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Anaesthesia for Nurses Mini Series

Session One: Prior Preparation for Anaesthesia Patients

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Anaesthesia for Nurses: Week 1

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Patients requiring anaesthesia can present with a wide variation in clinical signs and systemic conditions, all of which require some consideration before anaesthesia is commenced. Evaluation of patients should include a full clinical history, physical examination, diagnostic testing, as well as individual patient considerations, e.g. breed, reason for anaesthesia.

The aim of the preoperative evaluation is to determine if there is any disease present that will affect the uptake, action, metabolism, elimination, and safety of the anaesthetic. Primarily the cardiopulmonary, nervous, renal and hepatic are the systems of greatest concern. The history and physical examination are the best determinants of disease. Laboratory tests should only be performed on the basis of history/physical examination. It has been shown that the use of extensive laboratory screening has not improved outcome in human or veterinary medicine.

What is normal?

The reference ranges, 'normal' for laboratory tests are presumed to be within +/- 2 standard deviations of the mean, and therefore 5% of normal animals fall outside this range. The upper and lower values do not represent a cut off between normal and disease. Indeed, a normoglycaemic diabetic, or an animal with cirrhosis with normal hepatic enzymes and bilirubin will seem unremarkable on screening and therefore fall into the 'normal' category when that is far from the case. There seems to be no relationship in most cases between the presence and severity of disease and the extremeness of the laboratory values! These points stress the importance of accurate history taking and physical examination.

History

This should include previous and current health status questions, complaint severity and duration and other associated symptoms (diarrhoea, vomiting, PU-PD, exercise tolerance, dyspnoea etc), exposure to drugs (OPs, digitalis, diuretics, betablockers, anticonvulsants, steroids, NSAIDs, ABs etc), anaesthetic history, pregnancy and time of last feed.

Clinical Examination

A thorough clinical examination of all the body systems should be completed by both the vet and the technician. Depending on the history and examination laboratory tests or x ray, ECG etc. can be ordered. Following this initial evaluation it is useful to place the patient in ASA category I-V.

Category	Physical Status	Examples
I	Patient is normal and healthy	OHE, castration
II	Patient has a degree of mild systemic disease	Localised infection, F# no shock, skin tumour, cardiac disease-compensated
III	Patient has severe systemic disease	Anaemia, fever, dehydration, cachexia
IV	Patient has severe systemic disease that is constant threat to life	Toxaemia, severe dehydration, anaemia, CHF decompensated, emaciation
V	Patient is moribund and unlikely to survive >24 hours	Severe trauma, terminal malignancy, shock

Table 1. American Society of Anesthesiologists (ASA) Classification of Health Status

Signalment

Breed sensitivities are often quoted, but other than sight hound barbiturate sensitivity, BOAS and toy breeds (SA:Bdwt) all breeds have been successfully anaesthetised using the standard regimes. Age should be considered. <11 weeks and the geriatric patient will not metabolise drugs as well. Neonates have altered body water, respiratory dynamics and immature p/s nervous system and reduced thermoregulatory capacity. Healthy geriatric patients should receive sedative drugs at a reduced dose (30%). Intravenous fluids will be indicated in the geriatric patient to improve organ perfusion.

Patient preparation

Healthy dogs and cats should be starved for at least 6 hours prior to anaesthesia. The reason is twofold, firstly to reduce the risk of aspiration during induction and recovery (silent aspiration can occur too) and secondly, to reduce the pressure on the diaphragm and maximize functional residual capacity (FRC) thereby improving ventilation. Dogs and cats less than 8 weeks old should not be fasted for longer than 1-2 hours. Water is made available to the patient up to the time of premedication. In older dogs with nephritis the stress of the procedure/illness/hospitalization can be detrimental and intravenous fluids are indicated to induce a moderate diuresis.

The Anaesthetic Plan

The considerations for devising a plan are listed below and these should be considered before premedication.

1. Procedure being planned
    - a) Duration
    - b) Type of surgery/investigation/medical vs surgical
    - c) Anticipated post-op pain
2. Temperament of the patient
    - a) Nervous or excitable
    - b) Vicious
    - c) Recumbent/comatose
    - d) Calm and relaxed
3. Available equipment/expertise
    - a) Anaesthetic machine/inhalant available
    - b) Expertise of team surgeon/anaesthetist
    - c) Restraint
    - d) IPPV facilities
4. Breed
5. ASA category

Breed Considerations

Breed considerations can also influence anaesthetic protocols:

- The brachycephalic group should prompt us to consider possible difficult intubation and late extubation, careful monitoring after pre-medication and in recovery in addition to the considerations previously outlined.
- Dobermans are known to be a breed with a high incidence of abnormally low von Willebrands factor concentrations. Screening or at the least a buccal mucosal bleeding time should be assessed in all cases prior to anaesthesia. Dogs that are shown to be deficient in von Willebrands factor will require treatment usually with desmopressin and cryoprecipitate.
- Boxers appear to have a genetic disposition to acepromazine sensitivity and therefore acepromazine should be avoided altogether or doses should be significantly reduced.

- Greyhounds and sight hounds are not well suited to barbiturate anaesthesia due to the method of redistribution of these drugs and the inability of greyhounds to metabolise the barbiturate group. A different induction agent should be considered i.e. propofol or alfaxan.
- Miniature Schnauzers are at risk for developing sick sinus syndrome and should have an electrocardiogram (ECG) evaluated prior to anaesthesia.

Anaesthesia Complications and Fatalities

In 2006 Dr. David Brodbelt of the Royal Veterinary College (London, UK) completed a detailed prospective Confidential Enquiry into Peri-operative Small Animal Fatalities (CEPSAF), reporting overall mortality figures of 0.17% and 0.24% for dogs and cats respectively. Healthy dogs and cats had mortality rates of 0.05% and 0.11%, respectively, while 'sick' animals had figures of 1.33% and 1.4% for dogs and cats, respectively. For the purposes of CEPSAF, an anaesthetic-related death was defined as "perioperative death within 48 hours of termination of the procedure, except where death was due solely to inoperable surgical or preexisting medical conditions". Perhaps one of the most alarming issues to arise from the study was the timing of anaesthetic-related death: almost 50% of dogs and >60% of cats that died, did so in the recovery period, with around 50% of them succumbing within the first 3 hours after termination of the anaesthetic, and many animals were unattended at this time. This suggests that greater attention should be made to continued observation, monitoring and support of animals in the post anaesthetic period. CEPSAF identified a number of factors that may be associated with an increase in the odds ratio (OR) of mortality, and the different species included in the study will be discussed individually.

Dogs

Overall, when compared to control dogs, there was a 6 fold increase in odds of dying for every 1 point increase in ASA status, i.e. as dogs became sicker, anaesthetic mortality increased proportionally. This is perhaps not surprising, but emphasises the need, where feasible, to stabilise patients as much as possible prior to undertaking anaesthesia. There was also a 2.5 fold increase in odds associated with the urgency of the procedure the animal was undergoing, from elective, through urgent to emergency. While this may be confounded by the animal's health status discussed above, there seemed to be a genuine trend towards increasing mortality, independent of the ASA status. This may be because there was insufficient time to adequately 'work up' these cases, or may reflect the fact that many urgent procedures are performed outwith normal working hours, when there may be fewer staff available to help, or the staff who are available are fatigued from already working a full day. Similar results were identified in the CEPEF (Confidential enquiry into perioperative equine fatalities) study, and perhaps emphasise that only genuine emergencies should be anaesthetised outside working hours.

