Special Anesthetic Considerations in the Orthopaedic Patient

A. M. Klide

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In this chapter I will discuss the special anesthetic considerations in the orthopaedic patient by dividing the material into four major sections: elective surgery, multiple-trauma patients, spinal injury, and head injury. Some of the problems and considerations are certainly pertinent to two or more of these categories but will be presented in the section in which they are most significant. Many problems can be solved in various ways, all of which will be listed, but the major emphasis will be on the methods I use and my reasons for doing so. Table 8-1 presents a comprehensive listing of pharmacologic agents used in anesthetic procedures.

ELECTIVE SURGERY
PREANESTHETIC DRUGS
Preanesthetic drugs can be grouped into four major categories: anticholinergics, analgesics, sedatives/tranquilizers, and
disease-related drugs such as digitalis preparations, electrolytes, insulin, and antibiotics.

**ANTICHOLINERGICS**

Anticholinergics are given primarily to reduce secretions, prevent reflex vagal bradycardia during intubation, and prevent reflex vagal bradycardia as a result of visceral manipulation.

The need to reduce secretions has diminished to some degree with the changes from potent sialogogues like ether to modern inhalant anesthetics such as halothane. Antisialogic activity remains important in cats and in oral procedures under light anesthesia (with or without neuromuscular blocking agents). Cats are more prone than dogs to develop laryngospasm, which may be precipitated by secretions on and around the glottis; therefore, it is important to keep cats reasonably dry during induction. Oral procedures done with light anesthesia produce copious secretions that interfere with the surgical procedure.

Although intubation usually produces tachycardia and hypertension, occasionally bradycardia and hypotension may result. Anticholinergic premedication prevents the latter.

Reflex vagal bradycardia may occur from traction on viscera, another response that can be blocked by anti-cholinergic drugs; however, the duration of effect of the drug given in the preanesthetic period may be long enough, and additional intravenous doses may be required during the surgical procedure.

The three anticholinergic drugs used most commonly are atropine, scopolamine hydrobromide, and glycopyrrolate; atropine is used the most. A wide range of dosages has been suggested for atropine for preanesthetic administration: 0.044 mg to 0.11 mg/kg SQ or IM.(14,67) We routinely use 0.022 mg/kg IM. At higher dosages some animals, especially cats, get very dry mouths, and they start clawing at their mouths.

Scopolamine is sometimes used; its dosage is 0.011 mg to 0.017 mg/kg IM. Glycopyrrolate is sometimes used and in certain circumstances has some advantages over the previous two. The suggested dose is 0.011 mg/kg IM or SQ. When administering any of these drugs intravenously, I usually use half of the intramuscular dose (IV 0.011 mg/kg atropine, 0.005 mg/kg glycopyrrolate).

One of the unexpected effects of atropine sulfate, atropine methyl nitrate, and scopolamine is that these drugs may, especially in low dosages, produce bradycardia instead of tachycardia. This is due to a peripheral parasympathomimetic effect, and in the case of atropine sulfate, at least, a central parasympathomimetic effect.

Another cardiac effect sometimes seen with the intravenous administration of atropine is a transient atrioventricular block, probably due to a more rapid onset of effect at the sinoatrial node than at the atrioventricular node.

Atropine sulfate and scopolamine cross the blood-brain barrier and produce some central effects; scopolamine produces greater central effects than atropine sulfate. One of these is a prolongation of barbiturate-produced sleeping time,(37) which does not seem to occur with glycopyrrolate.

**NARCOTIC ANALGESICS**

Narcotic analgesics are useful preanesthetic drugs. Their particular advantage in orthopaedics is that they provide analgesia, which is especially important in the preanesthetic period because the animal is going to be moved. Any narcotic analgesic may be used; I most commonly use oxymorphone hydrochloride, 44ug to 88ug/kg IM; or morphine, 0.5mg to 2.2mg/kg IM.

Narcotics, especially morphine, may produce "morphomania" (dysphoria, excitement) in cats. The likelihood of this happening varies with the dosage and is less at low dosages. The incidence is also less with meperidine and oxymorphone, but the phenomenon does occur. The excitement can be prevented with concurrent administration of phenothiazine tranquilizers such as promazine or acetylpromazine.

**SEDATIVES/TRANQUILIZERS**

Sedatives/tranquilizers are commonly recommended for preanesthetic administration. I tend to avoid phenothiazine tranquilizers because they cause a fall in circulating red blood cells and white blood cells and may produce hypotension. (31,39,51,68) I also avoid xylazine in animals that are going to be given an inhalant anesthetic, especially halothane. Xylazine increases the already increased sensitivity of the myocardium to the ventricular arrhythmogenic property of epinephrine that is produced by halothane.(47) Xylazine also produces a decrease in cardiac output and arterial blood pressure.(35) The use of
disease-related drugs, such as insulin and antibiotics, will not be covered here; however, these drugs will be included in discussions of various situations in which their side-effects become important.

INDUCTION
INJECTABLE AGENTS
The most commonly used intravenously injectable anesthetic agents for induction are thiopental sodium and thiamylal sodium. Concentrations of 2.5% or less of either of these are preferred because decreasing concentration decreases the likelihood of tissue necrosis due to peri-vascular injection.

Methohexital sodium is no longer sold under a veterinary label in the United States but is still sold as a human product. This agent will be discussed in more detail under Sighthounds.

Ketamine is usually given with a tranquilizer, most commonly acetylpromazine, xylazine, or diazepam. These mixtures are most commonly used in cats for induction and maintenance of anesthesia. They have also been used in dogs; however, ketamine is not approved for use in dogs. In practice the most commonly used intramuscular dosages are ketamine, 22 mg/kg; xylazine, 1.1 mg/kg; acetylpromazine, 0.11 mg/kg; or diazepam, 0.55 mg/kg. We routinely use half of these dosages, except for diazepam, and give more if necessary, usually intravenously. If cats are going to be given inhalation anesthetics and if they are going to be induced with ketamine, we use the following procedure: preanesthetic intramuscular administration of 0.022 mg/kg atropine plus 4.4 mg/kg ketamine. They are then induced with a mixture of 0.55 mg/kg of diazepam plus 2.2 mg/kg ketamine IV. This is a smooth induction technique; however, its disadvantage is that ventilation is often poor, and the animal may require positive-pressure ventilation.

When maintenance with an inhalational agent is planned, I prefer not to use a phenothiazine tranquilizer or xylazine because of the potential for hypotension. I also prefer to not use xylazine because of the increased sensitivity to catecholamine-induced arrhythmias mentioned above.

A combination of a cyclohexylamine anesthetic, tiletamine hydrochloride, and a benzodiazepine tranquilizer, zolazepam, has recently been approved by the Food and Drug Administration (FDA) for use in dogs and cats. As indicated in the proposed package insert, this combination is not suitable for orthopaedic procedures in dogs.

A mixture of two steroid anesthetics, alphaxalone and alphadolone, is sometimes used as an induction agent in cats in those countries in which it is available. One of its advantages is its lack of respiratory depression. Its disadvantages are varying degrees of hyperemia and edema of various structures (paw, ear, nose, larynx) occasionally seen.

INHALATION AGENTS
Dogs and cats may be induced by an inhalational agent; however, this is not commonly done, especially in the dog. Inducing cats by inhalation, especially in a fish tank-type device, is occasionally useful.

Cats tolerate induction with halothane quite well, but not with methoxyflurane. Even if the cats are pre-medicated with atropine, methoxyflurane induction causes profuse salivation and occasionally severe laryngospasm.

MAINTENANCE
Anesthesia may be maintained by injectable or inhalant anesthetics. In general, we prefer maintenance with inhalational agents. Maintenance with barbiturates can lead to prolonged recoveries in any species, especially cats and sighthounds (see below). Five inhalant anesthetics will be discussed: halothane, methoxyflurane, enflurane, isoflurane, and nitrous oxide (N2O).

HALOTHANE
Halothane is the anesthetic I prefer to use in most instances. Its blood gas solubility coefficient of 2.3 makes it an agent with reasonably rapid induction, recovery, and regulability.

METHOXYFLURANE
I rarely use methoxyflurane any more. Its reported advantages over halothane are greater analgesia during and after anesthesia and greater muscle relaxation. In my experience and that of the orthopaedic surgeons at my institution, the muscle
relaxation obtained with reasonable levels of halothane anesthesia is satisfactory for most procedures. If profound muscle relaxation is required, I will use different techniques: skeletal neuromuscular blocking agents such as pancuronium bromide; epidural analgesia; or isoflurane. The package insert for human methoxyflurane recommends avoiding its use for muscle relaxation.

The analgesia produced by halothane is adequate for orthopaedic procedures, and there are no clinically significant changes in respiratory rate, heart rate, or blood pressure of dogs or cats as a result of its administration during such procedures.

