Module 10 – Anaesthesia

Objectives

The objectives of the section on anaesthesia are:

- To introduce the student to the administration of anaesthetics to laboratory animals
- To discuss anaesthesia under the following broad headings:
    - Preanesthesia
    - Effects of anaesthetic agents
    - Anaesthetic administration
    - Anaesthetic emergencies
    - Recovery from anaesthesia
- To provide information on the effects of drugs used during anaesthesia
- To consider the consequences of anaesthesia and the surgical procedures on recovery
- To discuss anaesthetic emergencies and their treatment

Introduction

In this module we will discuss the alleviation of pain during painful procedures such as surgery, through the use of anaesthetic drugs. Anaesthesia is also used for producing muscle relaxation, suppressing reflexes, and producing loss of consciousness for purposes other than prevention of pain perception.

Because of the wide variability of laboratory animal species, strains, and strains, as well as anaesthetic agents, an appropriate anaesthetic regimen should be developed in consultation with a veterinarian prior to the commencement of any study.

Remember - Animals must not be subjected to unnecessary pain or distress. The experimental design must offer them every practical safeguard whether in research, in teaching or in testing procedures.

The need to use an anaesthetic to perform a procedure implies that the procedure would be painful for an awake animal. In addition there may be some residual pain after the animal recovers from the anaesthetic and analgesics should be used. Some drugs described here appear in both the anaesthesia and analgesia modules.

Pre-anaesthetic Treatments

There are several reasons why the use of pre-anaesthetic agents should be considered:

- to reduce apprehension in the animal
- to allow a reduction in the dose of anaesthetic required
- to reduce some of the side effects of the anaesthetic agent
- to provide some analgesia after the anaesthetic has worn off

The pre-anaesthetic agent should allow a reduction in the dose of anaesthetic required. This applies particularly to injectable anaesthetics where control of the depth and duration of anaesthesia is often more challenging than with inhaled anaesthetics. The combination of pre-anaesthetic and anaesthetic drugs must provide sufficient pain blocking so that the animal does not feel pain during the surgical procedure.

Most anaesthetic agents do more than produce unconsciousness and pain relief. They are potent drugs that may affect every system in the body. The effects on the respiratory and cardiovascular systems may be particularly significant during the anaesthetic period; however effects on other organ systems may be more significant depending on the goals of the research. While some pre-anaesthetic agents may reduce anaesthetic side effects, more often it is the reduction in anaesthetic dose that provides the greatest relief from the side effects.

An ideal pre-anaesthetic agent should provide some analgesia after the surgery. Some analgesics are quite short acting in animals and depending on the length of the surgery may not last into the recovery period. It is important to ensure that analgesia continues through the surgical period, into and beyond recovery.

The effects of the ideal pre-anaesthetic as described above are not to be found in a single agent. Sometimes more than one drug is used but with care the undesirable side effects do not outweigh the potential beneficial effects.

Summary

The ideal pre-anaesthetic agent should:

- Reduce apprehension
- Allow a reduction in anaesthetic doses
- Reduce or eliminate some of the undesirable side effects of anaesthetics
- Provide some analgesia after the anaesthetic has worn off

Types of Pre-anaesthetic Drugs

The major groups of pre-anaesthetic drugs are analgesics (particularly the opioids), tranquilizers and anticholinergic drugs. Paralytic or neuromuscular blocking drugs are also used as adjuncts to anaesthesia, particularly in human surgery.

Analgesics. Some analgesics, as well as providing pain relief, also have a desirable sedative effect. They calm the animals and allow a reduction in the amount of anaesthetic required along with a smoother recovery from anaesthesia. Moreover, a pre-emptive strike against pain is thought to result in a reduced need for analgesics after the surgery. For these reasons, some analgesics may be given as pre-anaesthetic agents. Of the analgesics, the opioids are commonly used as pre-anaesthetic agents.

Opioids. Among the effects of opioids that make them useful as pre-anaesthetic agents are analgesia (they make pain more tolerable without abolishing it completely) and CNS depression (there is usually depression although some opioids may produce excitation and convulsions in some species). As a general rule, the suitability of any drug for a given species should be checked before using it. The combination of analgesia and CNS depression are both desirable for anaesthesia. This allows for a reduction in the dose of anaesthetic agent and provides pre-emptive analgesia.

