgical intervention. The decision to operate involves the assessment of many factors, some of which may be specific for a particular disease. In some patients, serial neurological examinations and monitoring of response to non-surgical treatment are essential in determining whether surgery is indicated. An overview of common neurosurgical procedures, general and specific indications for their use, and the complications that may result are outline below.

GENERAL INDICATIONS FOR NEUROSURGERY

- The surgical procedure has been shown to have a significantly better clinical outcome than medical treatment.
- The disease is unresponsive or no longer responsive to medical therapy (e.g. progressive neurological deterioration secondary to elevated intracranial pressure resulting from a space occupying tumor, unresponsive to corticosteroid and osmotic diuretic medications).
- The clinical signs are severe or rapidly progressive (e.g. an animal presenting with acute herniation of an intervertebral disc and loss of deep pain perception)
- The presence of vertebral column instability.

The clinical response to medical versus surgical treatment varies over time. Palliation of clinical signs with medical therapy may be effective in the short term, however, surgical intervention may result in an improved long term outcome (e.g. resection/debulking of tumors). The risks and benefits of surgery, together with the effects of delaying surgery to pursue medical treatment, must be assessed for each individual case.

When determining whether or not to pursue surgery, it is essential to have an accurate neuroanatomical localization. Lesions identified outside the region of localization may not be clinically significant, and treatment may not be indicated. Lesions found within the region of localization should be defined anatomically as completely as possible to allow precise surgical planning.

<u>Common procedures</u>

1. **Decompression** involves removal of part of the bony calvarium or vertebra and/or removal of space-occupying masses to alleviate ongoing compression of neural tissue.
2. **Fenestration** is the creation of an opening in the intervertebral disc by removal of a section of the annulus fibrosus to allow the removal of nucleus pulposus (pulpectomy).
3. **Realignment, stabilization and/or fusion** of one or more vertebrae is indicated when vertebral column instability is present secondary to fracture, luxation or malformation/malarticulation.
4. **Mass resection** may involve the removal of any infiltrative or compressive tissue including: disc herniation, neoplasia; inflammatory/infectious granulomas; haematomas; bony proliferation and hypertrophied soft tissues.
5. **Exploratory surgery and biopsy** is indicated when a definitive diagnosis cannot be determined by other neurodiagnostic procedures such as advanced imaging, CSF analysis, electrophysiology. Biopsy may also be accomplished as part of decompressive or excisional procedures, and can provide valuable information relating to drug sensitivity in infectious conditions such as discospondylitis. It is commonly used to determine the etiology of peripheral nerve and muscle disorders.

<u>Selection of a neurosurgical procedure</u>

Factors to consider when selecting a neurosurgical procedure are:

- Neuroanatomical location of the lesion along the neuraxis as well as the exact location of the pathological process (e.g. whether compression is situated ventral, lateral, or dorsal to the spinal cord)
- Intended goal (i.e. decompression, excision, biopsy)
- Regional anatomy and neuroanatomy
- Extent of the lesion and the amount of exposure needed
- Extent of removable bone and the impact this may have on regional biomechanical function and stability (especially if preoperative instability is present)
- Neurological status of the patient.

<u>Neurosurgical equipment and setting</u>

Neurosurgery should be done in a setting where intensive monitoring is available both during the anaesthetic procedure and in the immediate postoperative period. An anaesthestist should be present throughout the procedure and have available blood products for transfusion should this be necessary. In addition to routine orthopedic surgical instruments, the neurosurgeon should have available a high speed pneumatic or electric drill and burrs, monopolar and bipolar cautery, hemostatic sponge/agents and suction. Additionally, an ear hook and spoon, dural hook, and/or an array of microdissection instruments may be needed.

