

Field Sedation and Anesthesia of Ruminants



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KEYWORDS

• Bovine • Cattle • Ruminants • Field anesthesia • Sedation

KEY POINTS

- The general principles of anesthesia and monitoring should be applied to ruminants.
- Any change in the respiratory rate or tidal volume, subsequent to heavy sedation or general anesthesia, has a significant impact on respiratory function.
- Depending on the purpose of chemical restraint, different protocols and drug doses may be used; it is generally accepted that drug combinations are more effective for sedation and analgesia than any single drug.

INTRODUCTION

Dairy cows are generally tranquil and used to being handled; thus, many procedures can be performed using mild physical restraint with the aid of local or regional anesthesia while the animal is standing. This is fortunate, as recumbency and general anesthesia of ruminants have inherent risks. On the other hand, beef cattle are infrequently handled, and thus require more substantial forms of physical restraint and are more likely to require sedation. Additionally, beef cattle usually require larger doses of sedating and anesthetic drugs than do dairy cattle.

If recumbency is necessary for completion of a procedure, sedation can, in some cases, be used in association with a casting rope to induce recumbency. Surgical anesthesia is best performed with an endotracheal tube in place to protect the airway, but this may not always be feasible under field conditions.

Small ruminants, in contrast, are easier to handle, and many commonly performed procedures, such as cesarean section, can be done under local anesthesia, using mild physical restraint with the animal in lateral recumbency, and often without the need for sedation. Nevertheless, sedation has been shown to decrease the stress response and would be expected to improve the animal's comfort in some instances.

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CONSIDERATIONS FOR ANESTHESIA OF RUMINANTS

Sedatives and general anesthetics adversely alter cardiovascular and respiratory function; therefore, to improve patient safety, the general principles of anesthesia and monitoring should be applied to ruminants. In addition, ruminants have some unique features that distinguish them from monogastrics, and these must be considered in order to successfully manage the animal during the course of sedation and anesthesia.

Fasting

In adult cattle undergoing elective procedures, feed should be withheld for 24 to 48 hours, and water for 12 to 18 hours, depending on the size of the animal and the procedure to be performed. Small ruminants are generally not fasted longer than 24 hours, and water is not withheld for more than 12 hours. Excessive fasting should be avoided, as it may result in a change in ruminal flora and predispose the animal to ketosis.¹ In addition to decreasing the likelihood of regurgitation, fasting, by decreasing the mass of the ruminal contents, will ameliorate the effects of compression by the rumen on respiratory and cardiovascular function in the recumbent animal. Young ruminants on a milk diet are subject to developing hypoglycemia during episodes of fasting and anesthesia, as are all young animals; thus, they are not usually fasted. Additionally, it is prudent to periodically measure blood glucose in young animals under general anesthesia or, if that is not feasible, intravenous fluids should be supplemented with dextrose during the perioperative period. Older animals transitioning to solid feed are at a lower risk of developing hypoglycemia, and thus can be fasted for short periods.

Ruminal Tympany and Regurgitation

The volume of the rumen in the adult bovine can be up to 600 L, and because the rumen cannot be emptied by fasting prior to surgery, there is always a risk of bloating and regurgitation of ruminal contents. Distension of the rumen from gas accumulation and the loss of esophageal sphincter tone during a deep plane of anesthesia² can result in regurgitation of ruminal contents into the oropharynx.

Large volumes of gas, primarily carbon dioxide and methane, are produced in the rumen, and in the conscious animal, these gases are actively vented by eructation.³ However, under general anesthesia or heavy sedation, ruminoreticular motility and eructation are reduced or absent, and this can result in accumulation of these gases, leading to ruminal tympany. Ruminal tympany also compounds drug-induced respiratory and cardiovascular compromise by compressing the lungs and vena cava, respectively (see further discussion in the cardiovascular section). Tympany usually resolves when the animal is placed in sternal recumbency during recovery from anesthesia.

Saliva Production

The volume of saliva produced in ruminants is considerable, and volumes up to 16 and 160 L/d have been reported for sheep and cattle, respectively.³ The volume of saliva produced during anesthesia does not differ from the conscious state,⁴ but due to the inability of the animal to swallow, it appears to be greater. In any case, this copious volume of saliva can cause obstruction of the unprotected airway. Anticholinergics, such as atropine and glycopyrrolate, are not used by the authors to decrease saliva production, because large doses of these drugs are necessary to achieve a decrease,

and there is a concomitant increase in the viscosity of saliva, thus making it more difficult to drain the pharyngeal area.

Airway Protection

Endotracheal intubation is the ideal way to protect the airway of an anesthetized animal, but it is not generally practical under field conditions. Although fasting decreases the likelihood of regurgitation of ruminal contents, it is frequently necessary to anesthetize nonfasted ruminants for emergency procedures, and the risk of regurgitation and aspiration can be decreased by attention to some details. If the animal is in lateral recumbency, the risk of passive regurgitation can be decreased by elevating the proximal portion of the neck using padding and tilting the head downward to facilitate drainage of saliva and regurgitated material from the oral cavity. It is more difficult to drain the oral cavity with the animal in dorsal recumbency but, if possible, the animal's body should be placed on padding with the neck and head over the edge, and, thus, at a lower level. This placement will allow the head and neck to be placed in a more lateral position, and the head can also be tilted downward to facilitate drainage.

Endotracheal intubation poses some challenges in ruminants, and this is primarily due to their narrow and long oral cavity and the rostro-dorsal angle of the laryngeal entrance. It is also important that the animal be adequately anesthetized before attempting endotracheal intubation, as attempting intubation on an inadequately anesthetized animal may trigger regurgitation. In adult cattle, intubation is performed most easily by initially placing a mouth gag and passing a suitably sized stomach tube into the trachea using one's hand. The stomach tube serves as a guide over which the endotracheal tube is passed; the cuff of the endotracheal tube is then inflated and the stomach tube removed.

