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INTRODUCTION

This chapter discusses the considerations and techniques for anaesthetizing animals with neurological disease. The chapter will cover intracranial disease, spinal disease and NM disease. A thorough understanding of the pathophysiology of diseases affecting these regions of the nervous system is essential to select the most appropriate anaesthetic technique and drug combination.

INTRACRANIAL DISEASE

Considerations
The main aim of anaesthesia in animals with intracranial disease is to preserve neuronal function. Normal neuronal function depends on maintaining adequate CBF.

CBF regulation is complex and will not be described in detail in this chapter (for more details see Further reading). Put simply, CBF is maintained if CPP is maintained. The CPP represents the difference between MAP and ICP. The considerations for maintaining CBF and minimizing neuronal injury during anaesthesia will be discussed with reference to the stages of the anaesthetic procedure (stabilization, induction, maintenance and recovery from anaesthesia). This is summarized in Table 99 (p. 537).

Stabilization prior to anaesthesia
Any patient with increased ICP (404), regardless of the cause, requires stabilization before considering anaesthesia or sedation for further diagnostics.

Correction of hypoxaemia, hypercapnia and poor perfusion are the most important strategies for reducing ICP and stabilizing the patient prior to anaesthesia. (For specific details on supporting the respiratory and cardiovascular systems see Chapter 2.)

Specific management of increased ICP is indicated if deterioration of neurological status occurs rapidly or continues despite normal oxygenation, ventilation and perfusion. (For management of increased ICP see Chapter 20.)

Sedation
In animals with clinical signs of intracranial disease, the performance of procedures under heavy sedation is generally avoided. Heavy sedation may lead to excessive depression of cardiovascular and respiratory function,
which will exacerbate secondary neuronal injury (405). In addition, heavy sedation may interfere with accurate assessment of the neurological status of the animal and delay initiation of appropriate therapy.

In these cases, anaesthesia performed carefully with a good understanding of how to minimize detrimental effects is preferable, as this allows protection of the airway and control of ventilation. In addition, many anaesthetic agents, such as propofol and barbiturates, have the added benefit of reducing cerebral metabolic rate, which helps reduce neurological injury.

**Premedication**

The aims of premedication are to:

- Reduce stress and anxiety.
- Decrease the amount of anaesthetic induction and maintenance agents required.
- Provide analgesia.

Agents used for premedication should have minimal effects on cerebral perfusion and ICP. The advantages and disadvantages of different agents in animals with intracranial disease are detailed in Table 100 (p. 539). Drugs such as acepromazine and medetomidine are best avoided in animals with intracranial disease.

Opioids provide analgesia and varying degrees of sedation without affecting cerebral perfusion or ICP. Adverse effects associated with a decrease in heart rate and respiratory depression can be avoided by using conservative doses. Morphine administration is best avoided in patients with high ICP given its significant potential for causing vomiting (and transient increases in ICP).

Benzodiazepines may be useful as anxiolytics in critically ill animals. These agents should be used cautiously in animals with mild disease/minimal decreases in mentation, as the effects can be unreliable and excitement, dysphoria and disinhibition can occur.

Phenobarbital is the drug most often used to control seizures. The authors have found that the administration of phenobarbital at 2–3 mg/kg intramuscularly can be a useful premedicant in anxious dogs when used in conjunction with an opioid 30 minutes prior to induction of anaesthesia.

**Adjustment of dose rates of sedative and anaesthetic agents**

In animals with intracranial disease, damage to the blood–brain barrier and concurrent CNS depression due to the neurological injury will serve to exacerbate the effects of a given dose of anaesthetic or analgesic agent. As a result, the doses used in these patients should be lower than those used in healthy patients. As the agents have a rapid onset and short duration of action, the dose rate can be adjusted incrementally (i.e. titrated to effect) until the desired analgesic effect is achieved, while minimizing side-effects.

**Induction of anaesthesia**

A smooth and high-quality induction of anaesthesia is essential. Minimizing stress and struggling and maintaining oxygenation and ventilation during induction of anaesthesia is necessary to prevent adverse effects on the CNS. The induction of anaesthesia using intravenous agents minimizes struggling and allows rapid control of the airway.

Pre-oxygenation is performed by mask, if tolerated, or by flow-by (406) for 5–10 minutes prior to induction to minimize hypoxaemia during and immediately following induction of anaesthesia.
Maintain adequate CPP (CPP = MAP – ICP) | Maintain MAP between 80 mmHg and 100 mmHg. Maintain normal circulating blood volume. Minimize depressant effects of anaesthetic agents on cardiovascular function. Avoid/use carefully anaesthetic drugs that interfere with CBF autoregulation (e.g. volatile anaesthetics)

Maintain haemodynamic stability | Avoid sudden increases in MAP and associated increases in ICP caused by stress, pain, surgical stimulation and laryngeal stimulation. Provide adequate analgesia. Ensure adequate depth of anaesthesia before intubation

Ensure adequate ventilation and normocapnia (PaCO₂ 35–40 mmHg) | Avoid hypercapnia (PaCO₂ >40 mmHg) and associated increased ICP. Use positive pressure ventilation during anaesthesia. Avoid hyperventilation (PaCO₂ <30 mmHg) except in an emergency to avoid brain herniation. Do not decrease PaCO₂ below 30 mmHg

Maintain adequate oxygenation | Avoid hypoxaemia (PaO₂ <80 mmHg) by providing oxygen supplementation during induction, maintenance and recovery from anaesthesia

Decrease CMR | Select anaesthetic agents that decrease CMR (e.g. propofol). Avoid increase in CMR by preventing or controlling seizures, maintaining normothermia and avoiding anaesthetic agents that increase CMR (e.g. ketamine)

Ensure adequate venous drainage | Avoid interference with jugular venous blood flow and associated venous congestion and increased ICP. Avoid jugular obstruction, excessive airway pressure during ventilation and fluid overload. Mild head elevation (15–30 degrees) will encourage venous drainage

MAP = mean arterial blood pressure; ICP = intracranial pressure; CBF = cerebral blood flow; CMR = cerebral metabolic rate; PaCO₂ = arterial carbon dioxide partial pressure.

‘Flow-by’ oxygen therapy is useful for providing oxygen supplementation to animals that will not tolerate a mask over their face.
Manual ventilation with a close-fitting mask during induction of anaesthesia (407) may be necessary to ensure normocapnia until the anaesthetic depth is sufficient to minimize reflex responses (i.e. cough, increased heart rate and MAP) to endotracheal intubation. Once an oral ETT has been positioned and secured in place, ventilation via the tube is commenced. (Note: When ventilating via a mask, oxygen can be forced into the stomach, leading to gastric distension. Should this occur, a stomach tube can be passed once the animal is adequately anaesthetized and the stomach deflated.)

To maintain adequate cardiovascular and respiratory function during induction of anaesthesia, the use of short-acting agents that can be carefully titrated to effect without excitation is preferred. Drugs that minimally interfere with regulation of cerebral perfusion are also preferred. The advantages and disadvantages of different intravenous anaesthetic agents in the neurological patient are provided in Table 100. Propofol is the agent the authors most frequently use in animals with intracranial disease. The administration of ‘co-induction’ agents with fewer depressant effects on the cardiovascular and respiratory systems can be used to reduce the dose of the more depressant induction drugs. Co-induction agents (see Table 101, p. 540) are administered immediately prior to the induction agent and are usually given intravenously.