Neurosurgical emergencies

Indications for emergency surgical referral are based on either the presence of severe and/or progressively deteriorating neurological signs. For appropriate medical treatment prior to referral, e.g. cardiovascular stabilization, oxygen therapy, hyperosmolar treatment, the reader is referred to other texts on the subject. The most common neurological injuries that may require emergency surgery include:

Acute spinal cord trauma caused by:

- Vertebral fracture/luxation
- Acute, traumatic disc herniation
- Hemorrhage/hematoma
- Decompensating neoplasia

The presence of any or all of the following clinical signs may warrant the need for immediate surgical intervention:

- Rapid progression from paresis to paralysis
- Acute paralysis
- Loss of conscious pain sensation
- Schiff-Sherrington posture
- Hypoventilation
- Suspected vertebral column instability

Traumatic brain injury

- Intracranial hemorrhage/hematoma
- Depressed skull fractures
- Decompensating neoplasia
- Rapidly progressing intracranial edema/hypertension

The presence of any or all of the following clinical signs may warrant the need for immediate surgical intervention:

- Progressive deterioration in mental status (e.g. obtundation progressing to stupor or coma)
- Progressive loss of brainstem reflexes (e.g. papillary light reflexes, palpebral reflexes, gag reflex, etc)
- Decerebrate or decerebellate posture
- Abnormal ventilatory patterns

## SPINAL SURGERY

Terms commonly used in spinal surgery The most common indications for spinal surgery in dogs and cats are:

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| Laminectomy: | the excision of lamina, or the dorsal portion of the vertebral arch |
| Hemilaminectomy: | removal of one half of the vertebral arch (the lamina, articular process and pedicle on one side) |
| Dorsal laminectomy: | removal of the dorsal spinous process and the laminae of the vertebral arch |
| Deep dorsal laminectomy: | extension of the dorsal laminectomy ventrally to include the articular processes uni- or bilaterally +/- pediculectomy |
| Continuous dorsal laminectomy: | extension of the dorsal laminectomy cranially or caudally to include multiple vertebral arches |
| Pediculectomy: | removal of the pedicle, or the portion of the vertebral arch ventral to the articular processes |
| Facetectomy: | removal of an articular process/facet |
| Foramenotomy: | enlargement of an intervertebral foramen |
| Fenestration: | surgical creation of an opening in the intervertebral disc |

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| Ventral slot: | slot-like opening created ventrally thru the intervertebral disc and cranial and caudal endplate in the cervical region |
| Spinal stabilization: | the process of removing all motion between adjacent vertebrae by the application of various metallic/synthetic implants, bone cement and/or bone grafts |
| Laminectomy membrane: | a constrictive, fibrotic, usually hypertrophied, cicatricial tissue covering the region of a previous laminectomy site. |

The most common indications for spinal surgery in dogs and cats are:

- Degenerative disc disease
- Caudal cervical spondylomyelopathy (CCSM)
- Degenerative lumbosacral stenosis
- Trauma
- Neoplasia

Less commonly encountered indications for spinal surgery are:

- Congenital/acquired malformations (e.g. atlantoaxial instability, synovial cysts, scoliosis)
- Infectious disease (e.g. empyema, abscess, discospondylitis)
- Epidural/intradural hemorrhage.

General complications of spinal surgery

The major technical complications associated with spinal surgery are:

- Iatrogenic trauma to neural tissues
- Intra-operative hemorrhage (resulting in hypotension, anemia, or hematoma formation)
- Spinal vasculature compromise
- Vertebral column instability
- Excessive scar formation

The majority of these complications can be treated if they are recognized as they occur and appropriate measures are taken promptly. However, iatrogenic trauma of neural tissue and compromise of local vascular supply are complications that are not easily rectified. Meticulous surgical technique and a thorough knowledge of regional anatomy are essential to a positive outcome.

In the immediate postoperative period (24-48 hours), inadequate patient confinement can lead to ongoing hemorrhage, hematoma formation and compression of neural elements. This also is the time when recumbent patients, especially those on opioid drugs, can frequently aspirate and may develop pneumonia. In addition to postoperative pain, the neurological status of most patients is often temporarily worse following surgery.

Exuberant regrowth of bone leading to compression of neural structures and recurrence of neurological signs is a unique complication of laminectomy performed in immature animals. This is most commonly a problem with continuous dorsal laminectomies in the cervical region. When compressive bony regrowth occurs another operation may be indicated if conservative treatment is ineffective and the patient continues to deteriorate.

Similar potential complications apply for subsequent procedures in the same region. Additionally, altered anatomy, muscle fibrosis and scar tissue in the region of the previous surgical site can be problematic. By virtue of the fact that the neural tissue has sustained a second injury, the potential for recovery may not be as complete as with the initial event.

Bladder dysfunction and urinary tract infection are common problems in any patient with neurological disease particularly those with spinal cord dysfunction. Appropriate bladder management together with excellent nursing care, frequent patient assessment, and physical therapy is paramount to a positive outcome following neurological surgery.