Tranquilizers. The principal drugs in this group are the phenothiazine derivatives (e.g., acepromazine, chlorpromazine), the benzodiazepines (e.g., diazepam, midazolam), and the butyrophenones (e.g., droperidol, fluanisone). The alpha 2 adrenergic receptor agonists (e.g.,

xylazine, medetomidine) could be considered as tranquilizers as well as analgesics but they are seldom used for their tranquilizing effect alone because of their profound cardiovascular effects. The principal effect of tranquilizer drugs administered prior to anaesthesia is the reduction of anxiety in animals. This effect may be achieved with low doses and may not be accompanied by CNS depression. At higher doses, CNS depression may be profound, depending on the drug, and the species. Most of the tranquilizers do not have any analgesic effects and so a lack of response or a diminished response to painful stimuli should not be interpreted as a sign of analgesia. The alpha 2 adrenergic receptor agonists provide some analgesia as well as tranquilization. Tranquilizers generally cause minimal cardiovascular and respiratory depression and some have an effect in reducing the occurrence of cardiac arrhythmias during anaesthesia. There are some exceptions. The alpha 2 adrenergic receptor agonists have profound effects on both cardiovascular and respiratory systems. Some tranquilizers (e.g., chlorpromazine) can cause moderate to severe hypotension, and some phenothiazine derivatives decrease the seizure threshold in certain species.

Summary of effects of tranquilizers

- Minimal or no analgesia
- Minimal CNS depression
- Anxiolytic (calming)
- Minimal cardiovascular and respiratory depression

Anticholinergic Drugs. Anticholinergic drugs block the muscarinic actions of the neurotransmitter, acetylcholine. Acetylcholine is a neurotransmitter at many sites throughout the body and so the effects of anticholenergic drugs are widespread. Anticholinergic drugs are used to block two effects in particular during anaesthesia, secretions in the respiratory tract in response to the irritating nature of some inhalant anaesthetics, and bradycardia (slowing of the heart) which accompanies most anaesthetics. Respiratory secretions are a complicating factor especially in animals with small airways where even a low level of secretion may compromise respiration. With the advent of less irritating volatile anaesthetics, concerns about respiratory secretions have been reduced, and the primary use is to minimize the bradycardia that follows stimulation of the vagus nerve. Salivation is reduced in many animals although not in ruminants.

The muscarinic receptors in the eye are also affected resulting in dilated pupils (mydriasis). There may be a decrease in gastro-intestinal motility. The most commonly used anticholinergics are atropine and glycopyrrolate. Some rabbits possess atropinase, an enzyme which rapidly breaks down atropine and reduces its effectiveness in this species. Glycopyrrolate may be used in place of atropine in cases where the anticholinergic effect is required for a longer period of time. The effects are similar to atropine although the increase in heart rate may be less.

Types of Anaesthetic Agents

Anaesthetic agents should produce a loss of sensation with a minimum of side effects and they should have a calming effect on the animal during the recovery phase. While there is not a requirement for a loss of consciousness during anaesthesia, that is the case with general anaesthetics. Local anaesthetics for example will produce quite localized or even regionalized anaesthesia without any loss of consciousness. As well, it is advantageous for an anaesthetic agent to provide some level of analgesia during the recovery phase.

There are three broad groups of anaesthetic agent's namely volatile anaesthetics like isoflurane and halothane, injectable anaesthetics like ketamine, propofol and barbiturates, and local anaesthetics like lidocaine, procaine and bupivacaine. For general anaesthesia inhalant **anaesthetics** are highly preferred as the anaesthesia is much easier to control and the agent quickly cleared from the body.

Volatile Anaesthetic Agents

The common effects of anaesthetic agents described above apply to the volatile anaesthetics. These drugs are usually supplied as liquids and require a vaporizer and a carrier gas such as oxygen to deliver them to the patient. Altering the concentration of the anaesthetic agent in the inspired gases easily controls the depth of anaesthesia. In the event that the animal becomes too deeply anesthetised, the anaesthetic agent is quickly removed from the animal through the lungs. It is important to scavenge waste anaesthetic gases to minimize exposure of people to these agents.