1. Patient age

There was a significant increase (almost 10 fold) in anaesthetic mortality for dogs >12 years old, and, although this may have been influenced by worsened health status with advancing age, this is unlikely to completely explain the large increase over younger animals. Geriatric patients have both pharmacokinetic and pharmacodynamic alterations in their response to anaesthetic agents, so relative overdoses and prolonged recoveries may play some part in the increased mortality figures.

2. Body weight

Dogs <5kg were 7 times more likely to die than larger dogs, and several explanations may be offered for this. Small body size may lead to a greater likelihood of drug overdose, and there is likely to be a limited safety factor in patients of this size if this were to occur.

Secondly, patients with a high surface area : body weight ratio are predisposed to hypothermia, and this will reduce anaesthetic requirements (potentially leading to overdose if undetected) and also delay recovery from anaesthesia. Since almost 50% of canine deaths occur during the post-anaesthetic period, it would make sense that prolonging this phase is likely to be detrimental for the animal. Careful calculation of drug doses - and appropriate dilution, if necessary, to achieve a workable volume - as well as attempts to maintain body temperature during anaesthesia, may go some way to reducing mortality in these smaller patients.

3. Duration of procedure

CEPSAF identified an increase in mortality associated with increasing duration of anaesthesia, although this was difficult to quantify.

4. Complexity of procedure

'Major' procedures increased anaesthetic mortality over 'minor' procedures, with an odds ratio of 5.2. Some of this effect may have been related to increasing duration of anaesthesia with major procedures, but it appeared unlikely to be solely this effect at play. Major surgery contributes to greater fluid losses and haemodynamic effects than minor procedures, and this may account for the greater mortality observed.

5. Drug effects

It is tempting to think of some drugs as being inherently 'safer' than others. An earlier study by Clarke and Hall identified a significantly increased risk of mortality associated with the use of xylazine, and it may, therefore, be expected that CEPSAF would demonstrate an increased odds ratio associated with newer alpha-2 agents, such as medetomidine (dexmedetomidine was not available at the time the study was carried out). However, both acepromazine and medetomidine appeared to reduce the risk of death to a similar extent when compared with no premedication, although it is important to point out that medetomidine was used to a much lesser extent for premedication in this study than was acepromazine (5% vs. 78% of controls, respectively). Thus, it is difficult to make firm conclusions as to the safety of one drug over another. While xyalzine has been shown to sensitise the heart to the effects of catecholamines, medetomidine has been shown to not do this, and, in fact, may protect the heart against catecholamine-induced arrhythmias. A large scale prospective randomised study comparing the two drugs would be necessary to establish the relative safety profiles. Using multivariate analysis, there appeared to be no difference between thiopentone or propofol for induction of anaesthesia. Previous studies have suggested a greater mortality associated with propofol, but this was likely due to its greater use in 'sicker' animals. Sevoflurane was not available at the time CEPSAF was carried out, so the study was only able to compare halothane and isoflurane. There was a 6 fold increase in mortality when halothane was used for maintenance. This may be due to the fact that halothane sensitises the heart to catecholamines, whereas isoflurane does not, or may be associated with greater depression of cardiac output by halothane. Given the fact that halothane is no longer commonly used, the reasons behind its higher mortality may be moot. Total inhalational anaesthesia (i.e. mask induction followed by inhalational maintenance) was also approximately 6 times more likely to result in death than an injectable induction followed by isoflurane maintenance. Thus, facemask inductions should be avoided where possible.

6. Mode of ventilation

Within the 'sick' dog population, CEPSAF identified an increased risk of mortality in patients receiving controlled ventilation (intermittent positive pressure ventilation – IPPV) versus those breathing spontaneously. Although there was some association between this and the complexity of the procedure (i.e 'major' cases were more likely to receive IPPV, and it may have been the former contributing to increased mortality), there was also increased mortality in 'minor' procedures when IPPV was performed, so this would seem to be a genuine occurrence. There may, however, be some confounding effect from the actual procedure type.

While IPPV may have a number of detrimental effects, it is likely that some of the deaths would be as a result of anaesthetic overdose, due to greater uptake of inhaled anaesthetic agent during controlled versus spontaneous ventilation.

7. Pre-anaesthetic blood testing

The use of pre-anaesthetic blood testing is a contentious one among veterinary anaesthetists, and previous studies have failed to show any benefit in the absence of obvious clinical signs. However, CEPSAF demonstrated a decreased odds ratio of death in sick patients that had pre-anaesthetic blood screening performed. The significance of this is difficult to determine, as ASA 4-5 cases in the study were 3 times more likely to receive intravenous fluid therapy peri-operatively if they had blood screening performed before anaesthesia, i.e. the reduced mortality may be down to improved case management rather than blood testing per se.

Cats

In both the Clarke and Hall and CEPSAF studies, mortality was higher in cats than in dogs, for both healthy and sick individuals. In common with the canine data, mortality increased in cats with increasing ASA status (odds ratio of 3.2 for every 1 increment in ASA status), and also with the urgency and complexity of the procedure. A number of other factors were also shown to contribute to increased mortality in this species:

1. Patient age

CEPSAF identified a 2.1 odds ratio of mortality in cats >12 years old. This was significantly less than the risk associated with older dogs, and may reflect the fact that 12 years may be ‘less geriatric’ in a cat than a dog.

2. Bodyweight

Extremes of body weight in cats were both associated with increased mortality: cats <2kg were almost 16 times more likely to die than those between 2 and 6kg, while those greater than 6kg had an odds ratio of almost 3. Although the low body weight may have been confounded by age (i.e. it may also have reflected that some of these animals were paediatric), it is consistent with the increased mortality reported by CEPSAF in dogs <5kg.

3. Duration of procedure

There was no clear statistical evidence that increasing duration of procedure was associated with increased mortality in cats, unlike the situation in dogs.

4. Complexity of procedure

Cats undergoing major procedures were approximately 3 times more likely to die than those undergoing minor procedures.

5. Drug effects

There were no obvious effects on mortality of drugs chosen for premedication, induction or maintenance.

6. Endotracheal intubation

The Clarke and Hall study identified endotracheal intubation as being a factor increasing risk of death in cats, and this was confirmed by CEPSAF. The latter suggested that risk of mortality increased if endotracheal intubation was carried out in association with a ‘minor’ procedure, but decreased mortality if carried out in association with a ‘major’ procedure (although the statistics assessing this effect were complex). It is important to recognise that endotracheal intubation in cats is not an innocuous procedure, should not be performed unnecessarily, and must be carried out with due care.