### CERVICAL SPINAL SURGERY

Ventral cervical decompression (ventral slot): The main indications for a ventral approach to the cervical spine include removal of herniated disc material, cervical disc fenestration/biopsy and cervical vertebral stabilization. There is minimal soft tissue and bony dissection with this approach resulting in minimal postoperative morbidity and an early return to comfort and function. The window or slot created by the surgeon is directly on the midline, and is particularly useful for removing disc material located in the ventral aspect of the vertebral canal. Removal of larger ventral extradural masses, intradural/ intramedullary masses or lesions not primarily on the ventral midline should not be attempted because exposure of the spinal cord is very limited and complications are potentially life-threatening. Ventral slot procedure may be combined with cervical vertebral stabilization (fusion) and distraction when dynamic instability is present.

The primary disadvantage of the ventral slot is the limited exposure the surgeon has to the vertebral canal. If disc material or other space-occupying masses are located lateral to the midline, full decompression is generally not achieved without creating an excessively wide opening and predisposing the patient to vertebral column instability and subluxation. Ventral slots in adjacent vertebrae may also predispose to instability. Common complications seen in ventral slot procedures include:

- Profuse hemorrhage due to laceration of the internal vertebral venous plexus
- Iatrogenic spinal cord trauma
- Collapse of the intervertebral space.

This may manifest as worsening neurological signs, cervical pain, and/or thoracic limb lameness. Cardiac arrhythmias, respiratory compromise, hypotension and Horner's syndrome are uncommonly reported complications of cervical spinal cord injury and surgery. Damage to the recurrent laryngeal nerve, carotid artery, vagosympathetic trunk, and vertebral arteries may also occur during tissue retraction, which is required to expose the ventral aspect of the cervical spine. Retraction and trauma to the trachea, although uncommon, may result in subsequent tracheal collapse, particularly in animals with underlying clinical or subclinical tracheal disease prior to surgery.

Dorsal cervical laminectomy: This approach is indicated when greater exposure of the vertebral canal and/ or spinal cord is required and is particularly useful when:

- Lesions affect the dorsal and dorsolateral aspects of the spinal cord and vertebral column
- Multiple ventral compressive lesions are present
- Intramedullary tumours and congenital or acquired conditions (e.g. syringohydromyelia and dorsal spinal arachnoid cysts) need to be approached for biopsy, resection, or marsupialization.

Preservation of articular processes is essential to maintain as much vertebral column integrity as possible. The laminectomy can be extended cranially and caudally in a continuous fashion over several vertebrae. Careful palpation of the floor of the vertebral canal is possible from this approach. Dorsal laminectomy at C1 is possible, however, hemidorsal laminectomy is preferred at $C_2$ and $C_{2\text{-}3}$ in order to maintain integrity of the attachment of the nuchal ligament (Figure 3).

Lesions accessible by this approach include:

- Large ventral extradural compressions that cannot be removed via a ventral slot
- Laterally located extruded disc material
- Nerve root tumors
- Spinal cord and vertebral column tumors

Sufficient surgical access may require extension of the laminectomy laterally and ventrally (including partial facetectomy) and/or enlargement of the intervertebral foramen (foraminotomy). In addition, osseous and soft tissue stenoses, such as those created by synovial cysts, may be effectively removed by drilling away the inner lamina. The resultant widening of the vertebral canal also allows for decompression of neural tissue.

The main disadvantage of the dorsal cervical approach is the extensive soft tissue and bony dissection, especially in large and giant breed dogs, where the depth of the surgical approach adds to the difficulty in visualization.

- Profuse hemorrhage can occur from soft tissue dissection as well as laceration of the internal vertebral venous plexus. This can be potentially life threatening, especially when operating in the rostral cervical region (C1-3).
- Ongoing postoperative hemorrhage, hematoma formation leading to secondary spinal cord compression and hypoventilation are serious complications that may require further surgery and/or mechanical ventilation.
- Longer operating times, especially with continuous dorsal laminectomies, damage to the underlying spinal cord and slower return to function compared to ventral cervical procedures, are also considerations.
- Potential vertebral column instability and/or the formation of epidural scarring in addition to the development of a clinically significant laminectomy membrane are potential long-term complications leading to recurrence of neurological signs.
- Extensive soft tissue dissection predisposes to postoperative seroma formation, particularly in active patients.

