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Miniature Companion Pig Sedation and Anesthesia

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Miniature Companion Pig Sedation and Anesthesia

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KEYWORDS

• Anesthesia • Miniature companion pig • Pot-bellied pig • Sedation • Surgery

KEY POINTS

- Miniature companion pigs (MCP) are increasing in popularity, and as such, there is an increased need for veterinarians trained in sedation and anesthesia for the species.
- MCPs have several species-specific qualities that can complicate injectable drug administration and create challenges for inhalational anesthesia (eg, with endotracheal intubation).
- General anesthetic complications, such as hypothermia and hypotension, are commonly described in miniature companion pigs, so monitoring of vital parameters during anesthetic procedures and recovery is crucial.

INTRODUCTION

Miniature companion pigs (MCPs, Sus scrofa domesticus) are rapidly increasing in popularity in North America. Originally, the Vietnamese pot-bellied pig was the most common MCP breed, but now multiple breeds are being kept as pets, including Kunekune, Juliana, Ossabaw Island, and others. With increasing numbers of animals and their longer (potentially 15–20 year) life spans,[1,2] there is a need for sedation and general anesthesia to perform a variety of procedures, such as routine hoof maintenance, tusk trimming, ovariohysterectomy, and castration, and more advanced techniques for diagnostic imaging and surgical interventions. This article discusses the considerations for sedation and anesthesia of MCPs, highlighting species specifics, and reviews the agents and their applications commonly used in these animals.

The authors declare that they have no relevant or material financial interests that relate to the research described in this article.
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ANATOMIC CONSIDERATIONS

Physical Examination

MCPs are often not the most tractable patients, and the ability to perform a thorough physical examination before sedation or anesthesia is challenging. A suspending sling is sometimes used to facilitate physical examination (Fig. 1). Alternative methods for calming pigs to facilitate physical examination may include such techniques as "forking" (Fig. 2).[3] In this technique, a pig is stroked with a back-scratching device or plastic fork and will move from standing position to lateral recumbency. Additional techniques to facilitate preanesthetic examination may include providing small treats, such as Cheerios, or encouraging the owner to train the pig to present in lateral recumbency for belly rubs. Other considerations for physical examination and restraint include the use of pig boards to guide them, and earplugs to protect the animal from hearing surrounding noises. In addition to the pig board, the authors have had success with holding a bucket around the head of a pig to facilitate them backing up and directing their movement. The use of a commercial hog snare for MCPs is discouraged[4] because when these snares are used, they may strain and undergo musculoskeletal damage leading to lameness.[5] Additionally, the facial conformation of some breeds of MCPs, such as the shortened face of the Vietnamese pot-bellied pig, makes restraint with snares further challenging, because they are designed for securing the elongated nose of commercial pigs.

Venous Access and Catheterization

Another consideration of MCP anatomy is the challenge of obtaining venous access. Typically, the auricular vein is the easiest location for venous access and

Fig. 1. Restraint of a companion miniature pig with a Panepinto sling (Panepinto and Associates). (*A*) The pig is directed into the sling with a pig board while the sling is lowered. (*B*) The sling is raised, capturing the limbs in the openings. (*C*) The sling is raised the entire way. At this point, required restraint for examination and injections is achieved. Care should be taken to ensure that all of the pig's limbs fall into the corresponding openings in the sling, and the appropriate-sized sling is used to minimize the chances of the pig moving out of the sling.

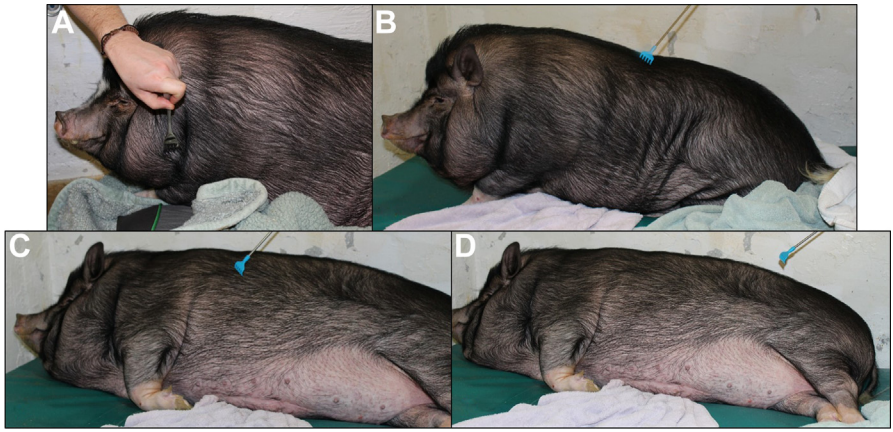

Fig. 2. Moving a pig into a lateral recumbency with tactile stimulation or "forking." (*A*) The skin around the neck is gently tapped or scratched with a fork. (*B*) The stimulation then moves to the dorsum. Alternatively a plastic "back-scratcher" is used for this purpose instead of an actual fork. (*C*) Stimulation is directed ventrally and/or caudally as the pig starts to lie down. (*D*) At the end the animal is presenting in lateral recumbency.