Postoperative analgesia is provided by methoxyflurane; however, I think that the many disadvantages of this agent outweigh its analgesic property, and postoperative analgesia can be provided as needed with narcotics. These disadvantages are greater cost per kilogram per hour than halothane, prolonged recovery periods, and potential morbity or mortality due to the production of inorganic fluoride ion by metabolism of methoxyflurane. Up to 50% of inspired methoxyflurane is metabolized in humans.(42) Inorganic fluoride ion is nephrotoxic in humans and rats of the Fisher 344 strain at levels of 50 umol/liter of serum. Dosages in the range of 90 umol to 120 umol/liter cause well established but mild nephrotoxicity manifested by serum hyperosmolality, hypernatremia, polyuria, and low urinary osmolality. Levels up to 175 umol/liter produce marked nephrotoxicity.(3) These blood levels are readily achieved in dogs; however, the dog kidney seems to be more resistant to the effects of inorganic fluoride ion than that of humans and rats. These effects can occur at higher dosages; the threshold appears to be about 206 umol/liter.(2) Relatively lean foxhounds anesthetized at 1.5 MAC (0.35% arterial) for 3 hours achieved a peak inorganic fluoride level of 180 uLmol/liter at the end of the third hour. Inorganic fluoride was still increased significantly at 7 days. It is easy to conceive of dogs receiving higher concentrations of methoxyflurane, and of occasional orthopaedic procedures for which dogs may be anesthetized for periods longer than 3 hours. Both situations could cause the blood level of inorganic fluoride to rise above the threshold for renal toxicity. Two other significant factors that can cause the blood level of inorganic fluoride to be raised higher than reported from experimental trials are obesity and the induction of liver microsomal (P450) enzymes by previous drug administration, such as phenobarbital given for control of seizures. Concurrent administration of some antibiotics such as tetracycline and gentamicin may enhance the toxicity.(3)

Methoxyflurane also impairs autoregulation of blood flow to the kidney, whereas halothane does not.(40)

ENFLURANE
Enflurane does not appear to offer any advantages over the other inhalant anesthetics available and, at the present time, costs about six times as much as halothane per kilogram per hour.

ISOFLURANE
Isoflurane has some properties that may be useful in small animal orthopaedics. Its blood gas solubility coefficient of 1.4 indicates that induction and recovery are faster than those of halothane, it seems to provide a great deal of analgesia at relatively light levels of anesthesia, it provides marked muscle relaxation, and it seems to have less depressant effect on the cardiovascular system than halothane. Its major disadvantages are cost and depression of ventilation, which often requires the use of positive-pressure ventilation. Isoflurane does not sensitize the myocardium to the arrhythmogenic properties of epinephrine as does halothane. (33)

NITROUS OXIDE
Several reasons are given for using N2O in small animals; however, I do not think that most of these are clinically significant. The first reason is to speed induction. In most cases there is no need to have an induction faster than can be achieved with halothane or isoflurane. The second reason is to decrease the consumption of volatile anesthetic. Owing to the requirement for high flows when N2O is used and to the small decrease in MAC provided by N2O in animals as opposed to humans, the consumption of volatile anesthetic is usually higher than if N2O were not used. In humans the addition of 66% N2O provides an MAC reduction of two thirds; for example, if 3% halothane were going to be used for induction without N2O, only 1% halothane would be needed with N2O. The MAC reduction in animals (dog, cat, horse, and monkey) is at best one third.

Another reason given is that N2O produces less cardiovascular depression. The experimental data for this are controversial. From most studies it appears that N2O is a direct myocardial depressant but that this is often overridden by indirect sympathomimetic effects such that the net result when N2O is added to a halothane anesthetic is usually, but not always, a slight increase in blood pressure and cardiac output; however, this slight improvement is not clinically significant in critically ill patients, and a different anesthetic technique is required for them (discussed in the next section). The disadvantages or contraindications for the use of N2O are as follows.
The use of such an impotent agent requires a high inspired concentration, thus limiting the inspired oxygen concentration, a possible disadvantage in a severely compromised animal (as discussed below). Wherever there is a collection of gas in the body, N2O will diffuse into the collection, causing the gas to increase in volume. The increase in volume is related to the concentration of N2O inspired. An inspired concentration of 75% will cause the original volume to increase to four times the original volume.

\[
F = \text{final volume} \\
o = \text{original volume} \\
x = \text{inspired concentration of N2O} \\
f = o + x \cdot f \\
f = o / (1 - x) \\
\text{if } o = 1 \text{ and } x = 75\% \\
f = 1 / (1 - x) \\
f = 4 \\
f = 4 \cdot o
\]

The most important clinical consequences of this property of N2O involve gas trapped within the gastrointestinal tract, especially in gastric torsions, but also in ileus due to trauma, shock, or surgery and pneumothorax.

SIGHTHOUNDS

Dogs classified as sighthounds include Afghan, Borzoi, Greyhound, Irish Wolfhound, Saluki, Scottish Deerhound, Whippet, Italian Greyhound, Pharaoh Hound, and Ibezan Hound. Others that should be included are any very thin, heavily-muscled dogs of any breed.

The primary difficulty in anesthetizing sighthounds involves the use of barbiturates, especially the thiobarbiturates, for maintenance. There is some difference of opinion concerning the factors involved in terminating anesthesia from a single dose of thiopental. It seems reasonably clear that redistribution,(52) metabolism,(55) and body fat(15,26) play significant roles. It appears to be the relative lack of fat in sighthounds that accounts for the prolonged recovery from thiopental in these breeds compared with other breeds.(13) Methohexital sodium, which does not depend on redistribution into fat, but primarily initial redistribution and then metabolism, is much shorter lasting in sighthounds(20) compared with thiobarbiturates.

There are several ways by which one can approach anesthesia in sighthounds. There are three primary techniques that I have used. The first is one I used for a while but have since abandoned: standard preanesthetic medication with atropine and a narcotic intramuscularly, induction with methohexital intravenously followed by intubation and an inhalant anesthetic, most commonly halothane. This is a reasonable approach; however, it has two disadvantages: methohexital is no longer available under a veterinary label, and on occasion there is considerable excitement during recovery. The latter would be most important in a short case. The second technique is the one I routinely use at the present time: preanesthetic medication with atropine, 0.022 mg/kg, plus two to three times our standard dose of narcotic (e.g., 0.044 mg/kg x 2 = 0.088 mg/kg oxymorphone IM or 2 x 4.4 mg/kg = 8.8 mg/kg meperidine IM). Sometimes glycopyrrolate (0.022 mg/kg) is used instead of atropine, since atropine has been shown to increase the thiopental sleeping time about 206%.(37) The increased dosage of narcotic allows a decrease in the dosage of thiopental used for induction. The dogs are then intubated and given halothane or, occasionally and most recently, isoflurane. Recently we evaluated the use of etomidate as an induction agent in greyhounds. The dogs were pre-medicated with either glycopyrrolate or atropine and oxymorphone and induced with either thiopental, thiamylal, or etomate. Maintenance was with halothane or isoflurane. The dogs were splenectomized or castrated or spayed. The time to sternal recumbency was obviously and markedly faster in the greyhounds induced with etomidate compared with those induced with thiamylal or thiopental. Etomidate may be useful in sighthounds but because of its cost and occasional side-effects of myoclonus, vomiting, and seizures is not likely to replace thiobarbiturates in veterinary practice. Another technique I use, if the anatomical site of the procedure is compatible, is epidural analgesia. For drugs and dosage, see discussion under Trauma Cases.

POSTANESTHETIC PERIOD

The postanesthetic period has several concerns: rate of recovery, excitement, and needs for analgesia. Often dogs, and sometimes cats, require postoperative pain relief. The most effective drugs for this purpose are narcotic analgesics. Narcotic agonist/antagonist analgesics, especially the newer ones, have some interesting properties that may make them useful.
NARCOTIC AGONIST ANALGESICS
Narcotic agonist analgesics include the natural, semi-synthetic, and the synthetic drugs. They appear to produce analgesia by attaching to mu (u) receptors. Any of these drugs can be used in dogs; however, the ones we use most commonly are oxymorphone, 22 ug to 44 ug/kg IM or IV; meperidine, 2.2 mg to 4.4 mg/kg IM only (not IV); morphine, 0.55 mg to 1.1 mg/kg IM or IV. The duration of effect of meperidine is very short, 30 to 120 minutes, whereas that of the other two is 2 to 8 hours.

Cats, at least theoretically, present a problem. Morphine, in high dosages, produces marked excitement (morphomania); however, narcotics, including morphine, may be used in cats when given in reasonable dosages and, if necessary, with a tranquilizer to prevent excitement. Meperidine and oxymorphone have reportedly been used in cats without producing excitement. In my experience, there will be an occasional cat that when given either of these narcotics as a preanesthetic will exhibit morphomania. I have not seen excitement with morphine or oxymorphone when these narcotics are given immediately postanesthesia in the following dosages: morphine, 0.1 mg to 1 mg/kg IM; oxymorphone, 2.2 ug to 20 ug/kg IM or IV. If necessary, a small amount of tranquilizer can be added: 1.1 mg/kg promazine or 22 ug to 44 ug/kg acetylpromazine. If hypotension, present or potential, represents a problem for a cat, 0.55 mg/kg diazepam IV or IM, instead of a phenothiazine tranquilizer, can be given with the narcotic.