Endotracheal intubation in small ruminants and calves is commonly performed with the aid of a laryngoscope and with the animal in sternal recumbency. It is also possible, with practice, to pass a tube blindly, and this is facilitated by the use of a stylet to stiffen the tube. For this method, it is easiest if the animal is in lateral recumbency with the neck extended; the mouth is held open by an attendant, and the larynx is grasped gently in 1 hand to stabilize it. Then, the endotracheal tube is passed to the oropharynx and gently manipulated into the larynx.

Nasotracheal intubation may be helpful in maintaining an airway if orotracheal intubation is not feasible.^{5,6} The nasotracheal tube should be a few sizes smaller than the corresponding tube used for orotracheal intubation. Passage of the nasotracheal tube is facilitated by initially passing a smaller tube as a guide, and, depending on the size of the animal, a stallion urinary catheter or small-bore stomach tube works well for this purpose.

Respiratory and Cardiovascular Systems

Ruminants are sensitive to anesthetic-induced alterations in the respiratory system, and, in comparison with many other mammals, disproportionately develop ventilation/perfusion mismatch.⁷ Unique features of the respiratory system in ruminants include their smaller tidal volume and higher respiratory rate in comparison with many other similarly sized mammals.⁸ Therefore, any change in the respiratory rate or tidal volume, subsequent to heavy sedation or general anesthesia, has a significant impact on respiratory function. Hypercapnia and hypoxemia are common complications in anesthetized, spontaneously breathing ruminants, and these complications occur more frequently and are of greater magnitude in nonfasted animals.⁹ For these reasons, oxygen supplementation is recommended, especially during prolonged anesthesia.

To provide oxygen supplementation, the oxygen line should be passed into the trachea and the flow rate set to at least 15 L/min in adults. In the intubated large ruminant, it is possible to assist ventilation with the aid of a demand valve (eg, equine demand valve: JD Medical Dist. Co, Incorporated, Phoenix, Arizona) and an oxygen source. An E-type tank is suitable as an emergency source of oxygen but only lasts about 40 minutes at a flow of 15 L/min. In small ruminants, ventilation can be supported using a bag valve mask (eg, Ambu bag, Jorgensen Laboratories, Loveland, CO) to deliver air or supplemental oxygen from an E-type tank.

Anesthetic-related effects on the cardiovascular system result from the depressant effect of anesthetic drugs, and the effect of recumbency and compression by viscera on venous return and cardiac output. The latter effects are compounded in animals in dorsal recumbency and in nonfasted animals.

Musculoskeletal System

Myopathy and peripheral neuropathy are risks when large animals are immobilized. Muscle perfusion may be compromised during recumbency due to arterial hypotension, pressure on dependent muscles, poor positioning, noncompliant surfaces, and prolonged periods of recumbency. Maintaining adequate arterial blood pressure and providing padding are important preventive measures to decrease the risk of neuropathy and myopathy, particularly in large animals. A soft, grassy location or a well-bedded stall may be the best location for anesthetizing large ruminants under field conditions.

CHEMICAL RESTRAINT OF RUMINANTS

In the United States, lidocaine hydrochloride is the only modern anesthetic-related drug currently approved for use in cattle. Therefore, the administration of other sedatives and anesthetics is considered extralabel drug use.¹⁰ On the other hand, the extralabel use of such drugs in cattle is increasing in order to improve veterinary care and welfare. In addition, withdrawal periods for commonly used drugs for animals used for milk and meat production, as recommended by the Food Animal Drug Residue Avoidance & Databank (FARAD), must be carefully followed (Table 1). Nevertheless, several different groups of sedative and analgesics, as sole agents or more commonly in combination, are used to provide restraint of small and large ruminants,

Table 1 Recommended withdrawal intervals for common anesthetic/analgesic agents in ruminants			
Drug	Route of Administration	Withdrawal Intervals (d)	
		Meat	Milk
Acepromazine	IV or IM	7	2
Butorphanol	IV or IM	5 (2 for sheep) ³⁵	3 (2 for sheep) ³⁵
Detomidine	IV or IM	3	3
Guaifenesin	IV	3	2
Ketamine	IV or IM	3	3 (2 d) ^{34,35}
Lidocaine	SC (volume >20 mL)	4 (1 d) ³⁵	3 (1 d) ³⁵
Tolazoline	IV or IM	8	2
Xylazine	IV or IM	4 (5), ³⁵ (5–10) ³⁴	1 (3), ³⁵ (3–5) ³⁴
Yohimbine	IV	7	3

Abbreviations: IM, intramuscularly; IV, intravenously; SC, subcutaneously.
Data from Refs. ^{10,34,35}

either as premedication prior to general anesthesia, or for performing diagnostic or minor surgical procedures.

Route of Drug Administration

The intravenous route is the most effective method of administration in terms of bioavailability and onset of action. However, the intravenous route may not always be practical under field conditions, especially when dealing with unruly large bovines; in these animals, the intramuscular or subcutaneous route can be used initially to achieve sedation. The limitations of intramuscular and subcutaneous injection include incomplete bioavailability, delayed onset of action, and the limited volume that can be administered.