To minimize coughing in response to endotracheal intubation, it is important to ensure that the depth of anaesthesia is adequate. The depth of anaesthesia required to prevent a response to intubation is comparable to that required for major surgery. It is common practice in cats to apply topical local anaesthetic (lidocaine) to the larynx before intubation (408). This is particularly effective for preventing the autonomic response to intubation and it is useful for canine patients as well. In canine patients, use of co-induction agents such as lidocaine (1–2 mg/kg) and opioids (e.g. fentanyl, 1–5 µg/kg) intravenously can also help reduce stimulation of the larynx during intubation.

407 Ventilation via a tight-fitting mask may be necessary during induction to ensure adequate CO₂ removal and delivery of oxygen.

408 Application of topical lidocaine to the cat’s larynx, after an adequate depth of anaesthesia has been achieved.
Table 100  **Intravenous sedatives and induction agents for use in animals with central nervous system disease**

<table>
<thead>
<tr>
<th>AGENT</th>
<th>CBF REGULATION</th>
<th>DIRECT CARDIOVASCULAR EFFECTS</th>
<th>CMR</th>
<th>ICP</th>
<th>SEIZURE ACTIVITY</th>
<th>COMMENT</th>
<th>DOSE RATE*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acepromazine</td>
<td>NR</td>
<td>↓↓ BP</td>
<td>NR</td>
<td>↑</td>
<td>↑</td>
<td>Avoid in intracranial disease. Useful anxiolytic in spinal disease. Contraindicated in hypovolaemic patients</td>
<td>0.01–0.05 mg/kg IM</td>
</tr>
<tr>
<td>Alpha-2 agonists</td>
<td>↓ Flow- metabolic coupling</td>
<td>↑ BP then ↓ BP</td>
<td>↓</td>
<td>-</td>
<td>↑</td>
<td>Avoid in intracranial disease. Useful in fractious animals. Care in hypovolaemic patients</td>
<td>Dogs: 2–10 µg/kg IM; Cats: 5–20 µg/kg IM</td>
</tr>
<tr>
<td>Opioids</td>
<td>Normal</td>
<td>↓ HR +/- ↓ BP</td>
<td>↓</td>
<td>↓</td>
<td>↓</td>
<td>Reduce the required dose of induction and maintenance agents. Reduce response to intubation and surgical stimulus</td>
<td>See Table 102 and Chapter 30</td>
</tr>
<tr>
<td>Benzodiazepines</td>
<td>Normal</td>
<td>No direct vascular effects</td>
<td>↓</td>
<td>↓</td>
<td>↓</td>
<td>Possible sedative/anxiolytic. Reduce induction agent. Potentiate respiratory depression of other agents</td>
<td>Diazepam, 0.1–0.5 mg/kg IV; midazolam, 0.1–0.5 mg/kg IV or IM</td>
</tr>
<tr>
<td>Lidocaine</td>
<td>Normal</td>
<td>↓ BP: VD and ↓ CO</td>
<td>↓</td>
<td>↓</td>
<td>Low dose: ↓</td>
<td>Reduce response to intubation and extubation. Decrease seizures. Analgesia (see Chapter 30)</td>
<td>Co-induction: 1 mg/kg IV</td>
</tr>
<tr>
<td>Thiopentone</td>
<td>Normal</td>
<td>↓ BP: VD and ↓ CO</td>
<td>↓</td>
<td>↓</td>
<td>↓</td>
<td>Excitement in unsedated animals. Accumulates with repeated dosing</td>
<td>Up to 10 mg/kg IV</td>
</tr>
<tr>
<td>Propofol</td>
<td>Normal</td>
<td>↓ BP: VD and ↓ CO</td>
<td>↓</td>
<td>↓</td>
<td>↓</td>
<td>Excitement-free induction. Suitable for maintenance of anaesthesia in dogs with intracranial disease</td>
<td>Induction: up to 2–4 mg/kg IV. Maintenance: 0.2–0.4 mg/kg/minute</td>
</tr>
<tr>
<td>Ketamine</td>
<td>Normal</td>
<td>↑ HR and BP</td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
<td>Avoid in animals with intracranial disease. Avoid in animals at risk of seizures (e.g. post myelography)</td>
<td>1–2 mg/kg IV</td>
</tr>
</tbody>
</table>

CBF = cerebral blood flow; CMR = cerebral metabolic rate; ICP = intracranial pressure; NR = not reported; BP = blood pressure; HR = heart rate; CO = cardiac output; VD = vasodilatation; VC = vasoconstriction.

* Note: These dose rates are based on those used in normal animals and lower doses may be required in animals with CNS disease.
### Table 101 Co-induction agents for use in animals with central nervous system disease

<table>
<thead>
<tr>
<th>AGENT</th>
<th>DOSE* AND TIMING</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Butorphanol</td>
<td>0.1–0.2 mg/kg IV 1–2 minutes prior to induction</td>
<td>Potent anti-tussive. Mild analgesia only; avoid in surgical or animals in pain. Antagonize effects of mu agonists</td>
</tr>
<tr>
<td>Fentanyl</td>
<td>1–5 µg/kg IV 5 minutes prior to induction</td>
<td>Bolus administration can cause significant bradycardia. Exacerbates respiratory depression of induction agent. Capnography and appropriate manual or mechanical ventilation should be commenced. Also useful for reducing the autonomic response to endotracheal intubation</td>
</tr>
<tr>
<td>Diazepam or Midazolam</td>
<td>0.1–0.2 mg/kg IV immediately prior to induction</td>
<td>Negligible cardiovascular depression. Can cause disinhibition and paradoxical excitement: follow with induction agent immediately. May exacerbate respiratory depression of induction agent. Capnography and appropriate manual or mechanical ventilation should be commenced</td>
</tr>
<tr>
<td>Lidocaine</td>
<td>1–2 mg/kg IV 1–2 minutes prior to induction</td>
<td>DO NOT USE IN CATS. Can exacerbate cardiovascular depression of other agents. Also useful for reducing the autonomic response to endotracheal intubation</td>
</tr>
</tbody>
</table>

*Lower end of dose range is recommended in critically ill animals.

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### Table 102 Opioids used intraoperatively to control pain and stabilize anaesthesia

<table>
<thead>
<tr>
<th>OPIOID</th>
<th>ADVANTAGES</th>
<th>DISADVANTAGES</th>
<th>COMMON DOSE RATES*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fentanyl</td>
<td>Potent analgesia (full mu agonist). Short acting after bolus administration (15–20 minutes). Suitable for infusion</td>
<td>Marked respiratory depression at higher doses. Duration of action increases with duration of infusion</td>
<td>Bolus: 1–2 µg/kg IV q15–20 minutes. CRI: 0.2–0.7 µg/kg/min</td>
</tr>
<tr>
<td>Alfentanil</td>
<td>Potent analgesia (full mu agonist). Fast onset: 1 minute. Short duration after bolus administration (5 minutes). Suitable for infusion</td>
<td>Marked respiratory depression at doses used intraoperatively. Duration of action increases with duration of infusion</td>
<td>0.5–2 µg/kg/minute</td>
</tr>
<tr>
<td>Remifentanil</td>
<td>Potent analgesia (full mu agonist). Very short acting (1–2 minutes). Suitable for infusion. Duration of action is constant regardless of duration of infusion</td>
<td>Marked respiratory depression at doses used intraoperatively. Very rapid recovery: additional analgesia required before stopping infusion</td>
<td>0.2–0.7 µg/kg/minute</td>
</tr>
</tbody>
</table>

* Doses are a guide only and should be titrated on an individual patient basis.
Maintenance of anaesthesia

Following induction of anaesthesia it is essential to select drugs and apply techniques that will either decrease or minimally increase ICP.