catheterization. This is done with the MCP in a sling or performed under sedation. A rubber band is placed around the base of the ear to aid in venous distention and identification. Topical lidocaine gel placed over the catheter site to desensitize the skin before antiseptic preparation is used for some animals if they are refractory to catheter placement. After catheter placement, it is recommended to tape a roll of gauze or an appropriately sized plastic syringe case inside the ear and incorporating the catheter into a wrapped bandage around the ear for security (**Fig. 3**). In addition to the auricular vein, catheterization of the cephalic and subcutaneous abdominal veins have been described in MCPs.[6,7] Catheterization of the jugular vein is possible, but this process

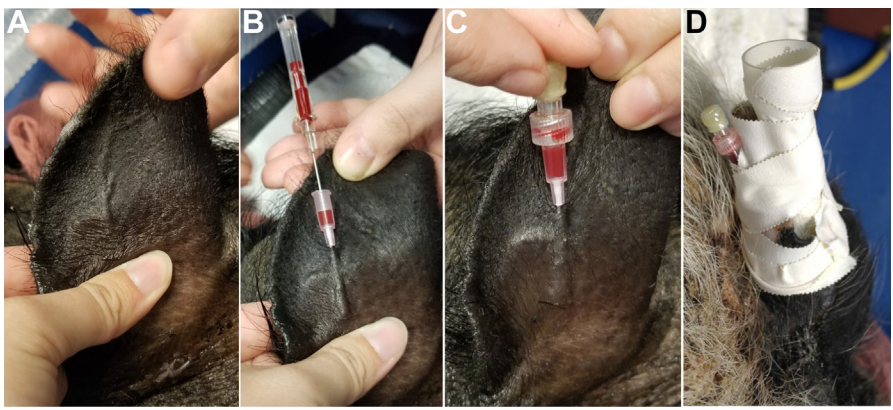

Fig. 3. Placement and securing of an auricular catheter. (*A*) The auricular vein is identified, clipped, prepared, and distended with digital pressure. (*B*) The catheter is placed in an auricular vein. (*C*) The catheter is capped before securing. (*D*) The catheter is secured with a white tape and a syringe case (alternatively, a rolled gauze is used) placed in the center of the ear to provide additional security.

typically requires a cutaneous "cutdown" approach in anesthetized patients. Multiple references exist for jugular catheter placement in commercial pigs without a cutdown approach, but these techniques are challenging in MCPs because the head conformation is typically shorter than commercial breeds. Some MCP breeds (eg, Vietnamese pot-bellied pigs) also have pronounced jowls that can complicate jugular catheterization without a cutdown. The use of ultrasound to guide jugular vein catheterization has been described for a Yucatan miniature pig.[8]

Injections

In MCPs, it is challenging to determine if injections are intramuscular (IM), subcutaneous, or potentially administered into fat deposits. To increase the likelihood of IM administration, a long needle (1.5–2 inch) is used for injection into the cervical musculature in an adult MCP.[9] A 1-inch needle may be adequate for smaller pigs.[1] The semimembranosus and semitendinosus muscles are also described for IM injection, with a 1.5-inch needle considered appropriate for most adult MCPs. When possible, the gluteal muscles should be avoided as injection sites because of the risk of injury to the sciatic nerve.[9] The intended drugs are administered via a needle connected to a 30-inch extension line with a syringe (**Fig. 4**). This prevents dislodgement of the needle and allows for the patient to relax before the injection is given to avoid trauma or incomplete injections. Alternately, a butterfly catheter can be used for IM injections in smaller pigs.

Laryngeal Anatomy

The anatomy of the porcine head and pharynx can present challenges for laryngeal visualization and endotracheal intubation. Additionally, pigs possess a separate bronchial branch (tracheal bronchus) that ventilates an accessory right lung lobe that presents a risk of being bypassed by the endotracheal tube (ETT), and thus bypassing ventilation of this lobe or intubation of the tracheal bronchus may occur.[10,11] Therefore, care should be taken to not advance the ETT too far past the level of the thoracic inlet. MCPs are also obligate nasal breathers and are prone to respiratory obstruction. Because of this, minimization of trauma during intubation should be a constant focus. Additional anatomic challenges for intubation include the elongated soft palate and the laryngeal diverticulum (discussed later in intubation section). A cadaveric image of the tracheal bronchus is presented in **Fig. 5**.