Intravenous administration of drugs

Depending on the animal in question and available facilities, intravenous drugs can be given into the jugular, auricular, or tail vein. The tail vein is commonly used for administration of small volumes when animals are restrained in a chute and when jugular injections are not practical due to an animal's disposition. It is advisable to place an intravenous catheter in a jugular vein if repeated drug administration is required or if tissue irritant solutions, such as guaifenesin, are to be administered. For large ruminants, a 14-gauge, 5.5-inch (approximately 14 cm) catheter is suitable for jugular vein cannulation, and an 18 to 20-gauge catheter is usually suitable for small ruminants or for auricular vein catheterization. Also, it is not prudent to administer guaifenesin and other potentially tissue irritant solutions into a small vein or an auricular vein, as thrombosis is likely to result, and, in the case of an auricular vein, this may result in sloughing of the pinna.

Drugs Commonly Used for Chemical Restraint of Ruminants

Alpha-2 adrenoceptor agonists

The main members of this group are xylazine, dexmedetomidine, romifidine, and detomidine. Xylazine is licensed for use in cattle in the United States and is the most commonly used sedative for chemical restraint of ruminants. An important aspect of alpha-2 adrenoceptor agonists is the availability of antagonists.

Generally, sedation induced by members of this group outlasts their analgesic effects, and xylazine administration results in the shortest duration of sedation and analgesia. Of interest, ruminants are much more sensitive to the sedating effects of xylazine than are horses; the dose of xylazine in ruminants is generally a tenth of the dose used in horses, and it also results in more profound sedation ([Table 2](#)).

Table 2
Doses of commonly used alpha-2 adrenoceptor agonists in ruminants

Drug	Route of Administration	Adult Cattle	Calf	Sheep	Goat
Xylazine (mg/kg)	IV	0.05–0.1	0.05–0.1	0.05–0.1	0.02–0.05
	IM	0.1–0.3	0.1–0.3	0.1–0.2	0.05–0.1
Dexmedetomidine (μg/kg)	IV	1–5	5–10	5–10	5–10
	IM	5–20	10–30	10–30	10–30
Detomidine (μg/kg)	IV	3–10	3–30	3–20	5–20
	IM	10–20	30–40	20–30	20–30
Romifidine (μg/kg)	IV	3–20	3–50	3–40	3–40
	IM	20–40	50–100	40–80	40–80

Abbreviations: IM, intramuscularly; IV, intravenously.

This is not the case for other alpha-2 agonists for which the drug dose is similar to that used in horses. It also seems that some breeds, particularly Brahman, are more sensitive than others to the sedating effects of xylazine. However, the response of an individual ruminant to xylazine can be quite variable, especially if the animal is excited or unruly. This topic is discussed further in the section on standing sedation.

Xylazine and other alpha-2 agonists have numerous dose-related adverse effects that necessitate special consideration. For example, small ruminants are particularly sensitive to the pulmonary effects of alpha-2 agonists.^{11,12} Activation of pulmonary intravascular macrophages (PIMs) is the primary reason for the adverse effects of alpha-2 agonists on the pulmonary system. Once activated, PIMs release prostaglandins and other vasoactive substances; this can result in alveolar edema, an increase in transpulmonary pressure, a decrease in pulmonary compliance, and pulmonary congestion.^{11,13} Although the cumulative clinical effect of these pulmonary changes can result in transient hypoxemia, these effects are well tolerated in healthy small ruminants.

Alpha-2 agonists, especially xylazine, increase the tone of the gravid uterus and constrict uterine vasculature, resulting in a decrease in uterine blood flow, and a decrease in fetal and maternal oxygen partial pressure.^{14–17} Therefore, their use during the last trimester may result in premature labor or fetal hypoxemia.

Alpha-2 agonists decrease gastrointestinal motility, secondary to inhibiting the release of acetylcholine, and this can contribute to ruminal tympany. In cattle and sheep, detomidine and xylazine inhibited ruminal contractions, and this resulted in ruminal tympany.^{18,19} The latter effect was eliminated by administration of the antagonist tolazoline, but not by yohimbine.

Phenothiazines

Acepromazine is the most commonly used agent in this group. Acepromazine has a delayed onset of action when compared with xylazine; maximum effect after intravenous administration may take 15 to 20 minutes, and its duration of action can be 4 to 6 hours. Acepromazine has minimal respiratory effects but may result in arterial hypotension, particularly at higher doses or in hypovolemic animals. Acepromazine lacks analgesic effects, and its sedative effect is less than xylazine. Therefore, as is discussed later, acepromazine is best used in combination with other drugs to achieve a clinically significant effect.

Benzodiazepines

Members of this family include midazolam, diazepam, and zolazepam. Zolazepam is commercially available only in combination with tiletamine in the product Telazol. These drugs act on gamma-aminobutyric acid receptors and, in the majority of animals, their administration results in sedation and muscle relaxation; however, when used alone in healthy animals, they can cause paradoxical excitation. It is recommended that diazepam be administered intravenously, as it is not water soluble, and intramuscular administration may be associated with tissue irritation and erratic absorption.

Benzodiazepines have minimal effects on the cardiovascular and respiratory systems and can be used for sedation in small ruminants and calves as the sole drug, but they are preferably used in combination with other agents. The use of benzodiazepines in cattle for standing sedation is not recommended, primarily because of the risk of inducing ataxia and recumbency; however, their muscle relaxant effects are beneficial when combined with ketamine for induction of anesthesia.¹

Opioids

Opioid receptors are present in the peripheral and central nervous systems and are important components of the pain pathway. Although sedation and analgesia are

the desired clinical effects of opioids, excitatory effects and behavioral changes have been associated with butorphanol administration to ruminants.^{20,21} Nevertheless, excitatory effects are more likely to occur if opioids are administered at higher doses intravenously to nonsedated animals. Butorphanol has minimal analgesic effects, but, based on the authors' clinical impressions, it seems to potentiate the sedative and analgesic effects of other agents in ruminants. Morphine is a more efficacious analgesic agent and is recommended for more painful procedures. Morphine was not associated with behavioral changes in cows in 1 study,²² but there have been anecdotal reports of morphine causing excitement in cattle (David Anderson, personal communication, 2015).