7. Fluid therapy

Peri-operative fluid therapy was associated with a 4 fold increase in feline mortality in the CEPSAF study, and, even accounting for the effect of health status and procedural complexity and duration on the likelihood of fluids being administered, there still appeared to be a genuine effect of fluid therapy on mortality. It is important to remember that cats have a smaller circulating volume than dogs, and are more prone to circulatory overload.

Care must be taken with both the volume and rate of fluid administration in this species if complications are to be avoided.

8. Monitoring

Pulse monitoring and/or use of pulse oximetry were associated with reduced risk in cats, with a reduction in mortality of 4-5 fold.

9. Nitrous oxide

The inclusion of nitrous oxide as part of the anaesthetic protocol significantly reduced mortality risk in sick cats. Although only a relatively 'weak' anaesthetic agent, nitrous oxide is virtually devoid of cardiopulmonary depressant effects, so, by allowing a reduction in the concentration of the volatile agent (halothane, isoflurane) - all of which are very depressant on blood pressure and ventilation - inclusion of nitrous oxide may allow improved cardiopulmonary function, and this may be particularly important in the sicker population.

Anaesthesia planning is multifactorial, and all aspects of the anaesthetic should be considered and planned for. Additionally the use of anaesthesia checklists should be considered, as they will improve the efficiency in which the anaesthetist can ready, and can help ensure no aspect of anaesthesia is missed. Checklists include the anaesthetic machine, breathing systems, monitoring equipment, resuscitation supplies etc.

http://www.alfaxan.com.au/documents/resources/downloads/UK/AVA_Anaesthetic_Safety_Checklist_FINAL_UK_WEB_(1).pdf

Basic Anaesthetic Machine Check

This is a modified version of how human anaesthetists perform an anaesthetic machine check, and should be carried out at the start of each working day. Although the following list looks long and complicated, the whole procedure can be completed within about 3 minutes once you have done it a few times.

1. Start with all pipeline supplies disconnected from the terminal outlet on the wall, all vaporizers turned off, and the main power supply to the anaesthetic machine (if fitted) turned on.
2. Check the scavenging is turned on and working, and connect the scavenge tubing to the common gas outlet of the anaesthetic machine (this will scavenge any anaesthetic agent discharged during the check procedure).
3. Check that only cylinders, which are to be used, are connected to the machine, that they are sitting securely in their yokes, and that they are turned off.
4. Open all flowmeter control valves.
5. Turn on the reserve oxygen cylinder, check the contents gauge, and see that oxygen now flows through the oxygen flowmeter. Turn off the reserve oxygen cylinder and repeat the test for the "in use" oxygen cylinder (if applicable).
6. Ensure the oxygen flowmeter can deliver a flow throughout the range of the flowmeter. Set a flow of approximately 5L / min.
7. Turn on the reserve nitrous oxide cylinder, observe the contents gauge (remember, this only gives limited information due to the liquid state of the nitrous oxide), and observe that gas now flows through the nitrous oxide flowmeter. Close the reserve cylinder and repeat for the "in use" nitrous oxide cylinder (if applicable).
8. Ensure the nitrous oxide flowmeter can deliver a flow throughout the range of the flowmeter. Set a flow of approximately 5L / min.
9. Turn off the oxygen cylinder and empty oxygen from the system by using the oxygen flush valve. The cylinder contents gauge should drop to zero, and the oxygen alarm should sound as the pressure drops. In addition, any cut-off device (if fitted) should operate to prevent delivery of an hypoxic gas mixture, turning off the supply of nitrous oxide to its flowmeter.

10. Connect the oxygen pipeline and perform a "tug test" (give a couple of sharp tugs to ensure that the pipeline is correctly connected to the terminal outlet). See that the flow of oxygen has been restored to the flowmeter, and that the oxygen alarm has cancelled. The nitrous oxide supply should now also be restored if an anti-hypoxia device had terminated it. Check on the pressure gauge that the oxygen supply pressure is around 400kPa.

11. Turn off the nitrous oxide cylinders and connect the pipeline supply, performing a "tug test". Check that gas begins to flow through the nitrous flowmeter again. Check on the pressure gauge that the nitrous oxide supply pressure is around 400kPa.

12. Turn off all flowmeters. Check any other cylinders fitted to the machine in a similar manner to that described above.

13. Depress the emergency oxygen flush and check there is no significant drop in pipeline supply pressure.

14. Check all vaporizers are correctly fitted to the anaesthetic machine, and that they are filled with the appropriate agent (this can only be checked during filling, not afterwards). Ensure the control knobs move through their full range, and that the filling ports are tightly closed.

15. Set a flow of oxygen of approximately 6L / min, and with the vaporizers turned off (and the scavenge tubing now removed from the common gas outlet), occlude the common gas outlet. There should be no obvious leak from the vaporizers and the oxygen flowmeter bobbin should drop. Failure of the oxygen flowmeter bobbin to go down suggests a leak within the anaesthetic machine. N.B. THIS TEST SHOULD ONLY BE PERFORMED WHERE IT IS KNOWN THAT THE MACHINE HAS A PRESSURE RELIEF VALVE, OTHERWISE THE FLOWMETERS MAY SHATTER!

16. Repeat this procedure with the vaporizers turned on, and observe for leaks around the filling port. AGAIN, ONLY WHERE A PRESSURE RELIEF VALVE IS FITTED!

17. The breathing system chosen for the patient should also be checked before use.

MAIN ANAESTHETIC MACHINE SAFETY FEATURES DESIGNED TO PREVENT DELIVERY OF AN HYPOXIC GAS MIXTURE

The most dreaded complication of the use of anaesthetic machines is delivery of an hypoxic gas mixture to the patient, and most of the machine check described above is directed at preventing this.

Summary

Most of us use anaesthetic machines on a daily basis, and a reasonable understanding of how they function can go a long way to ensuring the safety of the animals under our care. In particular, routine checking of machines prior to use will detect faults early, before exposing our patients to potentially dangerous situations.

Endotracheal Tubes

The placement of a tube into the airway will always add resistance and increase the work of breathing. This may lead to hypoventilation during anaesthesia. The important qualities of a tube that may affect resistance are:

1. Tube internal diameter – the smaller the internal diameter of the tube, the greater the resistance will be. If you imagine that an endotracheal tube inside the trachea is essentially a tube within a tube → the diameter of the airway must be reduced. The wall thickness of the tube influences the internal diameter and smaller tubes are affected more (the ratio of diameter to wall thickness is greater).
2. Tube length – the longer the tube, the greater the resistance. It is important that tubes of the correct length for the patient are selected to reduce resistance. Most commercially available tubes for humans are supplied with excessive length. The tube should be cut to the desired length (see later). Specific veterinary tubes may not be so easily modified.
3. Connector – the internal diameter of the connector will affect resistance as well as its configuration e.g. t-connector, swivel connector.

In addition to these 3 factors, anything within the tube will also increase resistance e.g. secretions, endoscope, suction devices etc.

Apparatus Dead Space - As the tube is always smaller than the airway, dead space arising from the tube is usually less. In small patients where the tube may be excessively long, dead space may be increased. Connectors, filters and other devices (e.g. capnograph) between the tube and the breathing system may also increase dead space.