NARCOTIC AGONIST/ANTAGONIST ANALGESICS
The first narcotic agonist/antagonist to be released was pentazocine hydrochloride. Two more recently released drugs in this category are butorphanol tartrate and nalbuphine.

Opinion on the use of pentazocine is somewhat divided: some people think it is a reasonable analgesic; others, including myself, think it is not efficacious.

We have had only limited experience with butorphanol, but we have used nalbuphine in several useful ways. Nalbuphine does not produce any sedation at all in dogs. In cats it produces some excitement and apprehension. Clinically it appears to produce analgesia in dogs but definitely not as profound as agonist analgesics in the dosages we have used: up to 10 mg/kg IV. It does not appear to produce excitement in the dog when given intravenously. It appears to be extremely useful and economical as an antagonist for narcotic agonists when given at a dosage of 0.1 mg to 0.2 mg/kg IV or IM. Its other advantage is its long half-life in the dog—7 to 8 hours.

MULTIPLE TRAUMA PATIENTS
PROBLEMS
Animals suffering multiple traumas can present cases that are very challenging both anesthetically and orthopaedically. The veterinarian should treat as many of the life-threatening conditions as possible before anesthetizing the animal for definitive reparative surgery. Every effort should be made to prepare the animal as well as possible for any anesthetic and surgical experience. Clearly, some life-threatening conditions require anesthesia for immediate repair; techniques for anesthetizing animals for such treatment are described below.

FLUIDS
The disturbances that need to be considered for correction before anesthesia and surgery are as follows: fluid loss, not only from the traumatic episode but also from inability or lack of desire to drink since the incident; and blood loss, not only obvious bleeding such as a severed artery or a fractured spleen but also blood lost into tissues, the prime example of which is a fractured femur (as much as one fifth of the blood volume may be lost into the surrounding tissue).

PULMONARY FUNCTION
Abnormalities of pulmonary function are common and may be due to one or all of the following: pulmonary contusion, pneumothorax, hemothorax, diaphragmatic hernia, and pulmonary edema (including that produced by head trauma). If there is pneumothorax, it is desirable to insert a chest tube before anesthesia not only to remove the gas in the pleural cavity but also to determine if there is still a leak and how fast it is leaking. Even if the leak has stopped, it is advantageous to have a chest tube in place in case the leak is reactivated by positive-pressure ventilation.

CARDIAC ARRHYTHMIAS
Cardiac arrhythmias are common in traumatized animals. The most common arrhythmias are premature ventricular contractions (PVCs). Other arrhythmias that may be seen are ventricular tachycardia, complete heart block, or ventricular
There is not complete agreement on when to treat a particular arrhythmia. If the animal has only an occasional PVC that always arises from the same focus, it probably does not need to be treated; if the animal has a ventricular tachycardia with a rate of 300, treatment is in order. The area in between is where the questions arise.

When possible, I prefer that an animal not have a ventricular arrhythmia during induction and maintenance of anesthesia. My usual procedure for treating ventricular arrhythmias is to start with lidocaine 2% (without preservatives or epinephrine), 1 mg to 2 mg/kg IV. If this restores normal sinus rhythm, I wait to see if the arrhythmia returns and how long it takes. In some cases I will use the lidocaine as the major component of the anesthetic technique (described below). If the arrhythmia does not respond to the lidocaine or if the effect lasts only a few minutes, I usually will use quinidine gluconate IV in 1 mg/kg-slow boluses up to 6 mg/kg. If this does not stop the arrhythmia and if it is a particularly dangerous one (e.g., multifocal with a rate of 250), I will try bretylium tosylate, 5 mg to 10 mg/kg IV slowly. Occasionally I will give the bretylium as a low continuous infusion. This is a pharmacologically complex drug that is approved for humans as a second line of defense antiarrhythmic to be used only for "life-threatening ventricular arrhythmias, principally ventricular fibrillation and ventricular tachycardia, that have failed to respond to adequate doses of a first-line antiarrhythmic agent, such as lidocaine or procainamide."

**FAT EMBOLISM**

Fat embolism occurs relatively frequently in traumatized human patients and in human surgical patients. The most common etiologic factor associated with embolic fat is long-bone fracture, especially of the femur and tibia.(7) The incidence after long-bone fracture is probably about 5%. In a study of 45 human patients with severe blunt trauma, fat embolism syndrome occurred in 13 (29%).(41) Total hip replacement has been associated with fat embolism,(27,35) severe hypotension, and deep vein thrombosis.(55) The mortality rate in human patients showing signs of fat embolism has been variously reported to be between 10% and 50%. Although the apparent incidence in animals is very low,(22) I do not think that its incidence has been adequately investigated. A traumatized animal is likely to be anesthetized during the period when signs of fat embolism are most likely to appear, namely, from almost immediately after injury through the next several days. It is unusual for initial symptoms to appear beyond a week after injury.(7) A review of 100 patients with fat embolism revealed that 25% showed symptoms within 12 hours of injury, 60% within 24 hours, 75% before 36 hours, and 85% within 48 hours.(7) The signs may include the following: dyspnea; tachypnea; cyanosis; increased central venous pressure; pulmonary edema; decreased arterial oxygen tension; impairment of consciousness including restlessness, delirium, lethargy, stupor or coma; convulsions; hyperpyrexia; tachycardia; petechial hemorrhage; and embolic retinopathy.

The treatment of patients with signs of fat embolism can be divided into two parts: treating the complication and treating the underlying disorder. There is only one group of treatments that is unequivocally and significantly effective: the proper management of respiratory failure. All other therapeutic maneuvers are either of much less importance or of doubtful effectiveness. Supportive therapy of all dysfunctioning systems must be maintained. The various therapies that have been used in an attempt to treat the underlying condition include ethanol, heparin, adrenal corticosteroids, and dextran.(7) A report in dogs showed that in three dogs insertion of cement into the femoral shaft resulted in medullary pressures of between 290 mm Hg and 900 mm Hg and the appearance of medullary contents in the lungs within 10 to 20 seconds. In five other dogs pulmonary embolization was not detectable when the rise in femoral medullary pressure was prevented by drilling a hole distal to the cemented area.(35) Total hip arthroplasty was shown to produce clear identifiable lesions in previously healthy veins distant from the surgical site in dogs.(55) Continuous intravenous infusion of lidocaine (loading dose of 1.25 mg/kg followed by continuous infusion of 0.125 mg/kg/min) decreased the incidence of these lesions from 75% to 30% (64).

Severe hypotension occurring during total hip arthroplasty needs to be treated. The pressure fall appears to be due to peripheral vasodilation. Rapid intravenous fluid administration may be tried first. If that produces an inadequate response, then adrenergic drugs are necessary. Any α1-adrenergic stimulant would probably do.

If the dogs are anesthetized with halogenated anesthetics, especially halothane, the adrenergic stimulants may cause various ventricular arrhythmias. This problem will be discussed further in the section on preanesthetic medication and inhalant anesthetics. We most commonly treat hypotension with ephedrine, 0.2 mg to 0.5 mg/kg IV, or with phenylephrine, usually given by continuous intravenous drip, to effect (10 mg diluted in 250 ml or 500 ml of 5% dextrose solution).
**ANTIBIOTICS**
When selecting antibiotics, most clinicians base their decision on the organism they are battling. They also consider commonly known toxic effects; however, other effects of antibiotics are too often overlooked. These effects include increased sleeping time, skeletal neuromuscular blockade, decrease in blood pressure, and increased serum potassium due to potassium penicillin.

It has been known for a long time that antibiotics such as chloramphenicol can markedly prolong the sleeping time produced by barbiturates.\(^4\) It has also been shown that in cats this antibiotic can prolong the sleeping time produced by ketamine as well as that produced by a mixture of tiletamine and zolazepam.

Antibiotics of many chemical classes, including aminoglycosides, polymyxins, tetracyclines, and licosamides, can have a blocking effect on the skeletal neuromuscular junction, thus producing muscle weakness. The antibiotics can do this by themselves, as well as when given with neuromuscular blocking agents; this effect may continue even after the clinical effect of the neuromuscular blocking agent has disappeared. The cat appears to be more susceptible to this effect than the dog.

Antibiotics of the above mentioned classes can also produce hypotension. Again, the cat appears to be more sensitive than the dog to this effect. In some cases the effect of the antibiotic may be reversible with the administration of calcium (0.136 mEq/kg = 0.3 ml/kg of 10% solution of calcium gluconate) and/or the administration of a cholinesterase inhibitor, such as neostigmine (as described under reversal of neuromuscular blocking agents).