Total intravenous anaesthesia

Total intravenous anaesthesia (TIVA) with suitable agents provides the best conditions for the maintenance of anaesthesia in the neurological patient, providing normocapnia (P'ETCO\textsubscript{2} 30–35 mmHg [4–4.7 kPa]) and systemic BP are maintained. TIVA can be achieved with variable rate infusions of propofol (0.2–0.4 mg/kg/minute) or target controlled infusion (TCI) of propofol (2.5–3.5 µg/ml of blood) using specialized infusion equipment. Propofol is frequently infused in combination with short-acting opioids ([409]) (see Table 102) to allow the dose of propofol and, therefore, its associated side-effects to be reduced. Additional information on TCI can be found in the Further reading list for this chapter.

The use of opioids (e.g. fentanyl (0.2–0.7 µg/kg/minute, remifentanil 0.2–0.7 µg/kg/minute) in combination with propofol allows the dose of propofol required for maintenance of anaesthesia and, in turn, the cardiovascular side-effects, to be reduced.

TIVA is the authors’ preferred technique for canine neurosurgical patients and unstable patients requiring diagnostic imaging. The TIVA protocol utilizing propofol in cats is less well established and less commonly practised. Cats are inefficient metabolizers of propofol, predisposing to prolonged recoveries. Their RBCs are also more prone to the oxidative effects of the propofol (this may cause a Heinz body anaemia). Alfaxalone may prove to be a suitable alternative, as it has a similar pharmacokinetic profile to that of propofol, thus making it ideal for infusion. Infusion rates of alphaxalone currently used clinically in healthy animals range from 0.07–0.1 mg/kg/minute. However, appropriate dose rates for use in neurological patients have not been determined and the quality of recoveries in these patients is not known.

Inhalation anaesthesia

Inhalation anaesthesia can be used for short anaesthetics in stable neurological patients. It is preferred by many anaesthetists for maintenance of anaesthesia in cats given the concerns about using propofol by infusion. The characteristics of inhalation agents are summarized in Table 103 (next page).

![Image]

Propofol can be administered by variable rate infusion where the rate is adjusted by the operator.

Sevoflurane and isoflurane have the least effect on ICP providing the dose is minimized and the animals are ventilated to normocapnia. As described below, infusion of short-acting opioids is a useful technique for reducing the required dose of inhalation agent. Despite efforts to prevent herniation of the brain, there are still anecdotal reports of this life-threatening complication occurring when these agents are used to maintain anaesthesia during intracranial surgery in small animals. Other volatile agents, such as halothane, desflurane and N\textsubscript{2}O, have a marked effect on ICP and are best avoided.

Maintain adequate ventilation and oxygenation

To maintain adequate ventilation and ensure normocapnia (P\textsubscript{a}CO\textsubscript{2} 35–40 mmHg [4.7–5.3 kPa]; P'ETCO\textsubscript{2} 30–35 mmHg [4–4.7 kPa]), the use of IPPV and measurement of end tidal CO\textsubscript{2} concentration breath by breath are essential.

To maintain oxygenation during diagnostic procedures and surgery it is not uncommon to use high inspired concentrations of oxygen during anaesthesia. For long-term ventilation the Fi\textsubscript{O}\textsubscript{2} is ideally adjusted to the minimum required to maintain P\textsubscript{a}O\textsubscript{2} >80 mmHg (10.7 kPa) and minimize the risk of lung damage. In animals with concurrent pulmonary pathology, ventilation strategies employing PEEP may be required to maintain oxygenation. (For more details on IPPV and PEEP see Chapter 2.)
Monitoring pulmonary function during anaesthesia is essential to ensure normocapnia ($P_{aCO_2} \simeq 35-40$ mmHg [4.7–5.3 kPa]) and adequate oxygenation ($P_{aO_2} > 80$ mmHg [10.7 kPa]). For short anaesthetic procedures, such as for diagnostic imaging or CSF sampling, capnography and pulse oximetry are adequate for monitoring ventilation and oxygenation. For unstable patients or animals undergoing long procedures, such as surgery, analysis of serial arterial blood gas samples is essential. (For details on monitoring techniques, see Chapter 2.)

### Table 103 Inhalation agents for use in animals with central nervous system disease

<table>
<thead>
<tr>
<th>AGENT</th>
<th>CBF REGULATION</th>
<th>DIRECT CARDIOVASCULAR EFFECTS</th>
<th>CMR</th>
<th>ICP</th>
<th>SEIZURES</th>
<th>COMMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Halothane</td>
<td>Autoregulation: ↓</td>
<td>Cerebral VD ↓ MAP</td>
<td>↓</td>
<td>↑↑</td>
<td>None</td>
<td>Avoid in neurological patients</td>
</tr>
<tr>
<td>Isoflurane</td>
<td>Autoregulation: ↓</td>
<td>Cerebral VD ↓ MAP</td>
<td>↓</td>
<td>↑</td>
<td>None</td>
<td>IPPV required. Rapid recovery. Use balanced anaesthesia to reduce dose and side-effects in neurological patients</td>
</tr>
<tr>
<td>Sevoflurane</td>
<td>Autoregulation: ↓</td>
<td>Cerebral VD ↓ MAP</td>
<td>↓</td>
<td>↑</td>
<td>Reported in humans</td>
<td>IPPV required. Very rapid recovery. Use balanced anaesthesia to reduce dose and side-effects in neurological patients</td>
</tr>
<tr>
<td>Desflurane</td>
<td>Autoregulation: ↓↓ Flow-metabolism coupling: ↓ Chemical regulation: normal</td>
<td>Cerebral VD ↓↓ MAP</td>
<td>↓</td>
<td>↑↑</td>
<td>None</td>
<td>IPPV required. Very rapid recovery. Use balanced anaesthesia to reduce dose and side-effects in neurological patients</td>
</tr>
<tr>
<td>Nitrous oxide</td>
<td>Not reported</td>
<td>Potent cerebral vasodilator. Minimal systemic effects</td>
<td>No effect</td>
<td>↑</td>
<td>None</td>
<td>Avoid in patients with increased ICP</td>
</tr>
</tbody>
</table>

CBF = cerebral blood flow; CMR = cerebral metabolic rate; ICP = intracranial pressure; VD = vasodilation; MAP = mean arterial pressure; IPPV = intermittent positive pressure ventilation.