Isoflurane

- Highly volatile and must be administered using a calibrated vaporizer to prevent exposure to high concentrations of gas
- Must be scavenged to avoid occupational exposure
- Respiratory depression greater than with halothane and may necessitate external ventilation
- Little hepatic metabolism and a lessened risk of hepatitis
- Rapid recovery (1-3 minutes)

Halothane

- Highly volatile and must be administered using a calibrated vaporizer to prevent exposure to high concentrations of gas
- Must be scavenged to avoid occupational exposure
- May cause cardiac arrhythmias
- May cause hepatitis in humans but rare in other species
- Will cause malignant hyperthermia in genetically susceptible pigs
- Rapid recovery (1-3 minutes) except from very long and deep anaesthesia

Nitrous Oxide

- Comes as a gas in cylinders
- Low anaesthetic potency and cannot produce anaesthesia in animals by itself
- Causes minimal cardiovascular and respiratory depression
- May be used to reduce the concentration of other anaesthetic gases although this effect is less than that seen in humans
- Use with caution in ruminants

Injectable Anaesthetics

The general effects of anaesthetics apply to the injectable anaesthetics, with some exceptions. Ketamine, for example, does not cause significant cardiovascular depression at the

usual anaesthetic doses. Injectable anaesthetics are easily administered requiring little more than a needle and syringe, but once they have been injected it is very difficult to control their effects. There are no specific antidotes for many of these drugs and recovery from anaesthesia depends on redistribution of the drug from the blood to the tissues or its metabolism or a combination of both processes.

There are many injectable anaesthetic drugs in use, ketamine, propofol, pentobarbital, methohexital, thiopental. The following notes on a few injectable anaesthetics highlight some important features or exceptions from expected effects. Full details on the activities of the drugs in particular species should be obtained from the veterinarian.

Ketamine

- Poor analgesia in most laboratory species and should not be used alone
- Increased muscle tone
- Many reflexes remain although animal is unresponsive to pain (e.g., swallowing and blink reflexes)
- Usually used in combination with another drug (e.g., xylazine, diazepam)
- Duration of anaesthesia depends on dose.
- Controlled drug status

Sodium Pentobarbital

- Narrow safety margin
- Poor analgesia until animal is completely unconscious
- Excitation during the recovery phase
- Gives up to 60 minutes of anaesthesia
- Controlled drug status

Urethane

- Provides long periods of surgical anaesthesia with little respiratory depression
- Urethane is carcinogenic
- Animals should not be allowed to recover from urethane anaesthesia

Animal Factors in Anaesthesia

There are a number of factors related to the animal that impact on the quality of anaesthesia. These factors should be considered when the type of anaesthetic agent is being chosen.

Species. Different species require different doses of anaesthetic agents. This applies particularly to the injectable anaesthetics. In general, the smaller animals require a higher dose in mg/kg of a given anaesthetic than larger animals. Familiarity with the effects of an anaesthetic agent in one species should not be assumed in another species. The volatile anaesthetics are more consistent in their application between species. The mean alveolar concentration of the anaesthetic agent required for anaesthesia is similar among species and this is controlled by the concentration of the agent in the inspired gases. Differences in the respiratory tract in birds (fixed lungs, air sacs) and other non-mammalian species must be considered when administering inhalation anaesthetics.

Age. Young animals and old animals may have an increased risk for anaesthetic complications. In older animals, pathological changes if present in the respiratory system may result in complications. Young animals may not have developed all the processes required to metabolize the drugs and so may have longer than expected recovery from anaesthesia. Volatile anaesthetics allow more refined control of the anaesthesia in both groups.

Weight. Very fat animals may not breathe as effectively during anaesthesia as thinner animals, leading to the problems associated with hypoventilation. In addition, if an agent is given on a mg/kg basis, there may be a relative overdose because the fat does not participate to a great degree in the circulation and distribution of the drug. If part of the recovery from an anaesthetic depends on its removal from the blood into tissues including fat (e.g., the short acting barbiturates) then animals with very little fat may experience longer than usual recovery from anaesthesia.

Sex. There is some evidence for a difference between the sexes for some anaesthetics.