Another effect is that produced by the intravenous administration of potassium penicillin. This drug contains 1.7 mEq potassium/million units of penicillin; thus, hyperkalemic toxicosis can result if too much total potassium is given or if it is given too quickly.

**PREANESTHETIC DRUGS**
The uses and contraindications of the various preanesthetic drugs will be discussed below. The effects of these drugs on intracranial pressure will be discussed in the section devoted to that problem.

**ANTICHOLINERGICS**
The decision to use anticholinergics must be based on the details of a particular case. If the heart rate is above normal and there are no other extenuating circumstances, I would not give such a drug. If the heart rate is below normal or if I were planning on using a vagotonic drug such as fentanyl, I would use one. If there is concern in a particular case about the central effects of an anticholinergic drug, glycopyrrolate should be used.

**NARCOTICS**
Narcotics are respiratory depressants, a factor that must be considered in deciding on their use. Pain, stress, and shock produce increased levels of circulating catecholamines (epinephrine and norepinephrine), which can have an adverse reaction with various anesthetics and preanesthetic drugs, especially xylazine and the potent halogenated inhalant anesthetics, particularly halothane. This interaction will be discussed under the appropriate drugs. Because traumatized animals may have severe pain and often are handled quite a bit preanesthetically, it is desirable to minimize the catecholamine response to pain. Narcotics should be used in these cases unless contraindicated. The cardiovascular effects of the individual narcotics vary greatly. The least hypotensive of the commonly available narcotics is oxymorphone, followed, in order of increasing likelihood of producing hypotension, by fentanyl, etorphine, methadone, morphine, and meperidine. Meperidine may produce severe hypotension in dogs, even when given in low doses intravenously.

**TRANQUILIZERS**

**PHENOTHIAZINES**
These drugs have the potential for causing severe dysfunction, especially in the severely injured animal. They can cause a lowering of the numbers of circulating white blood cells, red blood cells, and platelets(31,39) and, thus can decrease oxygen-carrying capacity and clotting ability. They are also (a-adrenergic receptor-blocking agents and may produce severe hypotension, especially in a hypovolemic animal. One positive attribute is that they decrease the increased sensitivity of the myocardium to catecholamines produced by halogenated anesthetics such as halothane.\(^{47}\)
BUTYROPHENONES
Two drugs belonging to the butyrophenone class are sold under a veterinary label: lenperone and droperidol. The more commonly used is droperidol, which is sold in combination with the narcotic, fentanyl. Droperidol is an α-adrenergic-blocking agent, thus it too causes a dose-related decrease in blood pressure. There is also a relatively high incidence of personality changes associated with this drug, a side-effect that, in my opinion, severely limits its usefulness.

BENZODIAZEPINES
DIAZEPAM
In the severely traumatized dog diazepam is useful in combination with narcotics; for use in the cat, it is combined with ketamine. Diazepam usually spares the cardiovascular system. Awake, healthy dogs given 0.5 mg, 1 mg, and 2.5 mg/kg IV showed no change in heart rate or blood pressure; 2.5 mg/kg produced a 10% increase in cardiac output.(63) We have seen decreases in the blood pressure of critically ill dogs given diazepam, but none were life-threatening or untreatable. Diazepam by itself, especially in low doses intravenously, often produces excitement. This is prevented or stopped by giving a narcotic such as oxymorphone.

MIDAZOLAM
Midazolam, a newly discovered member of this family, is advantageous because it is water soluble and less irritating to the veins. It is reported to be three times as potent as diazepam in animal studies; however, in my experience it is approximately equipotent to it, in both dogs and sheep. The drug has some effect on the cardiovascular system. In one study in awake dogs given 0.25 mg, 1 mg, and 10 mg/kg IV, there was a 10% to 20% decrease in mean arterial pressure at 1 mg and 10 mg/kg. Cardiac output was increased 10% to 12% in all three groups. No change in systemic or coronary vascular resistance was reported.(34) This drug will be useful once it becomes available commercially.

ZOLAZEPAM
Zolazepam will be available only in a premixed combination with tiletamine (similar to ketamine) for use in dogs and cats. It has been reported to cause belligerence when used by itself. Its effect on blood pressure has not been reported.

OTHERS
XYLAZINE Xylazine has been shown to produce marked changes in cardiovascular function in healthy dogs: a 44% decrease in cardiac output, a 160% increase in peripheral resistance, a 42% increase followed by a 12% decrease in mean blood pressure, and a 30% decrease in heart rate. Pretreatment with atropine did not alter these changes. There were no changes in arterial pH, PaO2, or PaCO2.(36) Similar changes occurred in cats except that there was no initial increase in blood pressure.

In addition to these very important cardiovascular effects, xylazine has two other important properties. The first is that it adds to or potentiates the increased sensitivity to the production of arrhythmias by catecholamines that results from halogenated inhalant anesthetics.(47) Since the levels of circulating catecholamines are increased, often markedly, after trauma and in shock,(24,25) a lethal combination may result. The second effect is a very high incidence of personality changes. Although usually short-lasting and not severe, such changes may make a pleasant dog uncooperative or nasty.

PENTOBARBITAL
Pentobarbital in low dosages (2 mg−4 mg/kg IM or IV), is very useful and safe as a sedative, especially in combination with a narcotic such as oxymorphone.

INDUCTION
Thiobarbiturates are the most commonly used drugs for induction; however, in the severely injured animal there are safer alternatives. The thiobarbiturates themselves produce ventricular arrhythmias in healthy dogs.(45) Thiamylal has been shown to enhance the arrhythmogenicity of catecholamines.(46) Thiopental, thiamylal, and methohexital have been shown to enhance the sensitization of the myocardium to catecholamines that results from halothane administration. Many severely traumatized dogs and cats already have ventricular arrhythmias.

All the common barbiturates (pentobarbital, thiopental, thiamylal, and methohexital) in anesthetic doses cause splenic enlargement with sequestration of red cells and a resultant decrease in packed cell volume (12%−18%).(70) In an anemic animal a serious decrease in oxygen-carrying capacity could ensue. The barbiturates also produce a decrease in white blood cells (12%−22%) not related to the effects on the spleen and with no change in the proportion of monocytes to granulocytes.
Many methods of management used in severely injured animals can influence the duration of barbiturate anesthesia. The concomitant administration of other drugs, including antibiotics such as chloramphenicol and nonnarcotic analgesics such as aspirin, can prolong sleeping time.\(^{14}\)

Decreased plasma proteins, particularly albumin, increase the available amount of active barbiturate produced by a given dose. Because there is decreased blood flow to many areas of the body, the changes in uptake and distribution of the barbiturates will produce higher blood, heart, and brain levels from a given dose.

In some of the more severely traumatized animals, we usually avoid "anesthetic doses" of barbiturates. We usually induce these animals with a sedative and narcotic combination, the most common of which is very low dosages of pentobarbital (2 mg-4 mg/kg IV) with oxymorphone (20 ug-200 ug/kg IV). This combination usually produces a smooth and safe induction.

We recently began using etomidate for induction because it does not depress the cardiovascular system. However, it produces a clinically significant incidence of vomiting or seizures, which may limit its usefulness.

If the animal already has a preexisting ventricular arrhythmia, antiarrhythmic agents should be considered as described above. If the arrhythmia responds to lidocaine, we occasionally will use the lidocaine as the part of the anesthetic technique, which is as follows:

1. A narcotic preanesthetic may or may not be given intramuscularly.
2. Lidocaine (2 mg-4 mg/kg IV) is given.
3. The dog or cat is given enough thiopental to intubate.
4. The animal is connected to an anesthesia machine delivering 100% oxygen.
5. Lidocaine is administered in the following schedule: 2 mg/kg IV for the next dose, then 1 mg/kg every 5 minutes for one half hour, and then every 10 minutes for the duration of the procedure. N2O may be added if not contraindicated.

MAINTENANCE
NITROUS OXIDE
The severely traumatized animal is likely to have myocardial contusions, pneumothorax, pulmonary contusions, ileus, or impaired blood flow. Such animals often require high inspired oxygen concentrations, which would preclude the use of N2O. Because of the problem of expansion of trapped gas by N2O, it is often contraindicated. The other advantages and disadvantages were discussed above. I rarely use N2O in any of the animals we treat.

POTENT HALOGENATED INHALANT ANESTHETICS
Halogenated inhalants were discussed in general in the previous section. There are several properties of these agents that relate more specifically to the multiple trauma patient.