Maintain perfusion and cerebral perfusion pressure

To maintain CPP in patients with increased ICP, it is recommended that mean BP is maintained between 70 and 80 mmHg and systolic BP above 100 mmHg. For short procedures in stable patients undergoing MRI or CT, non-invasive BP monitoring is adequate. For unstable patients or for monitoring during surgical procedures, invasive, direct monitoring of arterial BP and CVP is preferred. (For details on BP and CVP monitoring see Chapter 2.)
Reduce cardiovascular depression associated with maintenance agents
As most anaesthetic agents cause dose-dependent decreases in BP, it is preferable to combine short-acting anaesthetic agents that can be titrated to effect with short-acting opioids that cause minimal cardiovascular depression. This will reduce the required dose of the selected maintenance agent in a dose-dependent fashion. The doses of opioids commonly used for maintenance of anaesthesia are provided in Table 102. Animals with severe neurological impairment may require lower doses.

An expected side-effect of administration of these potent opioids is respiratory depression. Even at low doses, significant hypoventilation may occur and IPPV may be required to maintain normocapnia. Both alfentanil and fentanyl will accumulate after a period of infusion, so it may be prudent to terminate or reduce the infusion rate prior to the end of anaesthesia to ensure adequate ventilation on recovery. Remifentanil does not accumulate and has a duration of action of approximately 3 minutes regardless of the duration of infusion.

Maintenance of normal fluid balance
Providing animals have normal fluid and electrolyte balance prior to anaesthesia, fluid therapy during anaesthesia initially consists of isotonic, polyionic crystalloids administered at 10 ml/kg/hour. Subsequent infusion rates and types of fluid will depend on losses and cardiovascular performance during anaesthesia. Measurement of CVP, arterial BP and urine output (UOP) is the best way to assess the response to fluid therapy. (For details on selection of fluids and rates for varying conditions see Chapter 31; for details of techniques for monitoring of BP, CVP and UOP see Chapter 2.)

Avoid sudden/marked increases in blood pressure
Various stimuli during anaesthesia, including nociception from surgical stimulation, can cause increases in BP, which in a diseased brain may result in an increase in CBF and ICP. To minimize sudden or marked increases in BP during anaesthesia, the continuous infusion of an opioid (as described above) can help minimize this sympathetic stimulation and the haemodynamic responses to surgery. This in turn will contribute to the maintenance of stable BP and CBF.

Maintain venous drainage from the head
Diagnostic imaging procedures and craniectomy are invariably performed with the patient positioned in sternal recumbency with the head level with the spine (410). This position is excellent for ensuring adequate lung expansion and also encourages venous drainage from the head. However, it is important to ensure that the jugular veins are not occluded when the animal is placed in this position, as this will lead to venous congestion within the brain and marked increase in ICP. For animals in lateral recumbency, mild head elevation (15–30 degrees) is also recommended to encourage cerebral venous drainage.

Measurement of CVP is generally performed via a catheter inserted into the jugular vein. This may increase the risk of disturbance to venous return and increased ICP. Methods for reducing the interference with venous return are described in Chapter 2.

The use of IPPV may also impede venous return from the head during the inspiratory phase of ventilation. To minimize this adverse effect, the inflation pressures required to maintain normocapnia can be reduced by administration of NM blockade using drugs such as atracurium. Atracurium is initially administered at 0.2–0.5 mg/kg IV. This is followed by increments of 0.1 mg/kg, which is administered according to NM activity assessed using a nerve stimulator.

![](image)

\(410\) In animals with intracranial disease, venous drainage from the head is maintained by positioning in sternal recumbency with the head at the same level as the spine.
**Maintain body temperature**

Body temperature should be maintained as close to normal as possible. Hypothermia has numerous adverse effects on the patient including:

- Cardiovascular system depression with bradycardia and hypotension.
- Suppression of the immune system and an increased risk of infection.
- Delayed healing.
- Intra- and postoperative coagulopathy and increased blood loss.
- Slow recovery.
- Shivering on recovery, which increases oxygen demand when oxygen delivery may be compromised.
- Prolonged hospital stays.

Hyperthermia, on the other hand, increases CMR, which increases CBF and can lead to increases in ICP and further reductions in CPP.

It is important to remember that head trauma (especially if it involves the hypothalamus) can result in impaired thermoregulation. Close monitoring of the temperature in these animals is imperative and appropriate therapy should be initiated when abnormalities arise. Methods for maintaining normal body temperature in animals with neurological disease will be discussed in more detail in the NM disease section below.

**Recovery from anaesthesia**

The aims during the recovery period are to achieve a smooth emergence from anaesthesia with minimal excitement, coughing or straining, and adequate ventilation (411). The timing of extubation is a compromise between ensuring the animal can protect its own airway, breathe spontaneously and maintain normocapnia, while avoiding stimulation that can lead to increases in arterial BP and coughing.

**Ensure adequate ventilation**

**Reduce rates of opioid infusions**

If high infusion rates of opioids have been used during surgery, it is important that the infusion rate is reduced in preparation for recovery. Once the patient is extubated and IPPV can no longer be delivered, it is imperative that the patient can breathe spontaneously. Extubation should therefore only be performed when the patient can spontaneously ventilate adequately (check the capnograph or blood gases).

When using either an alfentanil or fentanyl infusion, the rate should be reduced approximately 30 minutes prior to extubation. This will depend to some extent on the duration of infusion and the total amount of drug that has been delivered (the higher the dose and the longer the infusion, the more time required to reduce serum concentrations).

Remifentanil does not accumulate and activity rapidly disappears after infusion is stopped, allowing prompt return to spontaneous ventilation. The disadvantage is that the analgesic activity is also rapidly terminated. If continued analgesia is required, another opioid must be administered prior to turning off the remifentanil infusion. This may be in the form of a long-acting opioid such as methadone. Alternatively, infusion of short-acting opioids at a lower dose (see Chapter 30) can be used to provide postoperative analgesia so long as the patient can breathe spontaneously.

▲411 Following brain surgery, animals should be recovered in a controlled, quiet manner. Extubation is a balance between ensuring normal ventilation and preventing coughing when the endotracheal tube is removed.
Assess adequacy of spontaneous ventilation periodically

When preparing to extubate, the ETT tie is undone and the cuff left inflated. As the depth of anaesthesia decreases, trial periods of apnoea are performed. If spontaneous ventilation and maintenance of normocapnia occur, then the animal can be extubated; otherwise IPPV is re-introduced before $\text{PETCO}_2$ exceeds 45 mmHg. Once extubated, the patency of the airway needs to be assessed, particularly in animals with brachycephalic airway syndrome. It is important to have ready access to an induction agent in case immediate reintubation is required.

Minimizing coughing and hypertension on recovery

To minimize laryngeal stimulation, the administration of agents such as fentanyl or lidocaine can be used as described for intubation. At the end of anaesthesia, the drugs are given just prior to expected extubation. Alternatively, in animals requiring ongoing analgesia, a continuous infusion of fentanyl (2–5 µg/kg/minute) can also help reduce coughing on extubation.

Hypertension in the recovery period despite adequate analgesia can be treated by administration of β receptor antagonists or blockers (e.g. esmolol, 50–200 µg/kg/minute CRI). More details on hypertension in neurological patients can be found in Chapter 2.

Minimizing agitation in the perianaesthetic period

Agitation is not uncommon in animals with intracranial disease. Administration of opioid analgesics will ensure the agitation is not caused by pain. If it persists, then sedative agents such as acepromazine or dexmedetomidine will be required, but as these agents have adverse effects on the CNS and the cardiovascular system, their benefits for controlling agitation and calming the patient need to be weighed against the adverse effects that may occur. If administration of these agents is deemed necessary, low doses should be used and blood volume and BP should be normalized before administration. For example, the authors have used acepromazine (5–10 µg/kg IM) to control agitation in dogs post craniectomy when other methods of controlling the agitation have failed and the animal is considered at risk of injury from the agitation. Trazodone hydrochloride, a triazolopyridine derivative and member of the phenylpiperazine class of drugs, can also be considered as an anxiolytic in these situations (see Further reading).