Rubber - Although this material has fallen out of favour in human anaesthesia, red rubber tubes are still manufactured for veterinary patients and remain in general use. The advantage of rubber tubes is that they can be re-used and re-sterilised multiple times. There are numerous disadvantages:

- They become hardened over time
- They are prone to kinking
- They are not transparent (so foreign material may not be obvious inside)
- The wall of the tubes is generally quite thick (which will ↓ internal diameter → increased resistance)
- They do not soften at body temperature and therefore do not conform to anatomy well

Polyvinyl chloride (PVC)

- Very common in disposable tubes used in humans.
- Highly suitable for use in veterinary patients
- Inexpensive
- Resist kinking but soften with body temperature
- Smooth surface which prevents the build up of secretions
- Transparent

Some different tube types

1. Murphy tubes – or Murphy-type tubes are tubes with a hole in the wall in the distal end opposite to the bevel. The function of the eye is facilitate passage of gas should the bevel become occluded, e.g. against the tracheal wall.
2. Magill tubes – or Magill-type tubes are those tubes without a Murphy eye. The absence of the eye means that the cuff can be positioned closer to the bevel and may reduce the risk of inadvertent endobronchial intubation.

3. Cole tubes – not frequently seen in veterinary medicine. Are uncuffed and have a patient end that has a smaller diameter than the rest of the shaft. They are used for neonatal resuscitation in human medicine because resistance is lower. In veterinary medicine, Cole pattern tubes have been used in small exotic patients.
4. Reinforced (spiral embedded or armoured) tubes – These are available in a variety of diameters but cannot be cut to length since the connector is moulded to the tube at the machine end. The tubes have a metal or nylon spiral embedded into the wall to resist kinking or compression during anesthesia and are useful for patients who must be positioned with the neck in flexion (e.g. CSF tap; cervical dorsal laminectomy). Care must be taken that the patient does not bite the tube since this may cause a permanent occlusion resulting in airway obstruction.

Tube size

1. Diameter. Manufacturers must state the internal diameter (ID) in millimetres of the tube on the body of the tube. For cuffed tubes, this will be printed somewhere between the cuff and the point where the inflation balloon exits the body of the tube. For uncuffed tubes, the figure is printed towards the patient end. French gauge may still be used on some tubes and you can determine the size of the tube by dividing it by 3 to give the outer diameter (OD) in millimetres e.g., a tube with a diameter of 30 Fr will have an OD of 10mm. Endotracheal tubes less than 6mm ID must also have the OD stated on the tube. Some manufacturers print the size on the pilot balloon so that the tube size can be identified once it is in the trachea.
2. Length. There is a minimum length of tube that increases as ID increases. However, all manufacturers produce tubes longer than the minimum to enable the anaesthetist to cut the tube to size.

Tube markings

From patient end to machine end
1. Radio-opaque marker (may be down the entire length of the tube)
2. The word oral or nasal (ET tubes are often passed nasally in humans)
3. ID in mm
4. OD in mm if present
5. Manufacturer name
6. Single use only if present
7. Graduations show the distance from the patient end in centimetres.

Cuff systems

The cuff is an inflatable sleeve near the patient end of the tube. A cuff system also includes the inflation tube, inflation valve and a pilot balloon. The cuff has 3 main functions:
1. To prevent oral or regurgitated fluid passing from the oesophagus into the lung
2. To prevent gas passing around the tube, especially during intermittent positive pressure ventilation – this also ensures minimal environmental contamination with volatile anaesthetics.
3. To centre the tube within the trachea

The cuff should:
1. be tear resistant
2. be soft and pliable
3. be tested to the same standards as the tube e.g. non-irritant
4. not encroach on the Murphy eye if present
5. not herniate into the bevel opening when inflated
6. inflate symmetrically

The cuff may be:

1. High pressure; low volume – these cuffs require a high pressure to overcome cuff compliance and form a seal in the trachea over a small area. They are present on red rubber tubes. The advantage of this type of cuff is that it offers better visibility during placement and better protection against aspiration. However, the pressure exerted against the tracheal mucosa may be higher than perfusion pressure and the tracheal mucosa may become ischaemic. Use the largest size of tube possible to minimise how much air is needed to inflate the cuff. These tubes should not be used for anaesthetics of long duration.
2. Low pressure; high volume – these cuffs are present on most PVC tubes and are large and compliant. The volume of air required to form a seal is large and the cuff forms a tracheal seal over a large area. Consequently the risk of tracheal mucosal ischaemia is reduced since the pressure inside the cuff is lower and the pressure is spread over a greater surface area. However, because the cuff is large, visualisation is reduced during placement. The cuff also becomes wrinkled if not fully inflated and this can allow regurgitated ingesta to pass from the oesophagus and into the lung. The cuff should be lubricated with a sterile water based lubricant to fill the wrinkles and reduce the incidence of aspiration. If IPPV is performed, the cuff will distort during inspiration (positive pressure phase) and the pressure inside the cuff will increase. The incidence of sore throat in humans may be greater with this type of cuff.

Cuff pressure should not be greater than 25 – 34 cm H2 O at the end of expiration in adult patients with normal blood pressure. Techniques whereby the cuff is inflated whilst squeezing the reservoir bag until no leak is heard have been found to be unsatisfactory. This is in part due to the fact that intracuff pressure will change over time, with temperature and with position of the patient. However, the measurement of cuff pressure with a manometer is uncommon in veterinary practice, and many anaesthetists use the minimal leak technique. Long term intubation e.g. in patients being ventilated in an intensive care setting, should have the cuff deflated periodically and tube repositioned or replaced.

Nitrous oxide and cuff pressure – the intracuff pressure in a cuff inflated with air and placed in a patient breathing a nitrous mixture will increase over time. This occurs because nitrous oxide diffuses into the cuff. Once the nitrous is turned off then the cuff pressure rapidly decreases. The amount of pressure change is dependant on the cuff wall permeability, the temperature and the duration of nitrous anaesthesia.

The inflation tube – take care not to tie this in place with the tube as deflation of the cuff may become impossible at the time of extubation. Many modern tubes now have a valve that must be depressed by the syringe tip to allow inflation. Once the syringe tip is removed, gas cannot pass back out of the cuff. Red rubber tubes have inflation tubes that must be capped after filling – these often fail during the procedure and can be made more secure by folding the inflation tube over and fixing it in this position by placing a needle cap over the folded portion.

Tube connector – ensure you choose the right size of connector for the right tube. A common mistake in large red rubber tubes is to insert the connector the wrong way around. In these circumstances, connection to the breathing system will be impossible because the connector is back to front. The use of superglue to fix metal connectors to tubes is a useful technique, although this may affect the lifespan of the tube. Connectors are available in a variety of forms: they may be straight or have a 90° bend. Some may swivel. In addition there may be suctioning ports, sampling ports or administration ports incorporated into the connector.