Halogenated agents vary markedly in their ability to sensitize the myocardium to arrhythmias produced by catecholamines.\(^{19,33,53,69}\) Of the four agents, halothane, methoxyflurane, enflurane, and isoflurane, halothane does this to the greatest degree; that is, the dose of epinephrine necessary to cause ventricular arrhythmias is lowest with halothane. Halothane lowers the dose of epinephrine necessary to produce arrhythmias to less than that required in the awake dog.\(^{19,33}\) Isoflurane does not significantly change the dose compared with that required in the awake state,\(^{33}\) and enflurane and methoxyflurane require a higher dose under anesthesia compared with the awake state.\(^{53}\) It is not clear from available studies if one of the latter two drugs requires a higher dose of epinephrine to produce arrhythmias than required by the other, although there does appear to be a difference between them in the severity of arrhythmia produced by increasing dosages of epinephrine: more dogs went into ventricular fibrillation with enflurane than with methoxyflurane in a study done with those agents in combination with N2O-53 These investigators also reported on the effects of narcotic-N2O anesthesia and epinephrine-induced arrhythmias; the narcotics studied were morphine, fentanyl, and meperidine. There was a moderate incidence of unifocal ventricular arrhythmias but no incidence of ventricular fibrillation in dogs given the maximum dose of epinephrine used in that study.\(^{53}\) The role of N2O in the production of the arrhythmias is not clear. The sensitization is decreased with increasing amounts of any of the anesthetics and also decreases as PaCO2 increases above normal. Since circulating catecholamines are increased in shock and trauma, these interrelationships need to be considered.
The other cardiovascular effects of these agents also need to be considered. They all decrease blood pressure in a dose-related fashion. A clinical impression is that isoflurane depresses blood pressure least, methoxyflurane next, halothane next, and enflurane most.

These effects, however, are modified during surgery. One index that is used to compare various agents is the cardiac anesthetic index. This is the concentration of anesthetic in the myocardium at the time of failure divided by the concentration in the heart of 1 MAC in rats being mechanically ventilated and with a normal PaCO2. The index for various agents is as follows: isoflurane-O2 = 5.7; methoxyflurane-O2 = 3.7; enflurane-O2 = 3.3; halothane-O2 = 3.0; halothane-N2O (50%) = 3.7, in rats.(19) Because of its relationship with catecholamines and because it seems to have an overall less depressant effect on arterial blood pressure, we often use isoflurane in these animals.

**NARCOTICS**

In the most severely traumatized dogs, we usually choose a technique based primarily on a narcotic, small doses of sedative, and oxygen. Among themselves, the narcotics vary quantitatively a great deal in many clinically significant ways. The narcotic we routinely use is oxymorphone. The next most frequent choices are fentanyl or hydromorphone and occasionally etorphine or methadone.

Oxymorphone has remarkably little effect on cardiovascular function even in very high dosages. Fentanyl and etorphine may produce a slight to moderate decrease in blood pressure, methadone and morphine may produce a greater decrease, while meperidine is the best at producing hypotension, even in dosages that are small compared with the others.(66)

Excitement is sometimes seen when narcotics are given intravenously. The likelihood and violence of such an occurrence are greatest when morphine is injected rapidly into healthy dogs, and it does not appear to be related to the production of hypotension. Excitement with oxymorphone given intravenously is not common and is usually mild. It is rare to see excitement with intravenous administration of fentanyl, and when it occurs it is mild. I have not seen it with etorphine. The drugs vary in their ability to produce apnea; I expect maintenance of spontaneous breathing with oxymorphone and expect apnea with etorphine. Fentanyl is in between but is more likely to produce apnea.

The narcotics can be given in two basic ways: frequently repeated small doses or an initial high dose given over 5 to 10 minutes. Our usual small dose of oxymorphone is 20 ug to 40 ug/kg IV about every 20 minutes. The equivalent small dose of fentanyl would be 4 ug to 8 ug/kg about every 10 to 15 minutes. In the high-dose technique with oxymorphone, it is wise to give 40 ug to 80 ug/kg and see if any hypotension develops. If not (which is usually the case), 400 ug to 800 ug/kg should be given over the next 10 minutes. For fentanyl the high-dose technique is 10 ug to 20 ug/kg followed by 50 ug to 100 ug/kg.

If there are no contraindications, we sometimes will use N2O or low-dose methoxyflurane (0.2% delivered at low flows) with this technique. Isoflurane may also be useful in this manner at about 0.25% to 0.5%. After the procedure is finished a decision needs to be made about whether the narcotic should be reversed with a specific narcotic antagonist. My preference is to allow the animal to control its airway, but I do not wish to remove all the analgesia.

If at the time of placing the animal in its recovery area I think it is too depressed, I will give one quarter of the usual dosage of the antagonist repeatedly until the animal is sufficiently awake. This would be 50/4 ug/kg levallorphan, 20/4 ug/kg naloxone hydrochloride, 10/4 ug/kg diprenorphine, or 100/4 ug/kg nalbuphine.

The relatively new agent, nalbuphine, which is a narcotic agonist/antagonist analgesic, is an excellent narcotic antagonist and has several advantages. It has a much longer duration of effect (its half-life in the dog is 8.3 hours), it is very economical when used as an antagonist at the dosage of 0.1 mg/kg, and it does not produce any sedation in the dog.

Nalbuphine may also produce analgesia. It is thought to do so through a different receptor than that which mediates the classic narcotics. The classic narcotics and their effects are thought to be mediated through mu receptors. Drugs such as nalbuphine are thought to produce analgesia through kappa (K) receptors and act as antagonists at mu receptors.(14) In humans nalbuphine is almost equipotent to morphine; thus a reasonable dose to try for analgesia in the dog is 1 mg/kg. Another interesting and potentially useful property of this drug is that it produces no sedation in the dog at doses up to 15 mg/kg IV. Clinically this drug is extremely effective and useful as an antagonist in the dog. It is also economically feasible to use this drug in endotoxic shock.

Recently there have been several papers suggesting that very high dosages of the narcotic antagonist naloxone (2 mg-10
mg/kg) may be useful for treating the cardiovascular effects of endotoxic shock. Nalbuphine may be an economically feasible alternative. Naloxone at 100 times the antagonist dose (100 x 20 ug/kg) would cost $12.50/kg of animal weight while the equivalent of nalbuphine would cost approximately $1.06.

I have given nalbuphine at a dosage of 10 mg/kg IV to three dogs in septic shock who previously were not responding to industrial dosages of all the usual drugs. Within 30 minutes there appeared to be a dramatic improvement in their cardiovascular function.

HYPOXIC PULMONARY VASOCONSTRICTION

In order to avoid perfusing a region of lung that is not being ventilated, a local reflex vasoconstriction occurs in the blood vessels supplying the low-oxygen area. This response is called hypoxic pulmonary vasoconstriction (HPVC). If something interferes with this response, a large alveolar to arterial oxygen tension gradient may develop, especially if there is much underventilated lung (49)

HPVC has been studied most in animals such as dogs, cats, and sheep, all of which have a meager response. Other species, including cattle, pigs, and especially coati mundi, have a much more vigorous response.(54) In the traumatized animal with pulmonary atelectasis, this response may be very important in the maintenance of adequate oxygenation of the tissues. Use of N2O should be avoided in these cases for at least two reasons. The first is that it is important to provide as high a concentration of inspired oxygen as possible, and the second is that N2O reduces hypoxic pulmonary vasoconstriction.(67) Generally, inhalant anesthetics may have to be avoided in such cases because they all appear to reduce HPVC. There are many conflicting reports, especially concerning the effect of halothane on HPVC(50) Barbiturates and narcotics do not appear to reduce HPVC.(12)

EPIDURAL ANALGESIA

The technique of epidural analgesia is frequently very useful, especially for the multiple trauma patient, as long as certain facets of the technique are understood and taken into consideration. In healthy dogs epidural analgesia of a level sufficient to perform abdominal surgery does not affect cardiovascular function.(49) However, if the patient is hypovolemic, severe hypotension may be produced. Blood volume must be vigorously supported before and during the effect of the epidural. If fluid support is not adequate in maintaining blood pressure, a sympathomimetic agent must be given, such as ephedrine, 0.22 mg to 0.55 mg/lb IV or IM. To try to avoid precipitating a crisis in a severely traumatized patient, I usually give an intramuscular injection of ephedrine immediately after the injection of the local anesthetic and then watch for signs that indicate that further treatment is required as the effects of ephedrine slowly dissipate.

The local anesthetics I use most commonly are lidocaine hydrochloride (2%) and bupivacaine hydro-chloride (0.75%). The onset of both is rapid, usually within 5 minutes. The duration of surgical analgesia that can be expected is as follows: lidocaine 2% without epinephrine, 3/4 to 1 hour; lidocaine 2% with epinephrine, 1 1/4 to 1 1/2 hours; bupivacaine 0.75% without epinephrine, 3 hours. In some cases, especially those in which it is difficult to predict duration, I may use a continuous epidural; that is, I place a catheter in the epidural space, through which repeated injections of local anesthetic can be made throughout the surgical procedure. The dosage requirements for this technique are as follows: lidocaine 2% with epinephrine, repeat 1/2 the initial dose every hour; bupivacaine 0.75% without epinephrine, repeat 1/2 the original dose every 2 hours. The initial dosage I use is lidocaine 2% with epinephrine, 1 ml/5 kg body weight to block the hindlimbs or 1 ml/3.5 kg for an abdominal block; bupivacaine 0.75% without epinephrine, 1 ml/4 kg, especially in very thin dogs. These dosages may need to be modified in some animals: increased with emaciation, decreased with obesity or large abdominal masses.