Standing Chemical Restraint of Adult Cattle

Depending on the purpose of chemical restraint, different protocols and drug doses may be used. It is generally accepted that drug combinations are more effective for sedation and analgesia than any single drug. Additionally, the response to a drug can be expected to vary greatly based on the animal's disposition and breed.

Various methods have been described to induce sedation in adult cattle. Regardless of the drug regimen used, it is important that the animal be left undisturbed for an adequate duration to get a clinically significant effect from the drug(s) before starting any manipulations. It is also important to keep in mind that the doses and combinations listed here are intended for use in healthy or minimally compromised animals, and doses should be adjusted in sick or debilitated animals.

Acepromazine

Although not a potent sedative when used alone, acepromazine combined with butorphanol or xylazine can be efficacious for sedation of tranquil bulls and dairy cows under certain circumstances. For example, in the authors' clinic, a mixture of acepromazine (10 mg) and xylazine (10 mg) is administered intravenously to sedate manageable bulls and cows for standing procedures, to facilitate placing animals on a tilt table, or to facilitate casting an animal using ropes (Sarel van Amstel, personal communication, 2016).

In a report on adult dairy cows undergoing standing cesarean section, intravenous acepromazine (7.5 mg) combined with butorphanol (10 mg) resulted in successful sedation.⁵ In adult Jersey cows undergoing laryngoscopy, acepromazine (0.035 mg/kg, intravenously) did not profoundly change the laryngeal anatomic position and function, and, thus was deemed more appropriate than xylazine for sedation when evaluating laryngeal function.²³

Alpha-2 agonists

Alpha-2 adrenoceptor agonists, particularly xylazine, are the mainstay of standing sedation, but it is important to give the appropriate dose to avoid inducing recumbency. On the other hand, if the animal is not adequately sedated with what seems to be an appropriate dose of an alpha-2 adrenoceptor agonist, it is best to add another drug from a different class rather than increasing the dose and causing recumbency or cardiorespiratory compromise.

Xylazine Xylazine is the most commonly used alpha-2 adrenoceptor agonist in cattle in North America. A simple and practical approach to achieving sedation in standing adult cattle is to administer xylazine (0.02–0.03 mg/kg, intravenously or 0.04–0.06 mg/kg, intramuscularly). These doses result in standing sedation in the majority of dairy cattle.

Detomidine Detomidine is licensed for intramuscular or intravenous use in cattle in Europe at doses of 0.01 to 0.04 mg/kg. In dairy cows, detomidine (0.01 mg/kg, intravenously) resulted in more profound sedation than did xylazine (0.02 mg/kg, intravenously), and the cows remained standing.²⁰

Alpha-2 adrenoceptor agonists combined with opioids In dairy cows, xylazine (0.02 mg/kg, intravenously) or detomidine (0.01 mg/kg, intravenously) was combined with butorphanol (0.05 mg/kg, intravenously) to compare their sedative properties. Butorphanol did not increase the duration or intensity of the alpha-2 agonist induced-sedation in that study.²⁰ However, it has been reported that butorphanol (0.05 mg/kg, intravenously), when used in association with xylazine, seemed to create better analgesia of the body wall for laparotomies.²⁴ Although it is stated that the administration of xylazine and butorphanol eliminated the need for local anesthesia during laparotomy surgery in some cattle,²⁴ it is important to understand that these combinations do not induce a state of general anesthesia; thus local or regional anesthesia of the surgical site should be provided.

Combinations of alpha-2 adrenoceptor agonists ketamine and opioids (ketamine stun) The use of sedative combinations that include ketamine is known informally as the ketamine stun. The original technique was introduced for restraint of adult cattle,²⁵ but variations of these protocols have been used.²⁶ Using these combinations, sedation and some analgesia are achieved by administering subanesthetic doses of xylazine and ketamine. An opioid, butorphanol, or less commonly, morphine, is generally added to this combination to improve sedation and analgesia. An advantage of this technique is that a smaller dose of individual drugs is given, which helps decrease the adverse effects of each drug. In addition, there is an additive, or perhaps synergistic, effect when using more than 1 drug.

The ketamine stun, using xylazine (0.05 mg/kg, intravenously) with ketamine (0.1 mg/kg, intravenously), decreased distress behavior at the time of castration and attenuated the cortisol response for the initial 60 minutes in 4- to 6-month-old Angus calves, when used without local anesthesia.²⁶ Nevertheless, as was mentioned earlier, local or regional anesthesia is necessary to achieve complete sensory blockade of the surgical site.

5-10-20 combination Intravenously administered combinations of butorphanol (0.01 mg/kg), xylazine (0.02 mg/kg), and ketamine (0.05–0.1 mg/kg) result in effective standing sedation in most adult cattle.²⁵ This drug regimen is known colloquially as the 5-10-20 combination because it contains approximately 5 mg butorphanol, 10 mg xylazine, and 20 mg ketamine, and, when given intravenously, it is suitable for standing sedation of most adult cattle (500–600 kg). With this combination, animals may show a brief period of unsteadiness, and this can be minimized by administering the ketamine intravenously 10 minutes after the xylazine–opioid combination. Alternatively, the higher end of the ketamine (0.1 mg/kg) dose can be given intramuscularly concurrently with intravenous administration of xylazine–butorphanol to prolong the sedative effect for up to 20 minutes, and to prevent the risk of behavioral changes induced by intravenous administration of ketamine (David Anderson, personal communication, 2015).