Tube Selection

1. Does the patient need to be intubated? Consider that placement of an endotracheal tube in the trachea will always cause some morbidity, whether or not this is detectable in the patient postoperatively. Intubation may even increase mortality in some cases (e.g. cats)
2. Cuffed or uncuffed? Traditionally it has been advocated that cats should be intubated with an uncuffed tube. This has the advantage that tracheal mucosal damage is less likely in this species. However, this may lead to problems in performing IPPV in that leaks may be present, and result in inaccuracies in capnography. If IPPV is anticipated (e.g. a cat requiring thoracotomy, diaphragmatic rupture repair) then a cuffed tube used carefully is a good option to facilitate ventilation. Studies in children have not detected a higher incidence of complications when using cuffed endotracheal tubes. The disadvantages associated with cuffed tubes are highlighted above, but in addition a smaller tube must be chosen which will increase the work of breathing. Cuffed tubes may cause problems on extubation if the cuff becomes caught in the larynx. For dogs, always choose a cuffed tube.
3. Size – it is important to choose a size of tube appropriate for the patient. Remember that the intubated trachea is really a tube within a tube. Therefore to reduce the affect of airway resistance and work of breathing, choose a tube that fits comfortably in the trachea and does not require overinflation of the cuff to produce a gas tight seal. If you find you are filling the cuff with excessive amounts of air, then the tube you have chosen is likely to be too small. Conversely, a tube that is very tight is likely to result in post-anaesthetic sore throat (will you recognise this?) and associated morbidity. There are studies which have used weight, width of the nasal septum and palpation of the trachea to judge the size of tube, but they are not failsafe and experience is a better tool. Always have a good selection of leak tested tubes ready as tracheal size is sometimes impossible to predict. If an uncuffed tube is used in a cat, then a suitable size for most adults is ID 5.0 – 6.0 mm. Some large cats may take an ID 7.0mm.
4. Length – presize the tube by measuring the length from the nares to the thoracic inlet or point of the shoulder. Tube lengths beyond this may be inadvertently inserted into a mainstem bronchus. Cut the tube to the correct length and reinsert the connector. If the tube is not trimmable to length then apparatus deadspace should be monitored using a capnograph by assessing inspired CO_2 levels.

Pre-Placement Checks

The majority of veterinary practices do not sterilise tubes between patients. However, the tubes should be cleaned with e.g. chlorhexidine and thoroughly rinsed and dried prior to re-use. Note that chlorhexidine may act as a tracheal irritant and tubes must be rinsed correctly. Check patency of the lumen by looking through the tube from one end to the other. This is made easier if the tube is made of a transparent material. Plugs of mucus can be difficult to dislodge and may be missed during the cleaning process. It is useful to have a selection of bottle brushes to ensure patency during the cleaning process. Inflate the cuff and leave inflated for 5 minutes to ensure that the cuff system is not leaking. Remember to deflate the cuff prior to placement Check that the connector is secured to the machine end of the tube, and in the case of metal connectors for large tubes, ensure that it is placed in the tube correctly. Lubricate the patient end of the tube immediately prior to intubation with a water based lubricant gel

Securing the Tube

Securement is essential following intubation to prevent inadvertent extubation, or advancement into a bronchus. Gauze bandage is suitable for securing tubes. The bandage is wrapped around the tube where it meets the connector and pulled tight. If the bandage is wrapped further down the tube then the tube may be distorted as the bandage is pulled tight. Once the tube is secured, then bandage ends are then passed around the maxilla or mandible using the canine teeth to secure it in place.

Alternatively the bandage can passed around the back of the animals head and tied behind the ears. Placement on the animals head is sometimes dictated by the surgery.

Confirmation of Tube Placement

1. Intubation of the trachea should ideally be performed under direct laryngoscopy. This goes a long way to confirm correct placement. Patients that are lightly anaesthetised may also cough on correct placement of the tube. Once in place, the tube placement can be checked by:

- Connection to a capnograph – the presence of carbon dioxide confirms placement of the tube without doubt. However, absence of CO2 does not necessarily indicate oesophageal placement. Cardiac arrest, pulmonary embolism and tube obstructions may all prevent CO2 being detected.
- Movement of the bag – can be unreliable as the oesophagus may have a tidal volume in association with breathing
- Palpation of the bag – again unreliable but may give an indication of oesophageal intubation
- Chest wall movement – unreliable. If the anaesthetist squeezes the bag, the chest wall may rise even if oesophageal intubation has been performed.
- Abdominal distension – may indicate oesophageal placement but occurs over time and oesophageal intubation require early detection
- Moisture inside the tube (transparent tubes) – unreliable, but if no moisture is seen then the tube is likely to be in the oesophagus.
- Oxygenation – hypoxaemia is a late indicator and cyanosis may not be detected.
- Palpation of the throat – can be useful. Often the tube can be felt to run over the tracheal rings during placement. The tube can be manipulated once placed and the neck palpated for oesophageal intubation. If the tube is in the oesophagus, 2 tubes will be felt in the neck: the ET tube in the oesophagus and the rigid trachea (the oesophagus will not normally be palpable unless there is a tube inside it).
- Air in cuff required to create a seal – excessive amounts of air will be needed if oesophageal intubation has been performed.

Complications

1. Trauma – usually associated with poor technique, rough intubations or repeated attempts at intubation. Injuries can include haematoma formation, lacerations, contusions, cartilage damage, tracheal avulsion (esp. cats), tracheal rupture and puncture wounds. Never use more than gentle pressure during intubation, always lubricate the tube and if using a stylet, never allow the stylet to protrude beyond the end of the tube. Cats appear to be more prone to problems compared with dogs as they are prone to laryngospasm and have delicate laryngeal structures. The larynx of cats should be sprayed with local anaesthetic prior to intubation and adequate time elapsed prior to placement of the tube. The intubation technique in all species should be careful, but probably more so in cats. The trachea of cats is also more prone to cuff-related injuries.

2. Brachycephalics – can be challenging to intubate. These breeds can have much redundant tissue in the oropharynx making visualisation of the larynx difficult. The trachea may also be hypoplastic so a good selection of tubes should be ready. A laryngoscope is very useful. Vagal stimulation may also occur during intubation and heart rate should be monitored or an anticholinergic included at the time of premedication.

3. Oesophageal intubation – can occur even with the most experienced anaesthetist. Recognition is essential (see above) to ensure the patient receives adequate oxygenation and anaesthetic gas.