MUSCLE RELAXANTS

Skeletal neuromuscular blocking agents can be very useful in the multiple, severely traumatized animal. The basic anesthetic technique may be inhalant or injectable, but the amounts of the anesthetic agents used are considerably reduced, and immobility and muscle relaxation are provided by the neuromuscular blocking agent. Succinylcholine is used by some. It is a depolarizing-type muscle relaxant that is metabolized by pseudocholinesterase. Its onset is the most rapid of available muscle relaxants. Its duration is related to metabolism, and its effect cannot be reversed pharmacologically. The level of pseudocholinesterase can be markedly effected by exposure to organic phosphates. Because organic phosphates are used so widely as parasiticides and insecticides, pseudocholinesterase levels in an individual animal can vary markedly. Succinylcholine often produces a tachycardia but occasionally may produce a severe bradycardia, even in a dog pretreated
with atropine. As a result, I do not often use succinylcholine, but I do use some of the nondepolarizing muscle relaxants. The oldest, d-tubo-curarine, should not be used in dogs and cats because it may cause severe hypotension due to histamine release and ganglionic blockade (14,44) Pancuronium is the muscle relaxant I use most commonly, and occasionally gallamine triethiodide, dimethyltubocurarine, or vecuronium. Gallamine is excreted almost exclusively through the kidneys unchanged (61) and therefore should not be used in an animal with compromised renal function. It is most useful in patients with liver dysfunction. Pancuronium is excreted in part by the kidneys and in part by the liver.(61) Its duration of effect may be increased by dysfunction of either system, but it can still be used in animals with decreased renal function. Dimethyltubocurarine appears to be excreted primarily by the renal system.(61) The effects of a new muscle relaxant, vecuronium, appear to be prolonged with liver dysfunction; occluding the blood flow to the liver caused a significant increase in both depth and duration of neuromuscular block. Renal artery ligation caused a slight but not statistically significant increase in depth and duration of vecuronium-induced block.

Doses commonly used at my institution are gallamine, .5 mg to 1 mg/kg; pancuronium, 20 ug to 40 ug/kg, and vecuronium, 10 ug to 40 ug/kg. The effects of nondepolarizing muscle relaxants can be overcome by administering a cholinesterase inhibitor, most commonly neostigmine. Since the administration of a cholinesterase inhibitor will have both muscarinic and nicotinic effects, atropine or another anticholinergic drug is given to prevent the muscarinic effects. I usually give 20 ug/kg neostigmine and 40 ug/kg atropine and then give more neostigmine if necessary. In a few cases we have used vecuronium. This drug is shorter lasting than the others: 30 minutes versus 60 to 90 minutes. It also appears to be easier to reverse than the others. It does not appear to have any autonomic effects except perhaps a slight slowing of the heart rate.

**RENAI FUNCTION**

One of the concerns in anesthetized patients is the maintenance of renal function. This is especially significant in the multiple trauma victim. Discrepancies in reported effects of anesthetic techniques on renal function are due in part to species differences, anxiety, dehydration, stress, preanesthetic medication, hypotension, surgical stimulation, differing experimental protocols, and the like.(5) In general, anesthesia decreases renal plasma flow and decreases glomerular filtration rate; therefore, the filtration fraction is increased. There is also usually an increase in renal vascular resistance. The degree of depression of renal hemodynamics is dose related.(5) Methoxyflurane appears to impair renal auto-regulation in the dog, while halothane does not.(40)

Data concerning the effects of anesthesia on the secretion of antidiuretic hormone are conflicting.(3) One reason for this is that some studies were done with mechanical ventilation and some were done with spontaneous respiration. Mechanical ventilation in dogs causes a decrease in plasma levels of antidiuretic hormone and an increase in urine production.(4) These effects are due to changes in arterial CO2 levels: decreasing levels of CO2 cause a decrease in plasma levels of antidiuretic hormone and an increase in urine production. Increasing levels of CO2 produce the opposite effect.(50)

Since we use narcotics as our primary agent in the critically ill, multiple trauma victim, their effects on renal function are important. Several studies have been done on this subject; however, most of these suffer from the fact that the animals were very lightly anesthetized before the narcotic was given, and the dose of narcotic given often did not produce general anesthesia; hence, super-imposed on the study was a severe stress. Most of the studies in dogs "anesthetized" with morphine or fentanyl report decreases in blood pressure, reduction in urine production, reduction in free water clearance, and elevation in urine osmolarity. Inulin,(9,10,32) para-aminohippuric acid (PAH), and osmolar clearances were not changed.(9,10)

The conclusion was that the narcotics probably caused an increase in secretion of antidiuretic hormone but no decrease in renal plasma flow.(9,10) The addition of N2O in the dog reversed the renal effects seen with the narcotics.(10) In dogs halothane decreased renal function and produced an antidiuresis. Adding N2O potentiated the antidiuresis, perhaps through stimulation of anti-diuretic hormone release.(30) One study in humans showed the differences in hormonal stress response and renal function in patients anesthetized with halothane compared with those anesthetized with fentanyl.(38) In the fentanyl group there was no change in plasma levels of antidiuretic hormone renin, or aldosterone; a decrease in levels of cortisol, norepinephrine, and epinephrine; an increase in urine volume; and no change in creatinine clearance.

In the halothane group there was an increase in plasma levels of cortisol, aldosterone, and antidiuretic hormone and a decrease in creatinine clearance. In our clinical experience, the use of narcotics (primarily oxymorphone and fentanyl) in critically ill dogs has not produced hypotension or renal dysfunction. Hypotension and its ultimate effects on renal function vary with the method used for its production; for example, return of normal renal function occurred more rapidly in dogs made hypotensive by the administration of sodium nitroprusside than in dogs made hypotensive by the administration of
trimethaphan or by hemorrhage.(3)

In humans methoxyflurane anesthesia may produce renal failure owing to inorganic fluoride ion produced by its metabolism. (5) Methoxyflurane is metabolized in dogs, also, with the resulting production of inorganic fluoride ions. The levels of fluoride produced in dogs anesthetized at reasonable levels for reasonable durations are well within the range that produces severe renal dysfunction in humans. It appears that the canine kidney is less sensitive to the fluoride; however, with increased levels renal dysfunction does occur.(21) (See previous discussion on methoxyflurane. ) There are no reports of the sensitivity of the feline kidney to fluoride ion. Regional techniques, such as epidural analgesia, have the least impact on renal function, providing that severe hypotension does not occur.(6)

PREOPERATIVE PREPARATION
IDENTIFYING HIGH-RISK PATIENTS AND PROCEDURES
Fluid losses should be replaced. Any evidence of pre-renal failure requires vigorous hemodynamic management before surgery. Peri-operative secretion of anti-diuretic hormone, renin-angiotensin, and aldosterone can be minimized by adequate fluid loading before the induction of anesthesia. Physiologic saline, rather than low-sodium solutions, help avoid aldosterone secretion, hyponatremia, oliguria, and hypokalemic alkalosis.

MONITORING
Urinary catheterization is the only way to follow renal function in the operating room. Cardiovascular monitoring is essential in anticipating and treating intravascular hypovolemia and preventing renal ischemia.

CHOICE OF ANESTHETIC AGENTS
Methoxyflurane should be avoided (see discussion earlier in the chapter). Phenothiazine tranquilizers have the potential for producing hypotension and probably should be avoided as well. They, along with droperidol, are dopamine receptor-blocking agents and would, therefore, interfere with the renal artery dilating effects of low doses of dopamine.(34)

Agents should be chosen that provide the best cardiovascular stability. In the critically ill patient we prefer a narcotic-based anesthetic technique, usually with oxymorphone or fentanyl.

If there is concern about the possibility of narcotics or other stimuli causing an increase in secretion of antidiuretic hormone, I will administer ethyl alcohol intravenously as part of the induction technique or any time during the procedure that this concern arises. The alcohol is used because it is supposed to inhibit release of antidiuretic hormone. I make up the ethyl alcohol in a solution of appropriate IV fluid so that the concentration of ethyl alcohol is 10% (V/V). It is administered in a dosage range of 0.25 ml to 1 ml/kg (of absolute alcohol) or 2.5 ml to 10 ml/kg of the mixture.