Cervical vertebral stabilization: The primary indications for cervical vertebral stabilization are:

- Repair of cervical vertebral fracture/luxations

- Cervical vertebral fusion with or without distraction for the treatment of dynamic forms of caudal cervical spondylomyelopathy (in large breed dogs)
- Atlantoaxial instability.

Implants placed in the vertebral bodies provide superior stabilization compared to implants applied to the spinous processes or articular processes/facets. The use of pins or screws and polymethylmethacrylate (PMMA) is the technique of choice for cervical vertebral fracture/luxations.

Many surgical procedures have been described to accomplish distraction and stabilization of dynamic compressive lesions in CCSM. These include:

- Ventral slot procedure with or without stabilization (using pins and PMMA)
- Vertebral body plating
- Inverted cone decompression technique
- Metal washers and screws
- Polyvinylidine spinal plates
- Harrington rods
- Dorsal laminectomy
- PMMA vertebral body plugs
- External fixators

Prospective studies comparing the various approaches have not identified one to be superior over another. The ventral approach to the cervical spine provides good visualization of cervical vertebral bodies for accurate realignment, with minimal trauma to soft tissues. Surgical stabilization may also be indicated following a ventral slot procedure in situations where the slot is excessively large or instability following the slot procedure is anticipated, e.g. large or giant breed dogs.

Complications unique to the application of implants to the cervical vertebral bodies may result from lack of visualization of the spinal cord and nerve roots during implant placement. The surgeon must be comfortable with 3-dimensional visualization of these structures, based on the unique landmarks of the ventral aspect of each cervical vertebrae, when placing pins, screws, etc.

Laceration of vertebral arteries, spinal nerves/nerve roots and trauma to the spinal cord are the major complications that may occur during implant placement. Implant failure may occur due to pin migration or inadequate size of implants/PMMA. The use of positive profile threaded pins significantly reduces pin migration. PMMA infection rarely occurs and is treated by removal of the implant.

Stabilization of vertebrae, particularly in the caudal cervical region may predispose to development of a second lesion involving adjacent disc spaces ('domino' lesion). Difficulty swallowing and esophageal dysfunction as a result of the cement mass is a rare complication.

Dorsal and ventral approaches for the repair and stabilization of the atlantoaxial (AA) joint have been described in the literature. However, most surgeons agree that ventral repair results in superior fixation. Complications relating to atlantoaxial stabilization vary considerably depending on surgical technique and expertise:

- Improper pin placement due to the lack of visualization of neural structures and fracture of vertebrae during pin/screw placement are potential complications of atlantoaxial stabilization, especially in miniature breeds, which frequently have congenitally malformed vertebrae.
- Placement of pins into cranial spinal cord, brainstem, atlanto-occipital joints or C1 spinal nerves are serious complications that can lead to vestibular signs, respiratory compromise (requiring assisted ventilation), severe neck pain and/or permanent paralysis.
- Dorsal fixation techniques have been associated with an increased incidence of implant failure and respiratory compromise.

Cervical disc fenestration: Chondrodystrophic breeds with degenerative disc disease benefit from cervical disc fenestration. This may be done at the time of decompressive surgery or prophylactically when there is radiographical, CT or MRI evidence of degenerative disc disease.

## THORACOLUMBAR SPINAL SURGERY

Hemilaminectomy: This is the best approach for most pathological conditions affecting the thoracolumbar vertebral column, spinal cord, and nerve roots. It is essential that the laterality of the lesion be known prior to this surgical procedure since the contralateral aspect of the spinal cord, nerve roots, and ligamentous and osseous structures are not visualized from this approach. Hemilaminectomy allows good visualization of the ventral and lateral aspects of the spinal cord and nerve roots and maintains significant stability of the vertebral column since the spinous process and associated ligamentous structures, as well as the contralateral articulations, are maintained.