Health of an Animal. Pre-existing disease or pathology may complicate an otherwise smooth anaesthesia. Any disease in the lungs will further compromise respiration during anaesthesia. Liver disease may interfere with the metabolism of anaesthetic agents and kidney disease may limit their excretion. Surgically altered animals (e.g., hypophysectomy, adrenalectomy, thyroidectomy) may be at increased risk at subsequent anaesthesias

Previous Anaesthesia. Some of the injectable anaesthetics are not completely cleared from the body for several days (e.g., pentobarbital), even if the animal has recovered consciousness and is behaving normally. Care must be taken if a second anaesthetic quickly follows the first. For those anaesthetics that are extensively metabolized as part of the excretory process, a second anaesthetic may result in more rapid metabolism of the drug than the first, with a shorter period of anesthesia.

Other Factors. Some non-anaesthetic drugs have effects on anaesthetic agents. Chloramphenicol may lengthen the duration of pentobarbital anaesthesia and some antibiotics potentiate the actions of muscle relaxants.

Side Effects of Anaesthetic Drugs

Like many drugs, anaesthetics also have other effects that may not be desirable. It may be necessary to take account of these side effects whether the animal is anaesthetized for a surgical procedure or for a physiological study of an organ system. The side effects described below occur to a greater or lesser degree with all general anaesthetics.

Central Nervous System (CNS) Depression. The commonly used anaesthetics provide CNS Depression to the point of loss of consciousness. This does not mean that all neuronal activity has been abolished. Many of the reflexes that are used to assess anaesthetic depth are retained after unconsciousness. However if anaesthetic depth increases, these are gradually lost and even automatic functions like respiration may be lost.

Cardiovascular Depression. Anaesthetics usually cause a decrease in cardiac output and a fall in blood pressure. These effects are a combination of a direct influence of the anaesthetic on the heart, reducing its contractility and an effect on the heart and blood vessels by way of the nerve supply to these tissues.

Respiratory Depression. One of the effects of anaesthetic agents is to cause a loss of muscle tone and a decrease in contractility. In the respiratory system, this results in smaller breaths i.e., the tidal volume is decreased. At the same time the respiratory rate is decreased. There is also a decreased sensitivity in the receptors that detect the level of oxygen and carbon dioxide in the blood. The overall effect is to reduce the respiratory capability of the animal.

Loss of Temperature Control. Anaesthetic agents inhibit the mechanisms responsible for maintaining a steady body temperature. These include the temperature regulating centres in the brain and processes like shivering. The result is a tendency for the animal's temperature to drift downwards towards the environmental temperature. Hypothermia is a major consideration in anaesthesia especially for small animals such as rodents, and controlled supplemental heat must be provided to maintain body temperature.

Anaesthetic Techniques

Inhalation Anaesthesia

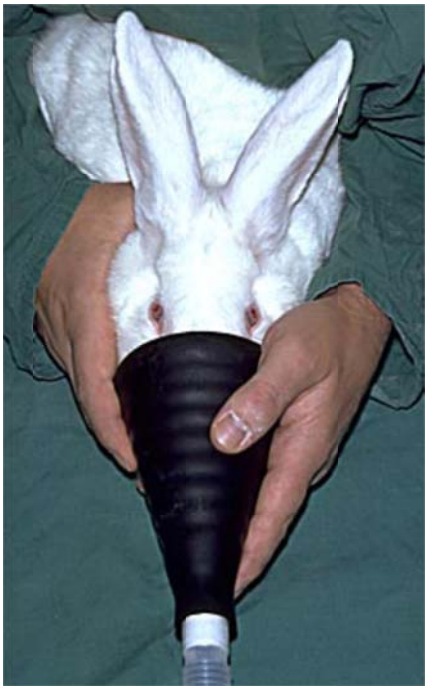
This type of anaesthesia requires the animals to breathe in the anaesthetic. Initially the anaesthetic concentration is highest in the alveoli and as the gas passes into the bloodstream, the animal becomes anesthetised. At the end of the surgery, the concentration in the inspired gas is reduced to zero and the agent passes from the blood to the alveoli and the animal recovers. The balance between blood and alveolar levels controls the depth of anaesthesia.

There are several techniques for anaesthetizing animals with volatile anaesthetics. The animal may be placed in a chamber and the chamber flooded with the anaesthetic gas in the

carrier gas at the required concentration. Once anaesthetized, the chamber should be opened in a fume hood and the animal may be removed and placed on a nose cone or some other apparatus for delivering the anaesthetic to prolong the anaesthesia, if that is necessary. This technique is most suitable for small animals.