HEMODYNAMIC MANAGEMENT
It is necessary to maintain cardiac output in order to maintain renal blood flow. There are many conflicting reports on the efficacy of various vasodilators, inotropes, and so forth on renal blood flow. A likely explanation for this discrepancy is the failure to maintain left atrial pressure, which, if allowed to decrease, may cause profound renal vasoconstriction. In experimental animals plasma renin activity varies inversely with atrial pressure.

INOTROPIC AGENTS
Calcium may be tried. Continuous infusions of drugs such as dopamine or dobutamine hydrochloride may be useful. Both drugs are beta 1 (B1) stimulants; hence, they increase myocardial contractility. They may increase heart rate and cause arrhythmias (especially under halothane anesthesia). Because they produce peripheral vasodilation, they may cause hypotension. Only dopamine stimulates the dopaminergic receptors in the renal arteries to cause renal vasodilation. The dosage of dopamine needs to be carefully controlled because as the dosage increases, dopamine begins to exert a direct alpha 1 (a1)-adrenergic effect and causes peripheral arteriolar constriction, including the renal artery. Dobutamine has little or no (a1)-adrenergic effect. Dopamine and dobutamine have both been used over the past few years. At rates of administration producing equal cardiac indexes, blood pressure, glomerular filtration rate, renal blood flow, systemic vascular resistance, and renal vascular resistance, dopamine produced much different diuretic effects. It inhibited solute and water reabsorption, resulting in an increase in urine flow that was accompanied by an increase in sodium and potassium excretion and the production of a more dilute urine.(29)

VASODILATING AGENTS
In patients with poor myocardial performance, vasodilators alone or in combination with an inotropic agent can be expected
to improve renal blood flow as long as left atrial hypotension is avoided and the decline in systemic arterial pressure is not excessive. Vasodilators are contraindicated in the presence of hypovolemia.

**VASOCONSTRICTOR AGENTS**
Inappropriate use of vasoconstrictor drugs to maintain blood pressure in the presence of hypovolemia worsens the renal insult. They should be reserved for life-threatening situations and then used only briefly until the underlying hypovolemia can be corrected. If cardiac output is inadequate, inotropic support should be provided.

**ANTIARRHYTHMIC AGENTS**
Arrhythmias that threaten cardiac output should be treated aggressively.

**FLUID**
Adequate fluid volume and type should be provided as indicated.

**KIDNEY MANAGEMENT**
In general there is agreement that mannitol is useful for protecting the kidney from swelling and other effects of ischemia when administered before, during, or after an ischemic insult. It may be given as an isotonic solution 5% to 6% or as a hypertonic 20% solution, depending on the hemodynamic and fluid status. It may be given as a slowly administered bolus 0.25 g to 1 g/kg over 10 minutes or as a continuous infusion at a rate of 0.2 g to 0.5 g/kg/hr.

Furosemide has also been shown to prevent decline in glomerular filtration rate when given before or after an ischemic insult in dogs. The dose was 10 mg/kg followed by an infusion of 10 mg/kg/hr. This dose is higher than that recommended on the package insert, which is 2.5 mg to 5 mg/kg every 6 to 8 hours.

**TREATMENT OF INTRAOPERATIVE OLIGURIA**
If the flow from the urinary catheter suddenly stops or decreases markedly, mechanical problems must be excluded first. Even if intravascular volume is thought to be appropriate, an empiric fluid challenge of 4 ml to 8 ml/kg normal saline should be given if not contraindicated because of concurrent problems. If, despite a patent urinary outflow tract, hemodynamic stability, and adequate hydration, oliguria (< 0.5 ml/kg/hr) persists, incipient acute renal failure is considered to exist. A bolus of mannitol (0.25 g-0.5 g/kg over 10 minutes) may be successful in restoring urine flow. Excessive use of mannitol without response will result in pulmonary edema, water intoxication, and dangerous hyponatremia. Loop diuretics, such as furosemide, may enhance the damage done by all renal insults and worsen hypovolemia if that is the cause of the oliguria. Furosemide should be classified with the vasoconstrictor drugs and be used only when intravascular volume is known to be adequate or excessive. In pulmonary edema, small doses (1 mg-2 mg/kg IV) may facilitate appropriate diuresis; its dilatation of capacitance vessels is also beneficial.

**SPINAL INJURY PROBLEMS**

**SPINAL COLUMN INSTABILITY**
Great care must be exercised in treating animals that have sustained trauma to the spinal cord and/or vertebral column to avoid causing further injury. The animal needs to be sedated or anesthetized if its own motion is likely to increase its injury, yet such animals must be handled very carefully after they are sedated or anesthetized because of the ease with which further injury can occur.

**RESPIRATORY INSUFFICIENCY**
Varying degrees of respiratory insufficiency may occur preoperatively, intraoperatively, or postoperatively. The type and severity vary with the site of the lesion, the degree of compression, and the degree of edema. Ventilatory assistance or control will have to be provided when reasonable respiratory function cannot be maintained by the patient.

**CARDIOVASCULAR RESPONSES TO SPINAL INJURY**
There are several different, in fact opposite, cardiovascular responses that may accompany spinal injury and that one must be able to prevent or treat.(60) At the time of injury, there is usually a short-lasting (minutes) hypertension not often seen by the clinician. This is followed by prolonged hypotension and bradycardia. Animals with spinal injuries have varying degrees of sympathetic block and therefore cannot compensate well for the hypotensive effects of motion, blood loss, or depressant drugs.
Anatomic hyperreflexia is a condition that may develop in patients with cervical or cranial thoracic lesions. It is precipitated by stimulation below the site of the lesion and may be seen with manipulation of the perineum and genitalia and distension of the bladder or rectum. The response appears to be due to an elevated level of catecholamine and increased sensitivity to catecholamines. Because the afferent limb of the baroreflex arc is still intact, bradycardia is part of the syndrome.

These anatomic imbalances need to be treated as they arise, for example, if autonomic hyperreflexia occurs during manipulation or surgery of the bowels or bladder, it needs to be controlled, preferably with a short-acting drug (as described under Head Injury: Problems).

Surgery in an animal that is partially sympathectomized should involve techniques to minimize blood loss and methods of supporting the blood pressure. These may include positional changes, appropriate fluid therapy, injection of longer lasting pressors, such as ephedrine, or continuous infusions of short-lasting pressors, such as phentylephrine or even epinephrine. Bradycardia may have to be treated with atropine, isoproterenol, or epinephrine, depending on degree, response, and anesthetic used.

MYELOGRAPHY
Myelography involves placing a needle into the cisterna magna, lumbar subarachnoid space, or both, followed by the injection of dye, which often produces stimulation. It is therefore imperative that the animal not move during this time. Either the anesthetic depth must be such that the animal does not respond or immobility must be guaranteed by skeletal neuromuscular blocking agents.

The responses that occur during injection are cardiopulmonary. In one study of 10 dogs anesthetized with halothane, we found no statistically significant changes in heart rate, blood pressure, or respiratory rate comparing measurements made 15 minutes after induction, 5 minutes before the tap, during the tap, and 5, 10, 15, and 30 minutes after the injection of the metrizamide. There were often changes (some very clinically significant) in some or all of the parameters, but the direction and degree were unpredictable. If the cardiopulmonary changes are clinically significant, they should be treated appropriately. Seizures or twitching may be seen any time after the injection of the metrizamide, even under light anesthesia.

The incidence of postmyelogram seizure with metrizamide has been variously reported. One paper reported incidences at two universities (19% at the University of Pennsylvania and 36% at the University of Illinois) and an overall incidence of 54% in dogs weighing more than 29 kg. Another paper reported a seizure incidence of 51% in dogs that were awakened from anesthesia immediately after the myelogram and 8% in dogs that had surgery after the myelogram. In a review of 25 animals that we anesthetized for myelography, the following results were obtained: post-anesthetic seizures occurred in 13 of the 25 animals (52%). Of these, six were anesthetized with halothane and seven with isoflurane; six had surgery immediately following myelography; six had cisternal taps, one a lumbar tap, and six had both; six had single attempts at tapping, seven had multiple. Seizures did not occur in 12 of the 25 animals (48%). Of these, eight were anesthetized with halothane, four with isoflurane; four had surgery immediately after myelography, eight did not; eleven had cisternal taps, one had a lumbar tap; eight had single attempts at tapping, four had multiple attempts. The metrizamide used was chemical grade.

Because of the high incidence of seizures, various anesthetic techniques have been recorded in the past. The most common use anticonvulsant drugs as preanesthetic medication delays the awakening from anesthesia, usually for an additional hour. I abandoned using anticonvulsant drugs as preanesthetics in part because the duration of effect was too short to be effective when they were needed, but mostly because the drugs did not appear to make any difference. I do not prolong the anesthetic period. If the animal convulses, I usually treat it with diazepam 0.2 mg to 0.4 mg/kg IV. If the animal convulses again within 5 to 30 minutes, I will treat it again with diazepam. If seizures occur again within 5 to 30 minutes, I treat it with pentobarbital sodium, 2 mg to 4 mg/kg IV boluses repeated until the seizures are controlled.