- The majority of clinically significant acute and chronic disc protrusions and extrusions are best treated in this manner.
- This approach also allows easy access to the lateral aspect of the disc for fenestration.
- Extradural and intradural space-occupying lesions in the ventral and lateral aspects of the cord are also best approached by hemilaminectomy which can be extended cranially, caudally, or dorsally to allow for more complete visualization and/or excision of the mass.
- Progressive swelling of the spinal cord can be addressed quickly by extension of the laminectomy cranially and caudally.
- Removal of bony fragments and hematomas secondary to trauma (vertebral fracture/ luxations), migrating foreign bodies (grass seeds, bullets) as well as exploratory/biopsy procedures of the lateral or ventral spinal cord and nerve roots are also routinely done via hemilaminectomy.

Complications associated with TL hemilaminectomy are uncommon. The major intraoperative complication of hemilaminectomies performed in the TL region include:

- Iatrogenic spinal cord injury
- Nerve root trauma
- Hemorrhage/hematoma

Vertebral column instability may be a concern in situations where the laminectomy is extended for more than three vertebral lengths (affecting three or more adjacent articulations) or in active large breed dogs. Weakening or fracture of the spinous processes may occur if the laminectomy is extended too far dorsally.

Dorsal laminectomy: Indications for dorsal laminectomy in the thoracolumbar region of the spine are the same as those for the cervical region. Occasionally fractures of the thoracolumbar (TL) region are approached via dorsal laminectomy allowing fragment removal and decompression. Instability is a particular concern following dorsal laminectomy of the thoracic or lumbar vertebrae. Bilateral loss of articular facets and/ or loss of the interspinous ligament can result in significant vertebral column instability and subsequent luxation.

Thoracolumbar vertebral stabilization: Vertebral alignment and stabilization is indicated whenever vertebral instability is suspected clinically or when it is documented with dynamic imaging. The most common neurological conditions requiring stabilization in the thoracolumbar region are vertebral fractures and luxations.

Surgical treatment of vertebral fracture-luxation includes vertebral realignment, decompression and stabilization. Occasionally neoplastic and infectious diseases causing vertebral instability, malalignment or malarticulation (e.g. discospondylitis) may require surgical decompression, debulking and stabilization.

Degenerative and/or congenital disease in the TL region leading to stenosis of the vertebral canal (e.g. synovial cysts, congenital vertebral anomalies and scoliosis) is often treated by stabilization in conjunction with a decompressive laminectomy.

Vertebral pins/screws and PMMA and vertebral body bone plates provide the most rigid fixation in this region, and permit the most accurate anatomical alignment of the vertebral column.

Intra-operative complications usually result from poor visualization of spinal cord and nerve roots during implant placement and result in iatrogenic trauma to neural tissues. Iatrogenic vertebral fractures, implant migration and failure, as well as infection, are less common postoperative complications.

Thoracolumbar disc fenestration: While debate surrounds the role of TL disc fenestration, it is the authors' opinion that annular fenestration with nuclear pulpectomy of at risk intervertebral discs ($T_{11}$-$L_3$) is indicated in chondrodystrophic breeds with degenerative disc disease.

Foramenotomy and/or pediculectomy: Enlargement of the intervertebral foramen may be done with or without removal of a portion of the pedicle. This provides access to masses within the intervertebral foramen and ventral aspect of the vertebral canal. This approach has the advantage of maintaining the integrity of the articular facets.

## LUMBOSACRAL (LS) SPINAL SURGERY

Dorsal laminectomy: Compression of the cauda equina may result from malarticulation/malformation, instability, and/or vertebral canal stenosis causing secondary degenerative joint disease, ligamentous hypertrophy and/or disc degeneration at the LS junction. Excellent visualization of the cauda equina, L7-S1 dorsal annulus, articular facets and surrounding soft tissues is possible following dorsal laminectomy at the LS junction. The cauda equina may be retracted gently to visualize underlying structures, such as the dorsal annulus, as well as to assess the L7 nerve root as it enters the intervertebral foramen. Nerve roots of the cauda equina may be easily biopsied from this approach and extradural as well as intradural masses excised. Secondary compressive osteoarthritis, ligamentous hypertrophy and disc protrusion may be treated by decompressive dorsal laminectomy with or without stabilization.

Complications associated with lumbosacral spinal surgery are uncommon. Intra-operative hemorrhage around nerve roots and iatrogenic trauma to nerve roots can cause pain and worsening of lower motor neuron signs (to the tail, bladder, anal sphincter and sciatic nerve).