SPINAL DISEASE

Considerations

Anaesthesia in animals with spinal disease should be designed to maintain spinal perfusion and minimize further neurological injury. As a result, many of the principles of anaesthesia for patients with intracranial disease are relevant to patients with spinal disease. Considerations for anaesthetizing animals with spinal disease are outlined in Table 104 (next page).

Stabilization

Animals with spinal trauma frequently have other injuries. Patients with spinal disease may have had reduced access to water due to reduced mobility (412). Stabilization of pulmonary and cardiovascular functions and correction of fluid and electrolyte deficits should be performed prior to anaesthesia. A full clinical examination should be performed with particular attention paid to the function of the cardiovascular and respiratory systems.

▲ 412 Spinal patients may have reduced access to water due to immobility. This may predispose to dehydration if supplemental fluid is not provided. Dogs, such as the one in this photograph, will need to be administered fluids intravenously or frequently ‘by hand’. 
Guidelines for sedating and anaesthetizing animals with spinal disease

Premedication

Premedication is important not only to provide analgesia and minimize the dose of induction agent required, but also to increase the ease of handling without the need for excessive physical restraint, which may be dangerous for these patients.

Choosing drugs and drug combinations

Opioids form the basis for premedication of animals with spinal disease and are generally administered on their own to patients with other systemic abnormalities. A variety of other agents can be used in conjunction with opioids to provide additional sedation if required. The doses and advantages and disadvantages of these agents are outlined in Table 101. Acepromazine is useful in anxious but otherwise stable animals. Medetomidine can be used in extremely anxious or fractious animals that are normally hydrated and cardiovascularly stable. Benzodiazepines are unpredictable and unreliable sedatives in healthy dogs and cats, but may provide useful sedation in critically ill animals. Medetomidine and benzodiazepines both cause skeletal muscle relaxation and should be avoided in animals with unstable spinal fractures (413). Ketamine is another option in normovolaemic cats with normal renal function in combination with opioids, acepromazine or benzodiazepines. However, ketamine is extremely painful when injected intramuscularly. This may cause additional discomfort to animals already in pain. In addition, sudden uncontrolled movement in response to the injection may be detrimental in animals with an unstable spinal fracture.

<table>
<thead>
<tr>
<th>CONSIDERATION</th>
<th>MANAGEMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maintain perfusion</td>
<td>Correct deficits in circulating blood volume and body water. Use agents/techniques that minimally depress cardiovascular function</td>
</tr>
<tr>
<td>Pain</td>
<td>Most spinal diseases are painful and effective analgesia (e.g. full mu agonists) is necessary</td>
</tr>
<tr>
<td>Anxiety</td>
<td>Anxiety is common in paralysed animals and decreases the pain threshold. Administering anxiolytics is an important part of pain management in spinal patients</td>
</tr>
<tr>
<td>Mechanical instability</td>
<td>Animals need to be moved carefully to minimize further trauma to the spinal cord, particularly when a fracture or luxation is suspected. Intubation of animals with suspected instability of the cervical spine should also be performed carefully. Flexion and extension of the head should be avoided</td>
</tr>
<tr>
<td>Respiratory insufficiency</td>
<td>Cervical spinal lesions can interfere with innervation of the diaphragm and intercostal muscles, leading to inadequate ventilation and respiratory arrest. Sternal recumbency during surgery restricts movement of the diaphragm and thus mechanical ventilation is recommended during surgery to ensure adequate ventilation</td>
</tr>
<tr>
<td>Maintain airway</td>
<td>Ventral approaches to the cervical spine require retraction of the trachea and may partially or completely obstruct the endotracheal tube</td>
</tr>
<tr>
<td>Blood loss</td>
<td>Blood loss during surgery can be significant and needs to be monitored closely by weighing swabs and measuring fluid in suction bottles. Transfusion is indicated if &gt;20% of circulating blood volume is lost or if signs of hypovolaemia (increased heart rate without increased MAP, pale mucous membranes) are observed</td>
</tr>
</tbody>
</table>
Induction

**Minimize further damage to spinal cord**

A rapid and controlled induction of anaesthesia with minimal struggling is best achieved with intravenous agents. Endotracheal intubation should be performed carefully with adequate support of the head and neck, particularly in animals with cervical spinal cord injury (414). Intubation is facilitated by the use of a laryngoscope (415). Excessive extension of the neck should be avoided in dogs with caudal cervical lesions, while excessive flexion should be avoided in animals with AA subluxation or other cervical fractures.

**Select induction agents that minimally interfere with spinal perfusion**

Selection of an appropriate induction agent is based on the same basic principles as those described for animals with intracranial disease. The characteristics of the intravenous agents and suggested doses are described in Table 100. To decrease the required dose of intravenous induction agent and to minimize cardiovascular depression, concurrent administration of a potent opioid, such as fentanyl or a benzodiazepine, can be used during induction (Tables 101 and 102).
Maintenance of anaesthesia

Select agents that maintain spinal perfusion

Maintenance of anaesthesia is usually performed with inhalation agents. As autoregulation of perfusion to the spinal cord and chemoreceptor response to carbon dioxide are better maintained with isoflurane and sevoflurane than halothane, these are the preferred inhalation agents. Nitrous oxide is reported to increase ICP as a result of cerebral vasodilation, so is best avoided in patients with intracranial disease. Whether the same precautions are warranted in animals with spinal cord injury and compression is not known.

Infusion of short-acting opioids can also be used in conjunction with inhalation agents. These agents provide analgesia, which is essential in most animals with spinal disease, and will help reduce the dose and thus the amount of cardiovascular depression observed with inhalation agents. Details of the use of these opioids are described in the section on intracranial disease.

Maintenance of anaesthesia can also be performed with a TIVA technique as described for intracranial disease. TIVA is especially useful for dogs requiring surgery of the cranial cervical spinal cord where manipulation of the cervical spinal cord and/or brainstem may occur (e.g. repair of AA instability).

Maintain adequate ventilation

IPPV is recommended during anaesthesia in spinal patients for several reasons. Firstly, the detrimental effects of inhalation agents on spinal blood flow regulation can be minimized by maintaining normocapnia. Secondly, surgical access frequently requires that the animal is positioned in sternal recumbency, which can interfere with diaphragmatic excursions and impair ventilation. Finally, the dose rates of the opioid agonists recommended for intraoperative use produce marked respiratory depression and therefore necessitate IPPV.

Maintain adequate perfusion

Intravenous fluid therapy is essential during anaesthesia in all spinal cases to maintain fluid balance, adequate BP and perfusion of the spinal cord. In hypovolaemic animals, the volume deficit should be replaced before anaesthesia. Intraoperative blood loss can be unpredictable and surprisingly high during spinal surgery. Blood loss should be estimated regularly by counting blood-soaked swabs, weighing swabs (1 ml of blood weighs approximately 1.03 g) or measuring the volume of fluid in suction bottles (taking into account dilution from irrigation fluids).