10-20-40 and 20-40-80 combinations The ketamine stun combination can also be given intramuscularly or subcutaneously to prolong the duration of effect and to decrease the risk of ketamine-induced behavioral changes.²⁵ In the authors' practice, approximately twice the intravenous dose is used for intramuscular or subcutaneous

administration. For cattle (500–600 kg), the combination is known colloquially as the 10-20-40 combination, because it includes 10 mg butorphanol (0.015–0.02 mg/kg), 20 mg xylazine (0.03–0.04 mg/kg), and 40 mg ketamine (0.06–0.08 mg/kg). The peak effect after intramuscular or subcutaneous administration is achieved in 15 to 20 minutes; thus, it is important not to disturb the animal in this time interval. Readministration of 25% to 50% of the initial doses of xylazine and ketamine can be performed to achieve the desired degree of cooperation and to prolong restraint.

For large bulls or more unruly animals, the 20-40-80 combination is used: 20 mg butorphanol, 40 mg xylazine, and 80 mg ketamine.

Table 3 contains a summary of the drugs administered for standing sedation in adult cattle.

Inducing Recumbency and General Anesthesia in Adult Cattle

Adequate sedation and analgesia are important to decrease distress and pain associated with immobilization and surgery. When recumbency is intended, particularly for general anesthesia, fasting the animal reduces the risk of regurgitation and ruminal tympany. As previously stated, adult cattle are fasted for 24 to 48 hours prior to general anesthesia for elective procedures. If repeated intravenous injections are planned or if a continuous infusion of drugs is contemplated, placement of a jugular catheter is

Drug(s)	Estimated Body Weight (kg)	Total mg of Each Drug	Route of Administration	Duration of Effect (min)	Comments
Xylazine	500–600	10–15	IV	10–20	Mild-to-moderate sedation
	500–600	20–30	IM	15–30	Mild-to-moderate sedation
Detomidine	500–600	5–20	IV, IM	40–50	Mild-to-moderate sedation; High end of dose range for IM administration
Acepromazine/ xylazine	500–600	10/10	IV	10–20	Mild-to-moderate sedation
Butorphanol/ xylazine/ ketamine	500–600	5/10/20	IV	10–15	Moderate sedation Alternatively, ketamine (50–60 mg) can be given IM instead of IV
	500–600	10/20/40	IM, SQ	20–40	More profound sedation To prolong effect, readminister 25%–50% of initial dose of xylazine and ketamine
	≥800	20/40/80	IM	20–40	For larger and/or unruly animals

Abbreviations: IM, intramuscularly; IV, intravenously; SC, subcutaneously.

recommended. It is important that the site chosen for induction of recumbency provides adequate footing and padding for the animal and, as mentioned previously, a soft, grassy area or a well-bedded stall are probably the best options.

A variety of drug regimens can be used to induce recumbency and general anesthesia, and the method used will depend on the intended purpose, type of patient, available drugs and facilities, and personal preference. Even if general anesthesia is induced, it is usually beneficial to also perform a local or regional block to anesthetize the surgical site to increase patient comfort in recovery, and help to prevent the animal from responding to surgical manipulation if the depth of anesthesia changes.

Xylazine

Use of xylazine as a sole agent can be a practical method of inducing recumbency for completion of nonpainful procedures, or it can be combined with local anesthesia for more invasive procedures. Most dairy cattle will become recumbent with xylazine doses of 0.05 to 0.10 mg/kg intravenously, and the dose is generally doubled for intramuscular administration. The administration of xylazine (0.05 mg/kg, intramuscularly) 15 minutes before positioning cows in lateral recumbency alleviated the stress response and pain-related behaviors associated with claw treatment and recumbency.²⁷ In general, beef cattle, and certainly boisterous cattle, require bigger doses of xylazine. Inducing recumbency in a xylazine-sedated animal is facilitated by the use of a casting rope.

Ketamine-xylazine-butorphanol

If the doses of individual drugs are increased over those used for standing restraint, the ketamine stun can also be used to induce recumbency and deep sedation, and, when combined with local or regional anesthesia, it is practical for performing some surgical procedures. To induce recumbency and deep sedation in an adult bovine (500–600 kg), using intravenous administration, 20 mg butorphanol, 25 mg xylazine, and 250 to 500 mg ketamine are used in the authors' practice. The duration of sedation and recumbency can be extended by administering half of the initial dose of ketamine alone or combined with 10 to 20 mg xylazine. Doses of xylazine and ketamine are doubled if the intramuscular route is chosen.

Xylazine-ketamine

A short duration (10–15 minutes) of surgical anesthesia can be achieved with the intravenous administration of xylazine (0.1 mg/kg) and a higher dose of ketamine (2 mg/kg). Alternatively, if the animal does not readily tolerate venipuncture, sedation can be induced with intramuscular xylazine (0.1–0.2 mg/kg), and anesthesia can be induced with intravenous ketamine (2 mg/kg) once the animal becomes sedated. Diazepam or midazolam (0.025–0.05 mg/kg) may be administered with ketamine to improve muscle relaxation, especially if endotracheal intubation is planned.

Another option is to administer xylazine (0.2 mg/kg) and ketamine (3–4 mg/kg) intramuscularly to provide a longer duration (15–30 minutes) of surgical anesthesia. The duration of surgical anesthesia can be further extended by administering ketamine (1–2 mg/kg) and xylazine (0.02–0.04 mg/kg) intravenously, as deemed necessary. Ideally the supplemental doses of xylazine and ketamine should be administered slowly to prevent apnea.