Courtesy of Dr Paul Flecknell, University of Newcastle

Animals may be masked down by placing a mask over the nose and mouth and allowing them to breathe the anaesthetic gases. Even fairly large animals may be anaesthetized in this manner but it usually results in some accidental exposure to the gases. Some species hold their breath when the mask is placed on their face.



Courtesy of Dr Paul Flecknell,
University of Newcastle

Animals may be anesthetised initially with a short acting anaesthetic, injected intravenously, an endotracheal tube placed in the trachea and the tube connected to an anaesthetic circuit delivering the volatile anaesthetic. This system has several advantages. It makes it possible to ventilate the animal using a respirator and so maintain normal breathing and respiratory values. It makes it easier to deal with anaesthetic emergencies should they occur and it allows for better control of stray anaesthetic gases in the room. However, endotracheal intubation is difficult in some small animals (e.g., rodents) and the reduction in diameter of the airway in the trachea may significantly affect respiration. Care must also be taken not to significantly increase the dead space i.e., the part of the respiratory system where exchange of gases with the blood does not occur. The ventilation rate and the tidal volume should be set to maintain normal blood gases and this should be discussed with a veterinarian.

Occupational Health and Safety Concerns

Human exposure to the inhalation anaesthetic gases should be avoided. Hepatic toxicity may occur with exposure to some volatile anaesthetics. Others are known to be carcinogenic

(e.g., urethane). Procedures should be in place to collect or remove all waste anaesthetic gases that leak out or are expired by the anaesthetized animal.

Injectable Anaesthesia's

Anaesthetics may be injected by a number of routes, intravenously, intraperitoneally, intramuscularly and subcutaneously. Injectable anaesthetic drugs may be used to produce general, regional or local anaesthesia. For regional anaesthesia, anaesthetics may be injected into the subarachnoid or epidural spaces to block both the sensory and motor nerves entering or emerging from the spinal cord at that level. Anaesthetics such as the thio-barbiturates should be given intravenously because their high pH (alkalinity) causes tissue damage if injected subcutaneously or intramuscularly.

Anaesthesia through Drugs Placed in the Animal's Environment

This refers particularly to anaesthetics administered in the water of fish and amphibians. There are several anaesthetics that can be added to the water and the animals allowed to swim until they become anesthetised. Tricaine methanesulfonate (TMS; MS-222®) is commonly used to anesthetise frogs and fish. In water, it is very acidic and must be buffered with sodium bicarbonate.

Cold-induced "anaesthesia" - Hypothermia

Induction of hypothermia has been used for immobilizing neonatal rodents since they do not yet have well-developed thermoregulatory mechanisms, and for immobilising amphibians and reptiles, for surgical procedures with an apparent wide safety margin. It is known that a neural tissue temperature less than about 9°C (5°C is sometimes cited as the desired core body temperature) results in blockage of transmission in the brain and central nervous system to produce unconsciousness. The lack of response to surgery trauma during such levels of hypothermia has been accepted as an indication of insensitivity to pain. However, there are important welfare concerns about the chilling down and warming up periods, the methods of doing so, and the absence of post-operative analgesia with this technique. Definitive studies on the anaesthetic and analgesic effects of hypothermia as the sole agent have not been reported, and since safe and effective alternatives are available, these should be used.

Assessment of Anaesthesia

Anaesthesia has been described as a series of four Stages.

- Stage 1: the period between administration of an anaesthetic and loss of consciousness.
- Stage 2: the period after loss of consciousness, which may include actions such as uncontrolled movement, delirium, vocalization.
- Stage 3: the level at which surgery can be performed. Stage 3 anaesthesia is divided into four planes.
    - Plane 1: "light" anaesthesia - the animal still has blink and swallowing reflexes, and regular respiration.
    - Plane 2: "surgical" anaesthesia - the animal has lost blink reflexes, pupils become fixed and respiration is regular.
    - Plane 3: "deep" anaesthesia - the animal starts losing the ability to use the respiratory muscles and breathing becomes shallow; may require assisted ventilation.
    - Plane 4: the animal loses all respiratory effort, and breathing may stop entirely.

- Stage 4: anaesthetic crisis! Respiratory arrest and death from circulatory collapse imminent.