Blood loss can also be estimated from the PCV of fluid in the suction bottle. This technique requires an accurate measurement of the patient's PCV at the time of blood loss. The PCV prior to anaesthesia may not be representative of the PCV during anaesthesia. The PCV may decrease due to splenic sequestration of RBCs in response to anaesthetic agents (propofol, barbiturates) and dilution by intravenous fluid therapy. If an accurate estimate of the PCV of the patient prior to haemorrhage is known, the amount of blood in the bottle can be estimated using the following:

\[
\text{Amount of blood lost (ml)} = \frac{\text{PCV of flush in bottle} \times \text{total volume of fluid in bottle}}{\text{PCV of patient at time of haemorrhage}}
\]

A blood transfusion is indicated when blood loss exceeds 20% of the circulating blood volume or haemoglobin concentration is <80 g/l (<8 g/dl). Blood loss of less than 20% can be managed by administering crystalloids +/- colloids such as hetastarch (maximum dose 20 ml/kg/day). (For more details on fluid therapy see Chapter 31.)
Maintain body temperature
Heat loss can be a problem, particularly when spinal cord injury causes sympathetic nervous system imbalance and peripheral vasodilation. Monitoring core body temperature should be performed during anaesthesia. Heat loss can be prevented during anaesthesia by heat pads, warm water beds or warm air blowers and ‘blankets’. Heat and moisture exchange devices (416) can be placed between the endotracheal tube and the breathing system to promote warmth and humidification of inspired gases.

Monitoring
During diagnostic imaging and surgery in animals with spinal disease, non-invasive monitoring of cardiopulmonary function with electrocardiography, non-invasive BP measurement, capnography and pulse oximetry is generally adequate. In animals where cardiopulmonary dysfunction (e.g. cranial cervical surgery, trauma involving multiple organ systems) or excessive blood loss is expected, invasive BP measurement is recommended. Monitoring techniques have been discussed in detail in Chapter 2.

Recovery
It is essential that the provision of analgesia is continued into the postoperative period to ensure a calm and comfortable recovery. In some cases the use of low-dose sedatives, such as acepromazine (0.01–0.02 mg/kg IM or IV) or dexmedetomidine (0.5–1.0 µg/kg IV bolus or infusion of 0.5–1.0 µg/kg/hour), may be required in extremely stressed or agitated animals exhibiting signs of suboptimal emergence. However, these drugs should only be used in animals with normal cardiovascular function. Trazodone (see p. 545) can also be used to treat postoperative anxiety. (For details on possible postoperative analgesia see Chapter 30.)

NEUROMUSCULAR DISEASE

Considerations
Considerations for anaesthetizing animals with NM disease are outlined in Table 105. The general principles for anaesthetizing these patients are similar, with some differences depending on the type of NM disease present. These principles are described in more detail in regard to premedication, induction, maintenance and recovery of anaesthesia.

Stabilization
Fluid and electrolyte abnormalities are common in these patients due to immobility and an inability to eat and drink. These deficits need to be corrected prior to anaesthesia when possible. Fluid and acid–base abnormalities associated with toxicities, such as metaldehyde, will also need to be corrected prior to anaesthesia (see Chapter 28).

Animals with aspiration pneumonia should be stabilized as much as possible prior to anaesthesia. Antibiotic and oxygen therapy forms the basis of symptomatic treatment in these animals.

Premedication
The use of premedication in animals with peripheral NM disease will depend on the type of disease that is present, how painful that disease is and how urgent the need for anaesthesia is (e.g. an animal with airway obstruction requires immediate anaesthesia). In anxious animals, the judicious use of sedatives may be needed to facilitate a smooth, stress-free induction. (Note: Sedation can interfere with the maintenance of a patent airway and increase the risk of upper respiratory tract obstruction and aspiration. If used, low doses are recommended and animals should be constantly monitored for any adverse effects.)

In animals with painful NM disease (which is uncommon), premedication should include an opioid, either alone or in combination with other agents. Opioid premedicants should also be given to animals requiring muscle and nerve biopsies and animals undergoing painful diagnostics such as electromyography.
Induction of anaesthesia

Maintain oxygenation

The patient should be pre-oxygenated for 5–10 minutes prior to induction when possible. If an animal objects to the placement of a face mask, the use of flow-by oxygen is recommended. Flow-by oxygen is preferred in animals predisposed to hyperthermia, because masks encourage re-breathing of warm expired gases. Pre-oxygenation increases the concentration of oxygen in the functional residual capacity of the lung and delays the onset of hypoxaemia in the event of a difficult intubation or in patients with cardiovascular or respiratory compromise.

Prevent regurgitation and aspiration

Induction of anaesthesia should be performed with the patient in sternal recumbency. If there is an increased risk of regurgitation (e.g. megaesophagus), cricoid pressure should be applied. Cricoid pressure is maintained until the ETT is placed and secured in the airway with the cuff inflated. Suctioning of the pharynx, oesophagus and stomach should be performed as soon as the airway is secure to minimize the risk of aspiration during anaesthesia (if the cuff becomes deflated). If vomiting or regurgitation occurs during induction of anaesthesia and before the airway is protected by the presence of an ETT, the animal should immediately be positioned with its head over the edge of the table to allow gravity-assisted drainage of the pharynx. The pharynx and oesophagus should be suctioned before intubation is performed.

Induction of anaesthesia should be performed with short-acting intravenous agents that facilitate rapid control of the airway. Furthermore, a prompt recovery from anaesthesia is important in order for the patient to regain control of its airway as soon as possible. Agents such as propofol and alfaxolone allow rapid recovery; however, in animals at risk of obstruction, titration of these agents to effect can delay intubation. Furthermore, bolus administration can lead to marked decreases in BP. To reduce the dose and thus the side-effects, co-induction agents (fentanyl + short-acting benzodiazepines) can be administered immediately prior to an intravenous induction agent. This combination of agents will invariably cause apnoea and therefore animals should be ventilated as soon as intubation is performed. Ketamine should be avoided in animals with tetanus and increased muscle activity. Thiopentone allows rapid control of the airway, but the recovery period is likely to be prolonged.

Maintenance of anaesthesia

Selection of agent

Agents with a short duration of action, thus allowing rapid recovery, are preferred. Inhalation agents, such as isoflurane, sevoflurane and desflurane, all have physicochemical properties that ensure a rapid clinical response to changes in vapourizer settings. In addition, recovery from anaesthesia is relatively rapid, with prompt return of airway reflexes.

▲ Animals that are at risk of regurgitation during induction should be maintained in sternal recumbency with cricoid pressure applied until the endotracheal tube is placed and cuff inflated.
Ensure adequate ventilation
Mechanical ventilation is recommended in all animals with peripheral NM disease as there is likely to be a component of respiratory muscle involvement. IPPV should be delivered with close monitoring of CO$_2$ concentration in the expired gas with a capnograph or serial arterial blood gas analyses. Monitoring of the haemodynamic consequences of ventilation is also prudent.

Maintain normal body temperature
Animals with NM disease may have difficulty maintaining normal body temperature (see Table 105). It is therefore essential to monitor core body temperature perioperatively in these animals. Mild decreases in body temperature can be managed with passive warming (e.g. warm air blankets or warm water beds). It is easier to prevent hypothermia than to treat it, so all efforts to preserve body temperature should be made. Although it is unusual for animals to develop hyperthermia under anaesthesia, increases in body temperature should be managed by passive cooling.