SKELETAL NEUROMUSCULAR BLOCKING AGENTS
Skeletal neuromuscular blocking agents such as succinylcholine and pancuronium, are sometimes used. Succinylcholine should not be used in animals with burns, trauma, nerve damage, or neuromuscular disease, or, if used, done so with caution, concern, and methods of determining serial serum potassium levels and the ability to acutely treat hyperkalemia.

Patients with these conditions may have a marked rise in serum potassium levels. The use of various drugs to prevent this increase has met with varying degrees of success. Small doses of competitive muscle relaxants given prior to the
administration of succinylcholine may prevent or decrease the response but cannot be depended upon for this effect. Hexafluorenium has been reported to prevent the increase in potassium levels in a dog study in which neither diazepam nor dantrolene controlled the response.(16) The potassium increases seen in patients with burns, trauma, nerve damage, or neuromuscular disease given succinylcholine may be clinically significant and have been responsible for causing cardiac arrest. This tissue response begins about 5 to 15 days after injury and persists for 2 to 3 months in patients who have sustained burns or trauma and perhaps 3 to 6 months in patients with upper motor neuron lesions.(23) Bleeding may be a source of several problems, including blood loss and obscuration of the visual field, which can interfere with accurate dissection and hinder the attainment of hemostasis, causing further blood loss. There are many anesthetic techniques for controlling bleeding, some easy and some more complicated.

Body position is a method that can often greatly decrease bleeding; the animal is positioned so that the surgical site is higher than the heart. Inappropriate mechanical ventilation may be used, namely, increasing the inflation time relative to exhalation. Drug-related methods vary from deepening the depth of anesthesia to the use of drugs such as sodium nitroprusside, as described under Head Injuries: Problems. With any of these techniques, care must be taken not to lower the pressure so low that perfusion of organs is compromised.

PREANESTHETIC DRUGS
There are no special considerations in regard to pre-anesthetic drugs except that phenothiazine tranquilizers, which lower the seizure threshold(14), should probably not be used in an animal that is going to have a myelogram.

INDUCTION
Any appropriate induction technique can be used.

MAINTENANCE
Any modern inhalant anesthetic is suitable; however, consideration needs to be given to the fact that plasma catecholamines may be increased. Enflurane probably should not be used in animals having a myelogram. Enflurane causes a spike and wave pattern of the electroencephalogram (EEG) similar to that seen with grand mal seizures, and dogs anesthetized with enflurane alone may have slight to very severe twitching.

POSTANESTHETIC PERIOD
The treatment of postanesthetic, myelogram seizures was discussed above. Tranquilizers or narcotics may be required postoperatively for pain or to sedate the patient until it gets accustomed to a strange splint or cast.

HEAD INJURIES
PROBLEMS
The major problem in animals with head injury is the fact that the brain can swell only a finite amount before the intracranial pressure begins to rise and severely interferes with neural function and cerebral blood flow. All facets of anesthesia for these animals must first and foremost be directed toward causing either no increase in intracranial pressure or, even better, a decrease.

All animals with head trauma being operated on for orthopaedic repair of their skull or repairs in other parts of the body should be handled in the same way. They should be put on high dosages of corticosteroids, starting Special the day before anesthesia: for example, 0.25 mg to 1 mg/ kg dexamethasone every 8 hours, including a dose after the induction of anesthesia. Monitoring should include the following, if available: arterial pressure, direct if possible; central venous pressure; arterial blood gases; serum potassium; urine output; electrocardiogram (ECG); and body temperature.

In regard to intubation, it should be stressed that coughing and bucking on the endotracheal tube causes large increases in intracranial pressure and are to be prevented.

As soon as the animal is intubated, intermittent positive-pressure ventilation should be started. Since cerebral blood flow changes with changes in PaCO2, that is, decreasing PaCO2 produces decreases in the cerebral blood flow, the goal is a moderate decrease in cerebral blood flow so that the PaCO2 remains within the range of 25 mm to 30 mm Hg.

Position is important. Every effort needs to be made not to impair venous return from the head. The head and neck should be kept in as neutral a position as possible. A 30 deg. head-up body position tends to decrease intracranial pressure and also will lessen bleeding during surgery on the head or brain.
Intravenous fluids should be kept to a minimum. Diuretics should be administered. There is some controversy about the timing of their administration. Initially, mannitol will cause a rise in intracranial pressure. If it is given slowly, the effect is minimized. Prior administration of furosemide is thought by some to prevent the rise. Some think mannitol and/or furosemide should not be administered until the skull is opened. If furosemide and mannitol are given, there may be large potassium losses that need to be replaced. Furosemide is given at 2.5 mg to 5 mg/kg IV. Mannitol dosage is variously reported, but 0.25 mg to 0.5 mg/kg should produce a 3- to 4-hour diuresis.

Controllable, induced hypotension is necessary for surgery on the brain or within the cranial vault. The production of induced hypotension often causes a tachycardia that confounds the attempts to produce hypotension; thus, B-adrenergic blocker, such as propranolol, is usually given.

Long-lasting drugs are not as desirable as short-lasting drugs in the production of hypotension because it is wise to have the blood pressure return to normal after surgery in and around the brain to make sure that hemostasis is adequate before the skull is put back together.

Propranolol should be given first, about 0.1 mg/kg IV, more if necessary, to control the heart rate, followed by a sodium nitroprusside infusion of about 20 ug/kg/min. The rate of nitroprusside infusion may vary among animals, and the fall in pressure may be precipitous. Because nitroprusside is metabolized to cyanide, it is important that too much not be given. No more than 1 mg/kg should be administered.(43) The prior administration of hydralazine may provide a background of hypotension on which to add the nitroprusside, making it more controllable and allowing a smaller total dose of nitroprusside. Nitroprusside should not be given until the skull is opened. A new drug that may be useful is verapamil hydrochloride; it will act like the propranolol and hydralazine to prevent reflex tachycardia and provide a background of hypotension. The dosage I would use is 0.1 mg to 0.2 mg/kg IV.

PREANESTHETIC DRUGS
Respiratory depressants need to be avoided until the animal can be intubated and hyperventilated; therefore, no preanesthetic medication should be administered, if possible.

INDUCTION
Induction should be with thiopental unless it is contraindicated because of the animal's condition: for example, if splenic dilatation and subsequent decrease in packed cell volume need to be avoided. Intravenous oxymorphone or fentanyl can be used in the dog. They should be given with a small amount of sedative, either pentobarbital sodium or diazepam. Lidocaine can be given 1 mg to 2 mg/kg IV to minimize the response to intubation. Etomidate may be considered as part of the induction technique since it appears to spare the cardiovascular system and to perhaps decrease cerebral blood flow, or at least not increase it. It might also be useful as part of the maintenance technique because it is believed not to accumulate. It has several side-effects, however, that may make it an unwise choice in animals with head trauma. In the unpremedicated dog there is occasional retching or seizures. Neither is ketamine to be used in the dog or cat. This drug will be discussed under Maintenance.

MAINTENANCE
Drugs that increase cerebral blood flow will also increase intracranial pressure. Halothane, methoxyflurane, enflurane, isoflurane, and N2O all increase cerebral blood flow. The increases reported vary with the individual study. Also, the rate and efficacy with which hyperventilation, that is, decreased PaCO2, can overcome the increase produced by the anesthetics are reported to be different for the various inhalants. It seems that the effects of halothane are the most difficult to overcome and those of N2O the easiest. The effects of enflurane are thought to be as difficult to overcome as those of halothane; those of isoflurane may not be too difficult. If an inhalant needs to be used, I would use isoflurane in as low a concentration as possible. The PaCO2 should be kept between 25 mm and 30 mm Hg.

Most intravenous anesthetics decrease cerebral blood flow except ketamine, which increases it. Thiopental is an excellent drug for animals with head trauma. It can be given intermittently or by continuous infusion. Concomitant administration of narcotics is useful. They decrease the total dose of thiopental required and will provide a method for rapid awakening from anesthesia, which is required in these animals. If a lot of narcotic and little thiopental is used, a rapid recovery will be
produced by the intravenous administration of a narcotic antagonist. The use of a small amount of isoflurane will also allow a reduction in the amount of thiopental needed, and recovery from the isoflurane is very rapid; its blood gas solubility coefficient is 1.4.

POSTANESTHETIC PERIOD
The major postanesthetic concern is rapid awakening and no respiratory depression, which was discussed in the previous section. Postoperative pain is usually not a problem. If the patient with head trauma has had extensive orthopaedic procedures, postoperative pain and its control must be considered. If possible, epidural analgesia may be used for several hours of postoperative pain relief without respiratory depression. In dogs a narcotic agonist/antagonist analgesic such as nalbuphine may be useful; in cats, low dosages of narcotics such as morphine or oxymorphone may be given with a tranquilizer such as diazepam.

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