Seroma formation at the surgical site can occur especially in animals not strictly confined in the immediate post-operative period. Extensive removal of articular facets and pedicles may encourage the formation of a clinically significant laminectomy membrane, although this is not often seen until weeks or months following surgery. Discectomy done in conjunction with dorsal decompression may predispose the patient to discospondylitis and/or instability at the LS junction.

Foramenotomy/facetectomy: Entrapment of the L7 nerve root is a common occurrence with many conditions resulting in lumbosacral stenosis. Foramenotomy in conjunction with dorsal laminectomy may be done to relieve compression of nerve roots and associated apparent pain and/or dysfunction. Complete facetectomy is rarely indicated.

Lumbosacral stabilization: Lumbosacral stabilization is controversial. Indications for stabilization of the LS joint have not been agreed upon uniformly. In general, stabilization of the LS joint may be indicated when there is strong evidence of excessive movement in the joint, based on dynamic imaging studies. Decisions are complicated by:

- Variations in normal and abnormal anatomy within and between breeds
- Variations in imaging techniques and positioning
- A paucity of biomechanical data relating to the LS joint

Techniques using transarticular pins or screws have been described, however, the authors' preferred technique for internal fixation of the LS joint uses PMMA and pins placed in the L7 and S1 vertebral bodies. This is accomplished accurately following decompressive dorsal laminectomy. Pin/screw placement may cause fracture of L7-S1 facets during stabilization as well as there being the potential for implant failure and migration.

## CRANIAL SURGERY

Intracranial surgery is done most frequently done to:

- Remove neoplastic masses
- Decompress and debride traumatized brain tissue
- Remove depressed skull fractures
- Biopsy intracranial lesions
- Stabilize elevated intracranial pressure (ICP)

Less commonly, surgery may be indicated for:

- Drainage/evacuation of intracranial granulomas (fungal, foreign body) or abscesses (bacterial, fungal)
- Treatment of congenital anomalies (e.g. fenestration of intracranial intra-arachnoid cysts)
- Placement of ventriculoperitoneal shunts.

In the future, intracranial surgery may also be indicated for the treatment of refractory seizures. Thorough neurological assessment along with a good understanding of underlying pathophysiological processes are essential for effective medical and surgical decision-making. Neurosurgeons need to be familiar with intracranial anatomy and have experience interpreting neuroimaging studies. Standard anaesthetic and physiological monitoring equipment is used to monitor body temperature, heart rate and rhythm, blood pressure, blood gases, and urine production. Patients should ideally recover in an intensive care unit where physiological monitoring is continued, and ICP monitoring, mechanical ventilation and blood products are available.

Approaches

Maximum exposure of a lesion is particularly important with intracranial surgery to avoid excessive brain manipulation that predisposes the patient to iatrogenic brain injury and associated complications. To this end, surgical approaches often consist of a combination of standard approaches (Table 2).

Table 2: Terms commonly used in cranial surgery

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| Craniotomy: | any operation on or incision into the cranium |
| Craniectomy: | removal of a part of the cranium |
| Rostrotentorial craniotomy: | removal of the parietal/occipital bones to expose the frontal, parietal, occipital and temporal lobes of the brain. |
| Caudal fossa craniotomy: | removal of the caudal portion of the occipital bone and underlying osseous tentorium cerebelli with occlusion of the transverse sinus to allow access to the cerebellomedullary |

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| | angle and caudal occipital lobe. |
| Transfrontal craniotomy: | entry into the cranial vault by removal of the frontal bones overlying the frontal sinus as well as the inner bony table to allow access to the olfactory bulb and frontal lobe. |
| Suboccipital craniotomy: | entry into the caudal aspect of the occipital bones to allow access to the caudal cerebellum/brainstem. |

Transfrontal craniotomy:

Lesions involving the olfactory and rostrolateral portion of the frontal lobes of the brain are best approached through a bilateral transfrontal craniotomy/craniectomy. Olfactory bulb/frontal neoplasms, abscesses or granulomas secondary to foreign body migration, fungal granulomas and nasal tumours invading through the cribriform plate are the most common conditions for which this approach is indicated.

Rostrotentorial craniotomy:

Lesions involving the lateral aspect of the parietal, temporal and occipital lobes of the cerebrum may be exposed by a rostrotentorial approach (Figure 8). The most common clinical indications are resection/ debulking of cerebral convexity or intraparenchymal masses and craniectomy for stabilization of elevated ICP.