Reflexes are used to estimate the depth of anaesthesia and while there is some variation in the activity of these reflexes with different anaesthetics, they are consistent enough to be useful as a group. A single reflex should not be used as the sole determinant of anaesthetic depth.

- **Pupillary Reflex**. Shine a light in the eye and the pupil constricts. This reflex is present at the start of Stage 3 and starts to decrease and will be absent by about the middle of Stage 3.
- **Palpebral Reflex**. Touch the corner of the eye and the animal blinks. This disappears early in Stage 3.
- **Corneal Reflex.** Touch the cornea and the animal blinks. This disappears early in Stage 3. Be careful not to damage the cornea if this reflex is tested.

- **Withdrawal Reflex.** Pull a limb gently, pinch the toe and the animal will pull back the limb. This reflex indicates whether the animal feels pain or not and should be absent before surgery starts. This will occur early in Stage 3.
- **Laryngeal (Swallowing) Reflex**. Stimulation of the larynx will cause the animal to swallow. The stimulation may be from outside, for example, an attempt to pass an endotracheal tube or may be internal for example the presence of secretions at the larynx. This is a mechanism to prevent accidental aspiration of fluids into the lungs. This reflex will disappear early in Stage 3. There are some other signs that will help judge the depth of anaesthesia.

Respiratory efforts. This can change as anaesthesia deepens. In Stage 1, the animal is awake and respiration may be quite rapid due to the excitation of being handled. It is evenly apportioned between the chest and abdomen and is quite regular. In Stage 2, breathing is still evenly apportioned between chest and abdomen but is less regular and breath holding may occur. Early in Stage 3, breathing is regular with equal contributions from chest and abdomen. As anaesthesia deepens, breathing becomes shallower and more predominantly abdominal. Late in Stage 3 it becomes irregular and in Stage 4 will stop.

Muscle tone. Decreases can occur from a maximum during Stage 2 all the way through Stage 3. Jaw tone is a good indication of muscle tone.

Response to Surgical Stimuli. Care should be taken to note any responses to surgical stimuli. Once it has been determined by the reflexes that an appropriate depth of anaesthesia has been reached, surgery will commence. The first incision should be observed to determine if the animal makes any response. A response could include a movement, a pause in respiration or a deeper breath if the animal is breathing spontaneously or an increase in heart rate or blood pressure. If there is surgery in the abdomen, traction on the abdominal viscera is known to be painful and this may provide another indication of whether the anaesthesia is adequate or not.

DEPTH OF ANESTHESIA

Stages	**Reflexes/Signs**
Stage 1: the period between administration of an anaesthetic and loss of consciousness.	**Respiratory efforts** change as anaesthesia deepens. In Stage 1, the animal is awake and respiration may be quite rapid due to the excitation of being handled. It is evenly apportioned between the chest and abdomen and is quite regular.
Stage 2: the period after loss of consciousness, which may include actions such as uncontrolled movement, delirium, vocalization.	**Muscle tone** decreases from a maximum during Stage 2 all the way through Stage 3. Jaw tone is a good indication of muscle tone. **Respiratory efforts**. In Stage 2, breathing is still evenly apportioned between chest and abdomen but is less regular and breath holding may occur.
Stage 3: the level at which surgery can be performed. Stage 3 anaesthesia is divided into four planes. • Plane 1: "light" anaesthesia - the animal still has blink and swallowing reflexes, and regular respiration. • Plane 2: "surgical" anaesthesia - the animal has lost blink reflexes, pupils become fixed and respiration is regular. • Plane 3: "deep" anaesthesia - the animal starts losing the ability to use the respiratory muscles and breathing becomes shallow; may require assisted ventilation. • Plane 4: the animal loses all respiratory effort, and breathing may stop entirely.	**Pupillary Reflex**. Shine a light in the eye and the pupil constricts. This reflex is present at the start of Stage 3 and starts to decrease and will be absent by about the middle of Stage 3. **Palpebral Reflex**. Touch the corner of the eye and the animal blinks. This disappears early in Stage 3. **Corneal Reflex**. Touch the cornea and the animal blinks. This disappears early in Stage 3. Be careful not to damage the cornea if this reflex is tested. **Withdrawal Reflex**. Pull a limb gently, pinch the toe and the animal will pull back the limb. This reflex indicates whether the animal feels pain or not and should be absent before surgery starts. This will occur early in Stage 3. **Laryngeal (Swallowing) Reflex**. Simulation of the larynx will cause the animal to swallow. The stimulation may be from outside, for example, an attempt to pass an endotracheal tube or may be internal for example the presence of secretions at the larynx. This is a