4. Endobronchial intubation – can occur relatively easily if the endotracheal tube is too long. Recognition can be difficult; changes in the capnogram may occur but is not reliable. Endobronchial intubation is easily recognised on a lateral thoracic radiograph. The nonintubated lung becomes atelectic and patients may experience reduced oxygenation. In healthy patients, one lung is able to compensate for the work of both if the inspired oxygen concentration is 100%. If IPPV is performed, the intubated lung may suffer barotrauma due to overinflation. Endobronchial intubation may occur subsequent to a normal placement of the tube, especially if the patient's position is changed. The problem is easily avoided by pre-measuring the length of tube (see above) and cutting the tube to the correct size.
5. Inhalation of foreign bodies – ensure that the tube patency is checked prior to use. Even so, dislodgement of teeth has occurred during intubation resulting in inhalation of the tooth.
6. Leaks are common – thoroughly check the tube prior to use, inflate the cuff to the appropriate volume to ensure a leak-free fit inside the trachea, and check this at regular intervals, especially during long procedures and after patient repositioning. If the leak cannot be resolved, it is prudent to check that the tube is actually still within the trachea. Leaks can normally be identified by loss of the capnogram alveolar plateau. If the leak continues then consider replacing the tube as the cuff may have become damaged during the intubation process.
7. Tube obstruction – recognition is imperative to patient safety. The patient may show evidence of increased respiratory effort, paradoxical chest movement or if mechanical ventilation is being performed, the unit may alarm. Increased resistance to gas flow can be manually 'felt' by squeezing the reservoir bag. Obstruction may occur because of:

- Foreign material – e.g. a plug of mucus, especially problematic in small ID tubes
- Kinking – usually encountered if the head of the patient is hyperflexed e.g. during CSF aspiration from the cisterna magna. However, instruments placed in the patient's mouth e.g. during dentistry, may also kink the tube. Tubes vary in their proneness to kinking – red rubber tubes kink more easily than PVC or silicone, and smaller tubes are more likely to kink. Consider replacing the tube with an armoured one.
- Cuff problems – the cuff may inflate asymmetrically and push the bevel of the tube against the tracheal wall; it may herniate over the end of the bevel; over-inflation of the cuff may compress the lumen of the tube.
- External compression
- Patient re-positioning
- Obstruction of equipment between the tube and the breathing system

In the first instance check the position of the tube and re-position the patient if kinking may be the cause. Deflate the cuff to see if this resolves the problem. If the tube is transparent, the visible portion of it should be checked for foreign material. A wide-bore urinary catheter can also be passed down the tube to check for obstruction. Eliminate other causes of increased resistance or reduced lung/chest wall compliance e.g. bronchospasm. If the problem continues then consider removal of the offending tube.
8. Difficult extubation – this may occur if the cuff fails to deflate. The pilot balloon may give no indication that there is a problem as the inflation tube may be sealed further down. If this is suspected then a needle and syringe may be used to puncture the inflation tube further down the tracheal tube and aspiration of air attempted. If this doesn't work, then the tube should be withdrawn until the cuff is visible within the larynx and carefully punctured using a sharp object. The animal should remain anaesthetised until this is performed. The tube may also be caught in suture if surgery has involved the trachea or larynx e.g. laryngeal tieback procedures.
9. Post-operative sore throat – very difficult to recognise in veterinary patients although very common in humans postoperatively. Reduce the incidence by careful intubation technique and choosing tubes of a suitable size.

10. Laryngeal oedema – again, probably occurs more often than realised. Animals may evidence stridorous or stertorous breathing. In its most severe form, complete airway obstruction will occur. Avoid by careful intubation and extubation technique, ensure adequate plane of anaesthesia prior to intubation, clean tubes with no residual disinfectant and head movement once intubated should be kept to a minimum.
11. Tracheal stenosis – a rare postoperative problem but may be associated with traumatic intubation or tracheal mucosal damage.

Extubation

Animals should be extubated once active swallowing has returned. Cats may be extubated earlier to prevent laryngospasm on extubation, and brachycephalics extubated later to ensure that they are conscious enough to maintain their airway. However, late extubation may result in the tube being chewed so it is essential to be vigilant as the sheared portion may be inhaled with disastrous consequences. The oral cavity should be examined prior to extubation and suctioning performed if deemed necessary. The cuff should be completely deflated just prior to extubation. The tube may be removed with the cuff partially inflated if it is suspected that there
may be fluid or ingesta accumulation above the cuff. Note though that this practice may result in injury. An alternative technique is to suction the trachea above the cuff prior to extubation.

Anaesthetic circuits: safe and effective gas administration

Selection of an appropriate breathing system for the patient and the procedure plays an important role in patient safety during anaesthesia. In order to select an appropriate system, it is important to understand how each one works, its advantages, disadvantages and limitations. This is also important when performing safety checks. An understanding of some basic physiology and concepts such as dead space and resistance is essential, as is an understanding of how to calculate fresh gas flow for both rebreathing and non-rebreathing systems.

Tidal volume and minute volume

The tidal volume is the volume of air the patient inspires in a normal breath. The minute volume is the volume of air the patient inspires in one minute. This is equal to the minute volume multiplied by the respiratory rate.
Minute volume = respiratory rate x tidal volume
Tidal volume is roughly 10 to 20 mL/kg body weight. Minute volume is therefore about 15 x body weight x respiratory rate. Minute volume is used to calculate fresh gas flows for non-rebreathing systems.

Oxygen consumption

Oxygen consumption is the volume of oxygen used per minute by the body for metabolism. It is roughly 10 mL/kg/minute for dogs and cats. Oxygen consumption is used to calculate the minimum fresh gas flow requirement for rebreathing systems such as the circle.

Resistance

Resistance in anaesthetic breathing systems means resistance to gas flow. There are two types of flow when considering gas flow through a tube. In laminar flow, the gas flows smoothly in layers along the tube. When gas flow is turbulent, there are lots of whirlpools in the flow. Resistance is higher with turbulent flow than with laminar flow.

<u>Factors increasing resistance</u>: When flow is laminar, resistance increases with the length of the tube and the viscosity of the gas. Turbulent flow creates higher resistance and is promoted by corrugated tubing, bends in the tubing, soda lime and valves.

Factors decreasing resistance: Resistance decreases with a larger radius of the tube. Of these factors the radius of the tube is the most important thing. If the radius is halved the resistance is increased 16 fold. Resistance in breathing system can be substantially reduced by using smooth inner bore tubing.

Why is resistance important? If you try to breathe through a very narrow tube (i.e. a tube with high resistance) you have to use more effort, so you increase the work of breathing. Under anaesthesia this does not happen due to muscle relaxation, and instead the patient is prevented from ventilating properly (hypoventilation), resulting in increased arterial and end expired carbon dioxide levels. Larger and fitter patients have stronger respiratory muscles and can cope better with resistance in the breathing system.

Resistance in breathing systems is caused by narrow hoses, long hoses, corrugations, bends, kinks, valves and soda lime. Controlled ventilation overcomes breathing system resistance, so that during controlled ventilation high resistance systems can be used for smaller patients.

Dead space

Dead space is composed of three parts: anatomical, alveolar and mechanical (or apparatus). **Anatomical** dead space is the part of the respiratory tract where no gas exchange occurs. It extends from the incisors to the conducting bronchioles. **Alveolar** dead space refers to gas in a small number of alveoli which are ventilated but not perfused. Since no blood is delivered to these alveoli no gas exchange occurs there. Anatomical dead space and alveolar dead space together comprise **physiological dead space**. **Mechanical dead space** is the part of the endotracheal tube (measured from the incisors) and breathing system where inspired and expired gases mix. Dead space gas is the last part of the breath to be breathed in and the first part to be breathed out.