Caudotentorial craniotomy:

The transverse sinus may be occluded unilaterally for more caudolateral exposure of the brain. This allows access to the cerebellomedullary angle, tentorial region and lateral aspect of the cerebellum. A bilateral rostrotentorial craniotomy/craniectomy also allows access to the dorsal aspects of the frontal, parietal and occipital lobes. However, complete occlusion of patent transverse sinuses bilaterally or of the dorsal sagittal sinus usually results life-threatening circulatory compromise.

Suboccipital craniotomy:

A suboccipital approach allows access to the caudal cerebellum, caudodorsal brainstem and craniodorsal spinal cord. Decompression and excision of mass lesions, and treatment of syringohydromyelia of the caudal brainstem/rostral cervical cord are done via this approach.

Transsphenoidal hypophysectomy:

Access to the pituitary gland for resection of microadenomas is achieved by transsphenoidal hypophysectomy. Ventral approach to the caudal brainstem is possible, however, as with the transsphenoidal approach, surgery is technically challenging, and exposure is extremely limited.

## Cranial surgery complications

Incidence of peri-operative complications associated with a poor longterm outcome from intracranial surgery involves many factors including:

- Pre-operative neurological status
- Location and size of mass
- Histological diagnosis
- Concurrent medical disease
- Age

Patients should be assessed on an individual basis when contemplating surgery. Serious common post-operative complications of craniotomy/craniectomy can be divided into neurological and non-neurological causes.

- Neurological complications generally result from iatrogenic injury to the brain
- Non-neurological complications consist primarily of hypoventilation secondary to pneumonia or brainstem dysfunction.

## Neurological complications

Iatrogenic brain injury leading to hemorrhage and/or cerebral oedema, ischaemia, and progressive intracranial hypertension is apparent immediately postoperatively and reflected by deteriorating neurological status and possible brain herniation.

Iatrogenic intracranial infection is rare in dogs and cats and usually not clinically apparent for at least 36- 72 hours. Exposure of the brain to the frontal sinus following transfrontal craniotomy may increase the risk of postoperative infection, however clinical incidence is low. Infection is more likely to occur following reconstruction of large skull defects with prosthetic material such as polymethylmethacrylate. Intraventricular pneumocephalus is a rarely reported complication following transfrontal craniotomy. The risk of both infection and pneumocephalus may be reduced by closure of dural defects with fascial transplants or synthetic dura. Further short-term complications of transfrontal craniotomies include ipsilateral epistaxis and subcutaneous emphysema.

Iatrogenic generation of seizure foci following lesion resection, nervous tissue retraction or postoperative haemorrhage and scarring is a significant potential complication. Extensive craniectomy without reconstruction, particularly involving lateral/ dorsal approaches may result in compression of cortical tissue by overlying musculature. The incidence of long-term sequelae is unknown, however cortical atrophy and acquired seizure disorders may occur.

The neurological status of many patients deteriorates immediately following surgery. This is often most evident following procedures involving the cerebellum and caudal brainstem, although long-term compensation is generally good. Specific postoperative complications have been reported following transsphenoidal hypophysectomy and can include:

- Decreased tear production
- Hypothyroidism
- Hypernatraemia
- Diabetes insipidus

Hypernatraemia and diabetes insipidus may also be associated with a variety of intracranial diseases and neurosurgical procedures.

### Non-neurological complications

Aspiration pneumonia with secondary bacterial infection and/or chemical pneumonitis is the most common complication in craniotomy patients during the first 24- 36 hours postoperatively. The risk factors for aspiration appear to be multi-factorial and may include:

- Length of anaesthesia
- Regurgitation and vomiting
- Depressed pharyngeal/laryngeal function
- Seizures.

Fever and leucocytosis are the first signs seen, with radiographical changes occurring soon thereafter. Aggressive treatment including tracheal wash and culture, intravenous antibiotic therapy, oxygen therapy, nebulization and coupage and mechanical ventilation may be necessary.

These notes are modified from *BSAVA Manual of Canine and Feline Neurology*, 3rd ed., Simon Platt & Natasha Olby editors, Chapter 21: Principles of Neurosurgery (Beverly Sturges & Peter Dickinson) and a subsequent lecture at the Veterinary Neurology Symposium at UC Davis 2005 by Beverly Sturges with permission.