<table>
<thead>
<tr>
<th>CONCERN</th>
<th>CONSIDERATIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pain</td>
<td>Presence and severity of pain will vary with the disease. Painful conditions include polyradiculoneuritis, some myopathies and muscle and nerve biopsy patients</td>
</tr>
<tr>
<td>Dysphagia</td>
<td>Weakness of pharyngeal muscles results in difficulty swallowing and predisposes to aspiration</td>
</tr>
<tr>
<td>Airway obstruction</td>
<td>Laryngeal paresis or paralysis. Laryngeal spasm (e.g. tetanus)</td>
</tr>
</tbody>
</table>
| Impaired ventilation         | Mechanical ventilation frequently required due to:  
  • Weakness of respiratory muscles (e.g. snake envenomation, myasthenia gravis, polyradiculoneuritis, tetrodotoxin, botulism).  
  • Spasm of diaphragm and intercostals (e.g. tetanus) |
| Impaired oxygenation         | Dysphagia, megaesophagus and inability to protect the airway predisposes to aspiration. Recumbency predisposes to atelectasis. Supplemental oxygen recommended in perioperative period |
| Impaired thermoregulation    | Laryngeal dysfunction and impaired ventilation reduce ability to pant and predispose to hyperthermia during exposure to warm environments. Muscle fasciculations and tetany increase metabolic rate and predispose to hyperthermia. Generalized weakness prevents shivering and predisposes to hypothermia during exposure to cold environments |
| Dehydration and electrolyte abnormalities | Recumbent animals may have restricted access to water. Dysphagia impedes ability to eat and drink. Regurgitation associated with megaesophagus increases loss of water and bicarbonate (from saliva) |

Neuromuscular relaxation
In animals with peripheral NM disease requiring surgery for other reasons (e.g. thoracotomy for thymoma removal in animals with MG), NM relaxation may be required to improve surgical access. Non-depolarizing muscle relaxants can be used, but extreme care is required as prolonged duration of skeletal muscle weakness can occur. Depolarizing muscle relaxants such as suxamethonium should be avoided.

Non-depolarizing NM blocking agents should be administered in incremental doses with careful monitoring of peripheral nerve blockade with a nerve stimulator. There must also be facilities to provide either mechanical or manual IPPV and assessment of adequacy of ventilation (capnography or blood gas analysis). Shorter-acting NM blocking agents, such as atracurium or vecuronium, administered at one tenth of the usual dose, are the preferred agents. Infusions allow more precise control of the degree of NM blockade than boluses, which create peaks and troughs in plasma concentration and thus cause relative overdose and relative underdose, respectively.
Recovery

Maintain adequate oxygenation and ventilation

As the animal recovers from anaesthesia, it is essential to monitor end-tidal CO$_2$ to ensure spontaneous ventilation is sufficient to maintain normocapnia. These animals will invariably have some degree of pulmonary pathology due to aspiration or atelectasis, so oxygenation should be monitored throughout recovery and supplemental oxygen provided until the animal can maintain SpO$_2$ >95% when breathing room air. Initially, this can be performed via the ETT; however, following extubation, oxygen can be provided by mask, oxygen cage or nasal catheters. Where oxygenation is expected to be poor for prolonged periods (e.g. animals with pneumonia or animals expected to be recumbent following anaesthesia), nasal catheters should be placed before the end of anaesthesia to provide a smooth stress-free transition from oxygenation via the ETT to the nasopharyngeal catheters. (Note: Animals that develop upper respiratory tract obstruction [e.g. laryngeal paralysis or laryngeal spasm] following extubation may require a tracheostomy to maintain adequate oxygenation and ventilation [see below].)

Prevent aspiration

Suctioning of the oesophagus and pharynx should be performed prior to recovery in order to minimize the risk of regurgitation at extubation. The animal is best positioned in sternal recumbency with the head elevated to maximize chest excursions and respiratory function. In addition, elevation of the head will help prevent passive regurgitation. Should vomiting or regurgitation occur during recovery, the animal’s head must be positioned over the edge of the table to allow fluid or stomach contents to flow out of the mouth. If the animal is still sufficiently anaesthetized, the pharynx and mouth can be cleared by suctioning and swabbing. To prevent oesophagitis associated with regurgitation of gastric contents, the oesophagus should ideally be carefully lavaged until the fluid retrieved is clear. It is essential that the ETT is secured in place with adequate cuff inflation when lavage is performed.

Maintain a patent airway

Animals with neuromuscular weakness or post-gastric lavage

In these animals extubation is delayed for as long as possible to ensure upper and lower respiratory muscle function is adequate. Recovery should be performed in a quiet, dimly lit environment to minimize stimulation on recovery. The cuff of the ETT=endotracheal tube is left inflated until the animal is ready to be extubated. Adequate analgesia must always be provided in animals with painful diseases to optimize conditions for a smooth emergence from anaesthesia. Low-dose infusions of short-acting opioids can also help reduce stimulation from the ETT and help maintain a patent airway for longer.

Animals with tetanus

Although tetanus does not cause NM pathology, it is associated with severe muscle spasms. Extubation in patients with tetanus can stimulate laryngospasm. The safest approach is to recover these animals with a tracheostomy in place. If a tracheostomy is not performed, laryngospasm can be minimized by extubating early, as long as the patient is ventilating spontaneously. Topical lidocaine applied to the larynx may also help. In any case, it is essential to be prepared to perform an emergency tracheostomy should laryngospasm occur and if reintubation is too difficult. Preparing the site beforehand is recommended to save time should a tracheostomy be required. The ability to provide oxygen supplementation via an intratracheal needle or catheter should also be available in case upper respiratory tract obstruction occurs (see Chapter 2). (Note: This method of providing oxygen is only suitable for short periods, as there is no concurrent ventilation, and overinflation of the lungs can occur because there is no outflow for the insufflated oxygen.)
SEDATION/ANAESTHESIA FOR CHRONIC INTUBATION AND MECHANICAL VENTILATION

The choice of agent used to maintain anaesthesia in animals requiring ventilation will depend on the indications for ventilation, the expected duration of ventilation and whether the animal has an oral ETT or a tracheostomy. Ventilation techniques are discussed in Chapter 2. Examples of agents that can be used to provide sedation or anaesthesia for ventilation are listed in Table 106.

Dose rates
Maintenance of anaesthesia has ‘lighter’ requirements than does surgical anaesthesia, and in some cases sedation only may be needed. In animals intubated via tracheostomy, the depth of sedation/anaesthesia will be even lower, as the stimulus associated with oral intubation is absent. Animals that are weak, paralysed or suffering from CNS depression will also require much lower doses than those with normal CNS activity. Therefore, short-acting agents that can be titrated to achieve the required level of sedation or anaesthesia in each individual are preferred.

Additional considerations for paralysed animals
The use of sedation or anaesthesia for ventilating paralysed animals warrants special mention. Sedation or anaesthesia is not required to tolerate the presence of an ETT; however, as they recover from paralysis, sedation or anaesthesia will be required to maintain intubation. The reason for this is the differential recovery of different skeletal muscles from paralysis, allowing these animals to move before being able adequately to ventilate or protect their own airway. As a result, these animals can start to struggle. Furthermore, it must be remembered that even when a patient is fully paralysed they are conscious and responsive to their environment, therefore some sedation and/or analgesia is required to minimize stress and discomfort.