An opioid, butorphanol (0.02–0.04 mg/kg), or morphine (0.05–0.1 mg/kg) can be added to either of these drug protocols, with the lower end of the dose range being used intravenously.

Telazol-xylazine

Telazol has minimal muscle relaxing properties and is best combined with other drugs. At the authors' clinic, a combination of Telazol and xylazine is used predominantly to immobilize large bulls (≥ 800 kg) for procedures such as foot trimming (Marc Caldwell, personal communication, 2016). Telazol is available as a powder, and each vial contains 250 mg each of tiletamine and zolazepam. In this case, the powder is reconstituted by adding 500 mg xylazine, and 3 to 5 mL of the mixture, depending on the size and demeanor of the animal, are given intramuscularly. This mixture will provide up to 45 minutes of immobilization, and the recovery is smooth. However, local anesthesia is necessary to perform surgical procedures on these animals. The main disadvantage of this protocol is the cost of Telazol. A variation of this method is to add 100 to 150 mg of xylazine to Telazol, and add ketamine to make the volume up to 5.0 mL (as described for capturing wild cattle).

Telazol can also be administered intravenously with xylazine to induce anesthesia in ruminants. In 1 study, a mixture of Telazol (4 mg/kg) and xylazine (0.1 mg/kg) was administered intravenously.²⁸ However, 4 mg/kg Telazol seems to be an excessive dose for intravenous administration in association with xylazine (0.1 mg/kg), and an initial dose of 1 to 2 mg/kg of Telazol is recommended for induction when used with this dose of xylazine, administering more Telazol, as needed.

Ketamine-xylazine-guaifenesin infusion (triple-drip)

This mixture is informally known as triple-drip, and it can be used to induce anesthesia or maintain a state of general anesthesia. Guaifenesin is used for its muscle-relaxing effects and does not appear to have clinically significant anesthetic actions. A caution with the use of triple-drip is that guaifenesin is an irritant to tissues; thus, perivascular leakage must be avoided.

Induction of anesthesia with triple-drip For induction of anesthesia with triple-drip in an adult bovine (500–700 kg), 50 mg xylazine and 1.0 to 1.5 g ketamine are added to 1 L of a 5% guaifenesin solution, and the mixture is given to effect. An advantage of inducing anesthesia with triple-drip is that the process is relatively gradual; thus, the animal is less likely to become apneic than when a bolus of induction drugs is administered. Also, the infusion rate can be changed depending on the desired effect.

Maintenance of anesthesia with triple-drip The triple-drip mixture can also be used for maintenance of anesthesia either after induction with triple-drip itself or 1 of the previously described methods. Triple-drip, as described previously, should maintain a surgical plane of anesthesia in an adult bovine (500–700 kg) for approximately 60 minutes, and the duration will be influenced by the drugs initially used for induction of anesthesia. If a large dose of xylazine was administered at induction, the amount of xylazine in the triple-drip should be decreased accordingly.

A constraint to the use of triple-drip is the lack of commercial availability and expense of guaifenesin; however, guaifenesin can be purchased in bulk as a powder, and it can be made into a 5% solution and autoclaved in preparation for clinical use.

Ketamine-Xylazine Infusion

Because of the aforementioned issues of cost and availability of guaifenesin, an alternative is to maintain anesthesia using an infusion of only xylazine and ketamine. To facilitate administration under field conditions, appropriate doses of xylazine and ketamine can be added to a 1 L bag of a balanced electrolyte solution, such as lactated Ringer solution, and administered to effect. As in the case of triple-drip, 50 mg xylazine and 1.0 to 1.5 g ketamine added to 1 L electrolyte solution should provide surgical

anesthesia for approximately 60 minutes for an adult bovine (500–700 kg). Muscle relaxation should be satisfactory if an adequate dose of xylazine is used at induction, or it can be improved by administering 25 to 50 mg of midazolam or diazepam intravenously as a bolus or by increasing the infusion rate of xylazine and ketamine.

Capture of Wild and Aggressive Cattle

In certain instances, the behavior of an animal necessitates that sedative and anesthetic drugs be delivered remotely, and this may involve the use of a dart gun, a pole syringe, or a pistol or rifle. Under these circumstances, the volume of anesthetics that can be delivered and the distance of the animal from the delivery system are limiting factors. A pole syringe can be used at distances between 1 to 3 m (3–9 feet), and can deliver volumes up to 10 mL. Pole syringes can also be used to deliver drugs once the animal becomes recumbent but is still regarded as too dangerous to approach for hand injection. Blow pipes are useful in the range of 5 to 10 m (16–30 feet), and can deliver volumes of 3 to 5 mL. Also, blow pipes cause minimum tissue trauma due to the low-velocity injection. Pistols are generally effective within a range of 20 m (65 feet), and at distances of 20 to 40 m (65–130 feet); it is necessary to use a rifle to project the dart. In general, the maximum dart volume is 5 mL for a pistol and 10 mL for a rifle.

The volume limitation of remote capture devices restricts the drug options for capture of adult cattle. Thus, a practical option is to use a drug regimen based on Telazol, and to reconstitute 500 mg of the drug mixture with 1 mL xylazine (100 mg/mL) and add 3 to 4 mL ketamine (100 mg/mL) to bring the total volume up to 4.0 to 5.0 mL. This mixture should be sufficient to immobilize a 600 to 800-kg animal. Alternatively, the vial of Telazol powder can be reconstituted with 300 mg xylazine.

As is the case for all drug protocols, the response to these drug mixtures depends greatly on the animal's disposition. For smaller animals, the dose can be prorated. Xylazine can be reversed, if deemed necessary, at the end of the procedure.