Dead space is important because it reduces the proportion of each breath that takes part in gas exchange. Each breath the patient takes in (the tidal volume) consists of gas which reaches the alveoli and participates in gas exchange, plus gas which occupies the dead space (mechanical and physiological):

Tidal volume = dead space + alveolar volume

Therefore: Alveolar volume = tidal volume – dead space

We said earlier that:

Minute volume = tidal volume x respiratory rate *Therefore:* Alveolar minute volume = (tidal volume - dead space) x resp rate.

Obviously the more gas that reaches the alveoli, the better the patient's gas exchange and the better the patient will ventilate and oxygenate. Decreased alveolar minute ventilation leads to CO_2 retention and possibly hypoxia. Keeping dead space to a minimum increases the proportion of useful gas per breath by maximising alveolar ventilation. The smaller the tidal volume the greater the significance of the mechanical dead space. A large volume of mechanical dead space compared to the patient's tidal volume means CO_2 is retained and the end of each breath which the patient then rebreathes. This results in increased inspired CO_2 ($FiCO_2$), which should be zero, resulting in higher arterial and end expired CO_2 levels.

We cannot easily influence physiological dead space. But we can reduce mechanical dead space by ensuring that the ETT does not extend beyond the incisors and by selecting a breathing system with a small dead space such as a T piece.

Adjustable pressure limiting valves are also known as pop off valves, APL valves or expiratory valves. These valves need to be closed for leak testing and sometimes to enable positive pressure ventilation. But they must be immediately opened otherwise pressure quickly builds up in the breathing system and this can damage the patient's lungs (barotrauma). Valves on systems made by Intersurgical have a safety device so that once a certain pressure is reached they open and the patient's lungs are protected (pressure relief valve).

Types of breathing system

There are two types of breathing systems: rebreathing and non-rebreathing systems. An understanding of how these systems work is essential for the safe and economical use of the systems.

Rebreathing systems:

With rebreathing systems, expired breath is recycled and rebreathed. The CO2 is absorbed by soda lime. Fresh gas flows are calculated based on O2 consumption, which is approximately 10 mL/kg/minute for small animals. So in theory a 10 kg dog could have a fresh gas flow of 100 mL/minute, but in reality technical issues make such low flows impractical.

Advantages The main advantage of these systems is the low fresh gas flow resulting in the use of less anaesthetic agent, making the system very economical for large animals. In addition, because the gas is recycled, expired moisture and heat are retained and there is less pollution. They can be used for spontaneous and controlled ventilation.

Disadvantages These systems have high resistance which smaller patients cannot cope with when spontaneously breathing. Regular replacement of the soda lime is required. The reaction between the soda lime and the inhalant agent is exothermic, and this, combined with the retention of heat can result in the patient becoming hyperthermic. The low fresh gas flow means that there is a slow response to changes in vaporiser settings. Because the gas is recycled and rebreathed, the concentration of anaesthetic agent which the patient breathes in is not the same as the vaporiser setting and is unknown unless there is agent monitoring.
When using nitrous oxide, it is possible to supply the patient with a hypoxic mixture of gases when using low flows. This is because the oxygen in the gas mixture is actually used up by the patient's body for metabolism, but the nitrous oxide is not used up but is recirculated. You can use nitrous oxide with a rebreathing system with certain safety measures in place. If you are using pulse oximetry or have an oxygen analyser on the anaesthetic machine, you can ensure that the patient is saturating adequately and that you are providing enough oxygen. Or, you can use higher flow rates: 30 mL/kg/minute O2 and 60 mL/kg/minute N2O.
Denitrogenation: room air is 21% oxygen, 79% nitrogen, and our bodies are saturated with nitrogen in equilibrium with the atmosphere. When the animal is connected to a rebreathing system with 100% oxygen at the start of an anaesthetic, nitrogen flows down its concentration gradient to leave the patient and enter the breathing system. Oxygen flows in the other direction. This means that initially there may be high concentrations of nitrogen and low concentrations of oxygen in the system. Nitrogen must be purged from the system either by having relatively high fresh gas flows initially or by regularly dumping the bag contents.
Rebreathing systems are more expensive to buy and more difficult to clean than non-rebreathing systems.

Closed or semi-closed?

These terms refer to the way the rebreathing system is used, not the structure of the system. A rebreathing system can be run as closed or semi- closed. If it is closed, the fresh gas inflow is equal to the O2 consumption and the APL valve is kept closed.

It is quite difficult to run a system this way. For gas flows less than about 250 mL/minute vaporisers become inaccurate and side stream capnographs remove up to 200 mL/minute for sampling. Also keeping the APL valve closed is potentially dangerous. Most people use the systems as semi-closed, where the fresh gas flow exceeds the patient's requirement and the APL valve is kept partially or fully open depending on the fresh gas flow. Because of technical difficulties as above, normally a minimum flow rate of 500 mL/minute on patients up to 50 kg in body weight is suggested. The flow rate should be higher than this for the first 10 to 15 minutes to ensure adequate denitrogenation and also to increase the volatile agent concentration more rapidly.

The circle system

This consists of a circular system of hoses with 2 unidirectional valves, a patient connection, a fresh gas inlet, an APL valve, a soda lime canister and a reservoir bag. The bag should be 3 to 6 times the volume of the patient's tidal volume, the soda lime canister should be at least twice the tidal volume. The unidirectional valves ensure that gas flows in one direction only so that the patient does not rebreathe CO2-rich gas. Because these systems have soda lime, two unidirectional valves and an adjustable pressure limiting (APL) or pop off valve, they have high resistance which smaller patients cannot cope with.

The to and fro system

Gas flows from the patient, through an absorbent canister to a reservoir bag and back again (to and fro). The canister may be vertical or horizontal. It has fairly high resistance due to the soda lime so should only be used in animals greater than 15kg. It is a low volume system, resulting in rapid denitrogenation. They are cheap, simple, portable and easy to sterilise. The APL valve and fresh gas flow inlet are near the patient's head which can be inconvenient. They are heavy with a lot of drag. As the anaesthetic progresses, the soda lime nearest the patient becomes exhausted resulting in increased dead space as the soda lime is used up. It is possible for the exhaled gas to channel over or through the soda lime so that is does not come into contact with it and the CO2 is not absorbed. Because the soda lime is so near the patient the patient can become hyperthermic. If a suitable filter is not present, the patient can inhale soda lime particles resulting in bronchiolitis.