Nursing and airway management of the chronically ventilated patient are covered in Chapter 2.

Table 106 Possible agents for sedating or anaesthetizing animals during long-term ventilation

<table>
<thead>
<tr>
<th>DRUG</th>
<th>DOSE</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inhalation agents: isoflurane/sevoflurane</td>
<td>1 minimum alveolar concentration equivalent or less</td>
<td>Not recommended for long-term ventilation in animals with intracranial disease. Isoflurane can be irritant to airway and therefore is best avoided. May have adverse effects in airway disease or prolonged anaesthesia</td>
</tr>
<tr>
<td>Propofol</td>
<td>0.05–0.4 mg/kg/minute</td>
<td>Ideal for animals with intracranial disease. Can be used for any animal requiring sedation or anaesthesia for ventilation</td>
</tr>
<tr>
<td>Midazolam</td>
<td>0.05–0.2 mg/kg/hour (do not dilute drug with Hartmann’s)</td>
<td>Can be used in animals with intracranial disease that require sedation for intubation. Dysphoria observed with prolonged infusion may cause stressful recoveries. Use cautiously in animals with neuro-muscular weakness</td>
</tr>
<tr>
<td>Fentanyl</td>
<td>0.2–0.7 µg/kg/minute</td>
<td>Can be used alone in paralysed animals or in conjunction with other agents to provide analgesia/sedation</td>
</tr>
</tbody>
</table>
SPECIFIC CONSIDERATIONS FOR DIAGNOSTIC PROCEDURES

Myelography
Myelography is associated with a risk of seizures on recovery from anaesthesia and a variety of cardiopulmonary abnormalities that can occur during anaesthesia, particularly during/after contrast injection (418).

Seizure activity
Seizure activity is a recognized adverse effect of injection of contrast agents into the subarachnoid space. The risk of seizures is influenced by several factors including the volume and rate of contrast injection, the site of injection, the size of the animal, duration of anaesthesia after injection and the position of the animal during injection. Seizures are more commonly observed after CMC myelography compared with lumbar myelography. Animals weighing >20 kg are also observed to have a higher incidence of seizures, possibly due to the relatively higher volume of contrast injected.

To reduce the risk of seizures, the dose rate should be calculated from surface area rather than body weight, the speed of injection should be slow and the head should be elevated as soon as injection is complete to promote the flow of contrast away from the head. The use of a tilting table allows head elevation while keeping the animal's spine straight and supported.

Pharmacological agents that decrease the seizure threshold should be avoided. Acepromazine, ketamine and medetomidine have been previously reported to decrease the seizure threshold, and most of the literature recommends that these agents are not used in animals undergoing myelography. However, the association between use of acepromazine and seizure activity has become increasingly unclear and its effect may depend on the cause of the seizure activity. The authors recommend that its use be avoided whenever possible and if required for sedation/anxiolysis, it is used carefully and at low doses.

Seizures have been reported to occur up to 6 hours after contrast injection, so these animals should be closely monitored during this time. If seizures occur, administration of diazepam (0.2–1.0 mg/kg IV) is recommended as the first-line treatment.

Cardiopulmonary disturbance
Cardiopulmonary side-effects during or immediately after the injection of contrast have been observed and include apnoea, tachypnoea, bradycardia, tachycardia, arrhythmias, hypotension and hypertension. Many of these effects are associated with the discomfort or pain of injection and can be minimized by slowing the injection rate and ensuring an adequate depth of anaesthesia during injection. Transient increases in ICP may also be responsible, particularly with cisternal contrast injections. Careful monitoring of cardiopulmonary function is necessary during myelography to detect any problems early and treat accordingly.

Magnetic resonance imaging
The main considerations for anaesthetizing patients with intracranial and spinal disease for MRI are described in the relevant sections earlier in this chapter. In addition, there are several important considerations unique to anaesthetizing a patient within a magnetic field.
Equipment hazards
Ferromagnetic objects can become dangerous projectiles and may result in injury and/or death to the patient or personnel within the scanning room. It is essential that these objects remain outside the 5 gauss line. Anaesthetic machines are required to be as close to the patient as possible to minimize the length of the breathing system and should be composed of non-ferromagnetic materials. If this is not possible, a non-rebreathing anaesthetic circuit (e.g. Bain) can be used, as the length of the inspiratory and expiratory tubes (which are coaxial) may be effectively infinite. Non-ferromagnetic objects within a magnetic field (e.g. ECG leads) have the potential to induce electric currents, leading to heating and burns. The risk of burns can be minimized by insulating the wires, separating the wires from the skin by padding, avoiding large loops of wire that allow the induction of currents and applying sensors as far away from the imaged area as possible.

Monitoring
Monitoring of the anaesthetized patient during MRI has inherent limitations. Equipment used for monitoring must be MRI safe and ideally MRI compatible. Equipment that is MRI safe has been demonstrated to present no additional risk to the patient. Equipment that is MRI compatible has been demonstrated to be both MRI safe and to not reduce significantly the diagnostic quality of the imaging procedure nor have its operation affected by the scanning procedure. MRI compatible equipment is currently available that allows distant monitoring of animals during MRI. Where cost is limited, some monitoring equipment, such as capnography, oesophageal stethoscope and oscillometric methods of non-invasive BP measurement, can be used if the electrical components are outside the 5 gauss line.

Cerebrospinal fluid collection
The collection of CSF may be performed by CMC or lumbar puncture. CMC puncture requires flexion of the neck, which can cause inadvertent kinking of the ETT and respiratory obstruction. In addition, flexion of the neck can obstruct jugular veins, impair venous drainage and contribute to increased ICP. IPPV is essential during CMC puncture to ensure adequate ventilation and normocapnia. ETTs reinforced with coiled wire resist kinking and can be used to prevent airway obstruction when the neck is flexed for collection of CSF. As these tubes contain metal, they are not suitable for use in animals undergoing concurrent MRI imaging.

In animals with increased ICP the collection of CSF carries the risk of parenchymal herniation. When sampling is essential for the diagnosis and treatment of the animal, pre-emptive use of mannitol (30 minutes prior to CSF collection) and reduction of PaCO\textsubscript{2} to 30 mmHg (4 kPa) by hyperventilation during the sampling period may reduce the risk of herniation.

Electroencephalography
Electroencephalography records the spontaneous electrical activity within the brain and may be performed in animals to identify areas of abnormal electrical activity responsible for seizures. Performance of electroencephalography in conscious animals is difficult, as muscle movement causes artefacts, which affect the diagnostic quality. Inhalational and intravenous anaesthetic agents also alter the electrical activity within the brain in a dose-dependent manner, thus limiting the amount of useful information that can be obtained from electroencephalography in anaesthetized animals. A sedative regimen used to perform electroencephalography in conscious animals has been described. This regimen was reported to limit spontaneous movement in conscious animals, while reducing the effects of deep sedation or general anaesthesia on the recorded EEG. However, this report describes the use of high doses of acepromazine, a drug that may decrease seizure threshold. As discussed above, the association between seizures and acepromazine is still unclear and its use in animals with pathological causes of seizure activity should be performed cautiously.