A summary of the drugs administered for inducing recumbency and/or general anesthesia in adult cattle is included in [Table 4](#).

Recovery from Recumbency and General Anesthesia in Cattle

In general, recovery from recumbency and general anesthesia in cattle is smooth, and the animals usually recover in a controlled manner. However, the site chosen for recovery should provide adequate footing and padding for the animal and be free of obstacles that could cause injury. Additionally, the animal should be placed and supported in sternal recumbency, and, if deemed appropriate, the alpha-2 portion of the drug combination can be antagonized (as will be discussed).

Alpha-2 adrenergic antagonists

A desirable property of alpha-2 adrenergic agonists is their ability to be reversed; however, the use of alpha-2 adrenergic antagonists must not be undertaken lightly. The available drugs in this category are yohimbine, tolazoline, and atipamezole. In the authors' experience, yohimbine is not an effective reversal agent in ruminants. Tolazoline is the most commonly used member of this group in ruminants and is efficacious at reversing the actions of commonly used alpha-2 adrenergic antagonists. Atipamezole is also effective in reversing the sedative (and analgesic) effects of alpha-2 agonists in ruminants,^{29,30} but its use in cattle may be cost prohibitive.

Overdosage or rapid intravenous administration of alpha-2 adrenergic antagonists can lead to adverse effects on the cardiovascular, respiratory, and central nervous system, and these effects can result in death. Hypotension, due to vasodilation,

Table 4
Examples of drug(s) and drug combinations for inducing recumbency or general anesthesia in adult cattle

Drug(s)	Estimated Body Weight (kg)	Total mg of Each Drug	Route of Administration	Duration of Effect (min)	Comments
Xylazine	500–600	25–50	IV	10–15	Generally induces recumbency Facilitates casting with ropes, if necessary
	500–600	50–100	IM	10–20	
Xylazine/ketamine	500–600	50/1000	IV	10–15	Short period of general anesthesia Top-up doses of ketamine (1–2 mg/kg) with xylazine (0.02–0.04 mg/kg) slowly IV to prolong effect
	500–600	100/2000	IM	15–30	
Butorphanol/xylazine/ketamine	500–600	20/25/250	IV	20–30	Heavy sedation; Dose of ketamine can be increased to 500 mg to prolong recumbency
Telazol/xylazine	≥800	Reconstitute 500 mg Telazol with 500 mg xylazine and give 3–5 mL	IM	30–45	Heavy sedation with longer duration of recumbency and immobilization
Telazol/xylazine/ketamine	Wild/aggressive cattle (600–800 kg)	500/100/400	IM	30–45	Heavy sedation/general anesthesia, depending on animal's demeanor

Abbreviations: IM, intramuscularly; IV, intravenously; SC, subcutaneously.

seems to be the main adverse cardiovascular effect at clinical doses. Higher doses of alpha-2 adrenergic antagonists have an amphetamine-like effect that can result in central nervous system stimulation and tachycardia. Although these compounds can be administered intravenously, the authors generally recommend intramuscular administration to decrease the likelihood of causing adverse effects. If it is determined that the reversal is best given intravenously in a particular circumstance, the dose should be decreased and administered slowly.

Chemical Restraint of Small Ruminants

In comparison with cattle, small ruminants, especially sheep, are generally docile, are easier to handle, and can be physically restrained for intravenous or intramuscular injection. On the other hand, small ruminants are likely to become recumbent once sedated, so it is unusual to perform surgeries on sedated standing small ruminants. The same concerns regarding regurgitation, bloating, and protection of the airway described previously for large ruminants apply to small ruminants. Various drugs and drug combinations are used to induce sedation and general anesthesia, and some examples will be discussed.

Acepromazine

Acepromazine provides mild sedation but is rarely used alone for this purpose. In the authors' practice, acepromazine is sometimes used as a premedication prior to induction of general anesthesia with midazolam and ketamine. In small ruminants, acepromazine is often combined with opioids to augment its sedative effects.

Benzodiazepines

When used alone, benzodiazepines have limited application, but they can be used to induce mild sedation for nonpainful procedures (eg, radiography, ultrasonography) in tranquil animals. Midazolam (0.1–0.5 mg/kg, intravenously or intramuscularly) or diazepam (0.1–0.5 intravenously) can cause paradoxical excitation, especially if administered rapidly intravenously to healthy adult ruminants.

Benzodiazepines and butorphanol

In the authors' clinic, midazolam and butorphanol are sometimes administered intravenously or intramuscularly to induce a more profound state of sedation, compared with benzodiazepines alone. For example, this combination can be used to provide mild sedation in sheep or goats undergoing cesarean section in lateral recumbency in conjunction with local analgesia and mild physical restraint. Midazolam (0.1–0.5 mg/kg, intravenously or intramuscularly) or diazepam (0.1–0.5, intravenously) is combined with butorphanol (0.1–0.2 mg/kg, intravenously or 0.2–0.4 mg/kg, intramuscularly). An advantage of this method is that the effects of the benzodiazepines on the newborn can be reversed with the administration of flumazenil (0.01–0.02 mg/kg, intravenously), a benzodiazepine antagonist. The umbilical vein can be used for intravenous injections in the newborn.

Opioids

Opioids are mainly used in conjunction with other agents such as acepromazine, a benzodiazepine, or an alpha-2 adrenoceptor agonist for sedation and analgesia. Butorphanol (0.1–0.2 mg/kg, intravenously or 0.2–0.4 mg/kg, intramuscularly) is the most commonly used opioid, but morphine (0.05–0.1 mg/kg, intravenously or 0.25–0.5 mg/kg, intramuscularly) provides more profound analgesia. The authors have not observed adverse effects when using morphine at these doses in small ruminants.