	mechanism to prevent accidental aspiration of fluids into the lungs. This reflex will disappear early in Stage 3. **Respiratory efforts.** Early in Stage 3, breathing is regular with equal contributions from chest and abdomen. As anaesthesia deepens, breathing becomes shallower and more predominantly abdominal. Late in Stage 3 it becomes irregular and in Stage 4 will stop.
Stage 4: anaesthetic crisis! Respiratory arrest and death from circulatory collapse imminent.	

Body temperature should be measured and steps taken to prevent the fall in body temperature that usually accompanies anaesthesia, particularly in small animals.

Capillary refill time may give an indication of the adequacy of cardiovascular function. If a pink paw is squeezed, it will go white but the pink will return within about two seconds. If the time is significantly longer than this, then blood flow through the capillaries is compromised, usually because anaesthesia is too deep and the blood pressure is too low. If a pulse can be felt and if the anaesthetist is experienced with respect to the feel of the normal pulse, it is possible to get an indication of the cardiac output. In addition, the pulse rate can be counted and compared with the heart rate as heard through a stethoscope or counted from an electrocardiogram. There should not be a difference between the two.

Blood pressure gives a good indication of the effectiveness of the heart's contractions and the resistance to flow in the peripheral vessels. It may be measured either indirectly (e.g., a Doppler system or directly with a catheter in an artery). A falling mean arterial pressure is a sure indicator of deepening anaesthesia, if there are no other possible causes like severe haemorrhage.

Additional Monitoring. If an arterial blood sample and the capability to measure blood gases are available, then this information provides a very accurate picture of the effectiveness of the ventilation. This information can be used to fine tune ventilation to maintain normal

physiological parameters. End tidal CO2 and pulse oximetry are non-invasive methods of obtaining information on the blood gas status.

Anaesthetic Management

Whenever possible, and particularly for more complex surgeries, there should be an "anaesthetist" involved. Anaesthetic management accounts for all the processes and events during a period of anaesthesia that will result in freedom from pain during the surgical procedure and a return to a normal physiological state as soon as possible after recovery. The assessment of the depth of anaesthesia is only one part of anaesthetic management. An important component is ensuring that all equipment is functioning properly.

During the course of the surgical procedure, there will have been changes in the fluid balance of the animal that should be corrected. Some of these are normal: continued production of urine, and losses from the respiratory tract. Continuous saliva production, especially in ruminants, will deplete body water and electrolytes. An anaesthetized sheep may produce 800 ml/hr of saliva high in bicarbonate, which is lost to the animal because it cannot swallow while under anaesthesia. This secretion is not reduced by anticholinergic drugs like atropine and will soon lead to fluid depletion and an acid/base imbalance.

Blood loss may account for a serious loss of fluids and this is particularly important in small animals that have a very small blood volume. (It is convenient to estimate the blood volume of an animal at 70 ml/kg. This is only an estimate for the purpose of rapid simple calculation of blood loss or the volume of blood that might be taken from an animal. A 20g mouse has about 1.4 ml of blood and a loss of 0.2 ml represents 14% of its blood volume.)

The loss of fluids through evaporation may be significant if deep body cavities are open during the surgery. It has been estimated that the fluid loss through evaporation from an open human abdomen is about 500 ml/hr. Fluid losses should be replenished throughout the surgery, rather than waiting to the end. Unexpectedly large losses should be replaced as soon as possible. It is not always possible or desirable to replace blood with blood but the consequences of a reduced circulating blood volume on cardiovascular performance must be considered.

If vascular access has been established, it is important to ensure that this access is patent. This is usually accomplished by slowly running fluids through the needle or catheter.

Occasionally, the needle becomes displaced or there is a kink in the tubing and the vascular access is lost through clotting of the needle.