Malfunction	Problem	Prevention/ solution
Exhausted soda lime	Inspired and expired gases mix, massive increase in dead space	Regularly check & replace soda lime. Capnography will detect this problem
Faulty unidirectional valves	Inspired and expired gases mix, massive increase in dead space	Check proper valve function regularly. Capnography will detect this problem
APL valve closed	Pressure build-up in system, barotrauma to patient's lungs	Always check valve is open before connecting patient
High resistance	Patient hypoventilates if spontaneously breathing	Only use on patients of about 10 kg more
Leaks	Patient does not receive desired concentration of anaesthetic, pollution	Leak test the system before use
Nitrogen build up	Hypoxic mixture of gases	Denitrogenate the system, Monitor SpO_2, inspired oxygen
Using nitrous oxide	Hypoxic mixture of gases	Monitor SpO_2, inspired oxygen concentration or use high flows
Mechanical dead space too large for patient	Rebreathing of CO_2	Cut ETT, choose alternative system. Capnography will detect this problem

Potentially dangerous problems with the circle system

Non-rebreathing systems

With non-rebreathing systems a continual high fresh gas flow from the anaesthetic machine flushes away expired gas containing CO2 so that only fresh gas is inhaled. No soda lime is required. Gas flows are calculated based on the minute volume and the circuit factor of the individual breathing system. The lack of valves and soda lime means that they have low resistance. They are cheap to buy and simple to use with no need to replace soda lime. There is a quick response to changes in anaesthetic concentration due to the high fresh gas flows used. There is no need for denitrogenation and it is easy to use nitrous oxide. But the high fresh gas flow requirements and therefore use of more anaesthetic agent means they are much less economical than rebreathing systems and they are too inefficient for larger animals. Expired heat and moisture are lost resulting in cooling of the patient. The different systems have different properties and they may perform differently if using controlled ventilation.

The Mapleson classification system

The Mapleson system classifies non-rebreathing systems in order of fresh gas flow efficiency. Mapleson A is the most efficient (lowest fresh gas flow requirement), (Magill, Lack); Mapleson B and C are rarely used clinically; Mapleson D (Bain), E (Ayres T piece) and F (Jackson Rees modified T piece) are the least efficient.

Mapleson A systems **(Magill, Lack)** are the most efficient non-rebreathing systems but are still far less efficient than a rebreathing system. The fresh gas flow requirement is equal to the minute volume, therefore the circuit factor is 1.

Magill: Consists of a single hose with the expiratory valve at the patient end and reservoir bag away from the patient near the anaesthetic machine. The reservoir bag volume should be 3 to 6 times the tidal volume and the expiratory hose volume must exceed tidal volume. The patient breathes oxygen from the hose and bag. When the patient breathes out, the breath returns down the hose towards the bag following the path of least resistance. When the pressure in the bag reaches the pressure required to open the expiratory valve, gas is expelled through the valve into the scavenging. In this way the first part of the expired breath (dead space gas not containing CO2) is retained in the system and rebreathed, but the last part of the breath (the alveolar gas containing CO2) is expelled into the scavenging.

The Lack functions in the same way as the Magill except that the expiratory valve has been moved away from the patient for convenience, resulting in two limbs. These can be arranged in parallel or coaxially. The Lack and Magill can be used in patients of 5 -10 kg or above, but they have quite a large dead space. They should not be used for controlled ventilation unless the fresh gas flow is significantly increased. The mini lack is a low resistance system designed for cats and small dogs. However it has a relatively large dead space and there is no pressure relief system on the APL.

The Mapleson D and E systems work in a similar way and can be considered together. The Mapleson D is the **Bain**. This consists of an inner tube which delivers the fresh gas flow to the patient and an outer limb which takes the gas away from the patient to the bag and the APL valve. There is a continual flow of gas from the fresh gas outlet along the inner tube and back via the outer limb to the bag and the APL valve. The patient inspires gas mainly from the outer 'expiratory' limb, which should exceed the patient's tidal volume. The expired gas also enters the expiratory limb. During the expiratory pause the CO2 rich alveolar gas is flushed away by the fresh gas flow. Therefore if the patient's respiratory rate increases, the expiratory pause shortens and the CO2 may not be fully flushed away. The Bain has a circuit factor of 2.5. The Bain has relatively high resistance and can be used on patients of about 10 kg or above.

The Mapleson E is the **Ayres T piece**. This consisted of two hoses arranged as a T configuration with no bag or valves. Thus it had extremely low resistance and was used for paediatric human patients. But since it had no bag, controlled ventilation was difficult. Scavenging was also difficult. Therefore the system was modified by Jackson Rees who added an open ended bag, enabling controlled ventilation.But scavenging is still difficult with this system and can result in the bag becoming twisted and closed and over-inflation of the patient's lungs.
The system most widely used now is a T-piece with an low resistance APL valve with a safety pressure limit. Confusingly, because it has an APL valve this is actually a Mapleson D with a T-piece configuration, but this is academic as the two sytems work in the same way anyway. The T-piece has a circuit factor of 2.5. It has low resistance and is suitable for very small patients, but is uneconomical for patients above about 8 kg.

The Humphrey ADE is a versatile system. Originally it comprised a Mapleson A, D and E system in one, but now it consists of a Mapleson A (parallel Lack) and a Mapleson E (T-piece), which can be selected by moving a lever. It is designed to use the Mapleson A (lever up) for spontaneous ventilation and the Mapleson E (lever down) for controlled ventilation using a mechanical ventilator. A soda lime canister can also be incorporated, in which case the system becomes a circle system.

Safety considerations for non-rebreathing systems. As with any breathing system, the APL valve should be open when before the system is attached to the patient otherwise there is a risk of barotrauma to the patient's lungs. With coaxial Therefore the system was modified by Jackson Rees who added an open ended bag, enabling controlled ventilation. But scavenging is still difficult with this system and can result in the bag becoming twisted and closed.systems such as the Bain, the inner tube may become damaged or disconnected. For small patients the volume of dead space of the equipment becomes important, and these systems vary in the amount of dead space they contain. Remember that the fresh gas flow requirement is high in order to flush away the CO_2, and if the flow rate is too low the patient will rebreathe CO_2. The fresh gas flow requirement is the minute volume of the patent multiplied by the circuit factor, and minute volume = tidal volume x respiratory rate. If the patient breathes more quickly under anaesthesia, e.g. during surgical stimulation, the minute volume increases and the fresh gas flow should be increased.

Malfunction	Problem	Prevention/solution
APL valve closed (especially mini Lack)	Pressure build-up in system, barotrauma to patient's lungs	Always check valve is open before connecting patient
Mechanical dead space too large for patient	Rebreathing of CO_2	Cut ETT, choose alternative system. Capnography would detect this problem
Bain: disconnection of inner tube	Inspired and expired gases mix, massive increase in dead space	Check inner tube before the anaesthetic
Fresh gas flow too low	Rebreathing of CO_2	Calculate fresh gas flow based on the patient's minute volume. Capnography would detect this problem
Twisted bag (Jackson Rees modified T piece)	Pressure build-up in system, barotrauma to patient's lungs	Ensure scavenging cannot twist, or use alternative system
Leaks	Patient does not receive desired concentration of anaesthetic, pollution	Leak test the system before use

Factors influencing breathing system selection

These include resistance and dead space, drag, how bulky the system is near the patient (especially for procedures near the patient's head), ease of cleaning and mode of ventilation. For small patients, the mechanical dead space should be minimised while for large patients mechanical dead space is not usually significant. Resistance of the system is important for small and weak patients and again not so important for larger animals. Non-rebreathing systems with their low resistance are suitable for smaller patients but are uneconomical for larger animals. Rebreathing systems are very economical especially is used as a semi-closed system at low flow rates (approximately 10 mL/kg/minute, with a minimum fresh gas flow of 500mL/minute for any patient). If controlled ventilation is used this overcomes resistance so that rebreathing systems can be used or smaller patients.