Alpha-2 adrenoceptor agonists

Xylazine is the most commonly used drug in this group, and it produces reliable sedation; however, small ruminants are sensitive to the effects of these drugs. Xylazine doses of 0.03 to 0.05 mg/kg intramuscularly produce mild sedation, and a dose of 0.1 to 0.2 mg/kg intramuscularly produces deep sedation. However, the response depends greatly on the disposition of the animal. Nevertheless, deeply sedated animals can still be aroused and will respond to noxious stimuli. As was discussed earlier, alpha-2 agonists, particularly at higher doses and when administered intravenously, may result in significant ventilation-perfusion mismatch and hypoxemia; thus, it is best to limit the dose of these drugs and add a drug from a different group to augment sedation and analgesia.

Xylazine and butorphanol

The authors have used this combination to induce mild-to-moderate sedation at doses of 0.02 to 0.05 mg/kg intravenously for each drug, or intramuscularly at 0.05 mg/kg for xylazine and 0.1 to 0.2 mg/kg for butorphanol.

Xylazine and ketamine

This combination, at the appropriate doses, can be used to induce deep sedation in small ruminants. Administration of xylazine (0.1–0.2 mg/kg, intramuscularly) and ketamine (2–3 mg/kg, intramuscularly) produces deep sedation, but not surgical anesthesia, for about 30 minutes. For intravenous administration, the dose of each drug should be reduced; to prevent apnea, xylazine (0.02–0.05 mg/kg) can be administered initially to induce sedation, and ketamine (0.5–2.0 mg/kg) can then administered to effect. Alternatively, the mixture can be given slowly intravenously.

Xylazine and Telazol

Telazol can be substituted for ketamine for administration with xylazine, and the dose of each can be varied to attain the desired degree of sedation. Administration of xylazine (0.1–0.2 mg/kg, intramuscularly) and Telazol (0.5–1.0 mg/kg, intramuscularly) will produce profound sedation for 30 to 45 minutes, and smaller doses of each can be given intravenously to induce a lesser degree of sedation.

General Anesthesia of Small Ruminants

Depending on the circumstances and the disposition of the animal, premedication may or may not be administered. Under field conditions, most drug regimens are based on ketamine. Although ketamine has been used as the sole anesthetic agent in small ruminants, the authors do not recommend this, because ketamine alone does not provide a complete state of general anesthesia. Ketamine is primarily used in combination with xylazine, but several other combinations have also been described.

Propofol could be used for induction and maintenance of anesthesia, but it is not practical under field conditions, as it has to be administered as an infusion to maintain anesthesia. Additionally, propofol is likely to cause apnea, which would have serious consequences if the animal was not endotracheally intubated and there was no means to supply positive pressure ventilation.

Ketamine and xylazine

For intramuscular administration, xylazine can be administered at 0.1 to 0.2 mg/kg, depending on the animal's health and disposition, in association with ketamine at 5 to 15 mg/kg. Surgical anesthesia usually lasts 20 to 30 minutes, depending on the dose of ketamine administered. The authors use this drug regimen for disbudding of

kids, and the animals are usually standing within 45 minutes after xylazine (0.1 mg/kg) and ketamine (10–15 mg/kg) administered intramuscularly. The duration of anesthesia can be extended by readministering ketamine (3–5 mg/kg, intramuscularly) or 1 to 2 mg/kg intravenously as needed.

Animals may also be sedated with xylazine (0.1–0.2 mg/kg, intramuscularly), and anesthesia may be induced with ketamine administered IV to effect, but care must be taken to avoid causing apnea. In sheep, ketamine has been administered at a dose of 7.5 mg/kg intravenously in association with xylazine (0.1 mg/kg), and the combination induced a state of surgical anesthesia for 25 minutes.³¹

Ketamine and benzodiazepines

Anesthesia can be induced in nonsedated animals with ketamine (5–7 mg/kg) and a benzodiazepine (eg, midazolam or diazepam 0.25–0.5 mg/kg) administered intravenously. The dose of ketamine needed to allow endotracheal intubation depends greatly on the speed of administration. However, the duration of anesthesia is short (5–10 minutes), and premedication with xylazine (0.1–0.2 mg/kg, intramuscularly) will prolong anesthesia and decrease the dose of ketamine needed for induction of anesthesia.

Telazol and xylazine

In 1 study, Telazol (13.2 mg/kg) was administered intravenously to sheep either alone or in association with 0.11 mg/kg xylazine.³² The duration of analgesia was approximately 40 minutes in the Telazol group and 100 minutes in the Telazol and xylazine group; however, this dose was associated with apnea in some animals. As mentioned previously, this dose of Telazol is excessive for most small ruminants, and it would be best to induce anesthesia with a much smaller dose (1–3 mg/kg) and supplement as needed.

Ketamine-xylazine-guaifenesin infusion (triple-drip)

This method can be used to induce and maintain anesthesia in small ruminants. In a study in sheep, a mixture of guaifenesin (50 mg/mL), ketamine (1 mg/mL), and xylazine (0.1 mg/mL) in 5% dextrose induced anesthesia at a mean dose of 1.2 mL/kg and maintained anesthesia at 2.6 mL/kg/h. Significant hypoxemia and hypercarbia were observed throughout the course of the study; however, administration of 100% oxygen via an endotracheal tube reduced the magnitude of hypoxemia. After 1 hour of anesthesia, the sheep stood at a mean time of 96 minutes, but recovery was prolonged another 50 minutes in others.³³ Administration of lower doses and titration of the infusion to effect would presumably reduce the severity of the adverse effects.

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