Paralytic Agents (Neuromuscular Blocking Drugs)

Neuromuscular blocking drugs are used as an adjunct to anaesthetics to provide greater muscle relaxation during a surgical procedure or when control of respiration is necessary. These compounds paralyze skeletal muscle so that voluntary control of the muscles is lost. Most significantly, there is loss of activity in the muscles of respiration and in muscles that are responsible for some reflexes used to judge the depth of anaesthesia (see above). Loss of the muscles responsible for respiration means that an artificial method of respiration must be used. Loss of reflexes means that it is difficult to ensure how deeply the animal is anaesthetized.

The major concerns about the use of paralyzing agents are that they produce paralysis, but not loss of consciousness or pain relief, and that their effects may last beyond the anaesthesia. Thus an animal may appear to be anaesthetized (i.e., unresponsive to any painful stimuli) while in reality, it is unable to respond because of the muscle paralysis.

Emergencies

The three major emergencies while an animal is anaesthetized result from anaesthetic overdose, blood loss and equipment failure. Any of these could result in the death of the animal. Anaesthetic overdoses with injectable anaesthetics are the most difficult to deal with because there are no specific reversal agents. Respiratory depression is the most easily observed effect of the overdose and takes the form of a decreasing ventilator effort. If this occurs artificial ventilation should be initiated to try to maintain normal blood gases until the animal metabolizes the anaesthetic or otherwise reduces the concentration in blood. It is advisable to have respiratory support equipment always available when animals are anaesthetized.

Blood loss will be recognized if a large vessel is accidentally cut. However, the continual loss of small amounts of blood may add up to a serious problem. This may occur if the animal has been given anticoagulation drugs like heparin and there is no spontaneous clotting. If the level of anaesthesia has been deep at the start of the surgery, there may have been little bleeding due to the low blood pressure. The surgeon may not have had to deal with the many small bleeding points that would have been obvious if the blood pressure had been higher. Many of

these will start to bleed as the animal recovers or if the anaesthesia is lighter. If blood loss is anticipated then appropriate replacement fluids should be available as well as a venous catheter placed at the start of anaesthesia so that fluids, drugs, etc., may be administered if necessary.

The anaesthetist should be aware of the functioning of the equipment at all times and have backup plans to protect the animal if there should be a failure. Such failures could include a massive electrical shutdown that halts all electrically driven devices.

Recovery from Anaesthesia

Recovery from anaesthesia more or less mirrors the induction pathway although the timing differs. Thus while rapid induction pushed the animal through Stage 2 and avoided the excitement stage, recovery is slower and some excitation may be seen particularly following barbiturate anaesthesia. Very close monitoring of the animal must continue into the recovery phase, and particular care must be taken to ensure that the airways are patent and that breathing is unimpeded. Any anaesthesia-induced abnormalities present at the end of the anaesthesia, such as hypothermia or dehydration, should be corrected. One dangerous effect of hypothermia is that the anaesthetic drugs will not be metabolized as quickly and the duration of the anaesthesia unnecessarily prolonged.

There are a number of factors that will influence the rate and quality of the recovery. If a *preanaesthetic agent* was used, this may increase the time to full recovery because of the tranquillizing effects of some of these drugs. On the other hand they will make recovery calmer with less of the excitement phase. The anaesthetic agent will determine the rate of recovery. Volatile anaesthetics are quickly blown off and the animal regains consciousness. Injectable anaesthetics are slower since they depend on metabolism and excretion for their inactivation.

The duration of anaesthesia may govern the rate of recovery, especially for those agents where rapid recovery is due to clearing into tissues from the blood with metabolism later (e.g., thiobarbiturates). Long anaesthesia with one of these drugs will result in saturation of the tissues and prolonged rather than rapid recovery. The longer the period of anaesthesia, the more difficult it is to keep everything normal, even with very extensive monitoring. It is likely then that recovery will be different compared to a short anaesthesia.

The quality of the anaesthesia may be important in the recovery. If anaesthesia was turbulent with periods of very deep anaesthesia, the likelihood of abnormal physiology and biochemistry is greater, with delayed recovery.

The surgical procedure, especially if it was accompanied by blood loss may affect recovery. The duration of the surgery and the insult on the organs may be important. For example, a thoracic procedure may result in incomplete expansion of the lungs and the compromised ventilation may need longer to return the respiratory parameters to normal. Some of the animal factors described as influencing anesthesia may also affect recovery. Older and younger animals, for example, may not metabolize the drugs as quickly.