As a monogastric species, MCPs should have some degree of withholding of food, and possibly water, before anesthesia to reduce the risk of regurgitation and aspiration. Recommendations for withholding vary from ranges of food material for 6 to 12 hours before anesthesia,[6,9,12–14] and water for 2 to 6 hours prior.[1,6,9] The authors acknowledge previous water withholding recommendations, but recommend clinical judgment because water deprivation can lead to dehydration and increase stress in hospitalized patients. These time recommendations do not always lead to complete gastric emptying, especially in pigs with grazing habits or access to browse, so diet and environment should be taken into consideration when determining withholding time periods for MCPs. For pigs younger than 8 weeks of age undergoing anesthesia, it has been recommended to reduce access to food and water for a period of time of 1 to 4 hours before anesthesia,[9] with no withholding considered for suckling animals.

SEDATION

Multiple classes of agents may be considered for sedation in MCPs. A detailed chart of dosage, route, and particular considerations for sedation is listed in **Table 1**.

Fig. 4. Using a 30-inch extension line connected to an 18-gauge needle to administer anesthetic premedication/induction medications in a companion miniature pig by intramuscular injection in the neck (*top*). The *bottom* image displays the setup of 18-gauge syringe, extension line, and syringe.

Sedatives, such as acepromazine and benzodiazepines, may cause hypothermia in MCPs, so practitioners should monitor temperature during periods of extended sedation.

Benzodiazepines

Benzodiazepines, such as diazepam and midazolam, have been commonly used. Midazolam has higher affinity for receptors, quicker onset, and increased potency, but has a shorter duration of effect when compared with diazepam. Commonly administered at dosages of 0.2 to 0.5 mg/kg IM, midazolam can also be administered

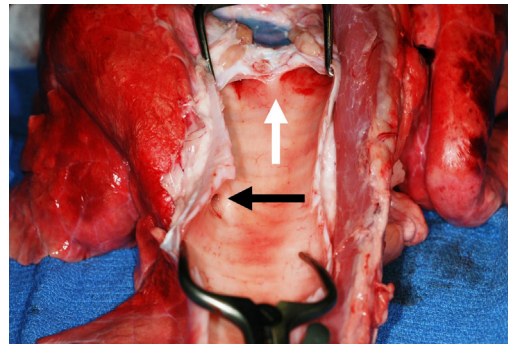

Fig. 5. Tracheal bronchus in a porcine cadaveric specimen. Opening of the tracheal bronchus (*black arrow*) is shown in proximity to the bronchial bifurcation (*white arrow*).

intranasally. This is achieved via a catheter with the stylet removed and injected during inspiration in small volumes. Although only rarely indicated (eg, overdosage), midazolam and diazepam can be reversed with flumazenil (0.01–0.02 mg/kg). Although repeated administrations of flumazenil may be necessary for complete reversal because of a short half-life. Benzodiazepines may cause unpredictable sedation when used as a single agent for sedation and require regulatory oversight for their use. For MCPs that require frequent sedation with benzodiazepines, tolerance may develop after long-term administration (28 days).[15]

α_2-Adrenergic Agonists

The α_2-adrenergic agonists, such as xylazine, dexmedetomidine, and medetomidine, have also been described for sedation in pigs.[16] These agents are commonly used in combination with an opioid and ketamine to induce heavy sedation or general anesthesia (dose-dependent). α_2-Agents result in sedation via central nervous system depression, analgesia, decrease in gastrointestinal function, bradycardia, hypotension, respiratory depression, and hypothermia. The authors have observed vomiting when α_2-agents are used, particularly at high doses. Currently, it is recommended to use α_2-agents in combination with other agents for multimodal sedation protocols. The α_2-agents in pigs are reversed with yohimbine or tolazoline.

Ketamine

Ketamine has been described as part of multiple agent protocols for sedation in MCPs. Ketamine is considered a dissociative sedative/anesthetic and induces analgesia via an *N*-methyl-D-aspartate antagonistic effect. Ketamine's sedative/anesthetic mechanism of action involves inhibiting γ-aminobutyric acid activity and potentially blocking serotonin, norepinephrine, and dopamine in the central nervous system. It does not generally cause profound cardiovascular depression, but it can result in apnea at higher doses. When the authors use ketamine for sedation, they typically incorporate it into a multiagent protocol with an opioid and α_2-agonist. Although rare, adverse reactions to ketamine have been reported in a case series of three MCPs. The signs observed ranged from erythema and tachycardia to respiratory and cardiac arrest.[17] All three pigs recovered well after implementation of epinephrine, fluid therapy, discontinuation of sedation, and supportive care. Because of the clinical appearance of these adverse effects it can be assumed that anaphylaxis to ketamine, an extremely rare phenomenon observed in people, could also be a possibility in

Table 1
Common sedative and anesthetic premedication agents in porcine

Drug	Mechanism of Action	Dose	Route	Comments	Reference
Acepromazine	Antagonism of post-synaptic dopamine receptors	0.05–1.0 mg/kg	IM, SC, IV	More sedative effect is achieved when used in combination with other drugs. Onset should be within 20-30 minutes with a duration of 30 min to several hours, depending on the dose used. Lower dosages should be considered for IV administrations.	Van Amstel[55]; Mitek[56]; Anderson & Mulon[16]
Alfaxalone	Neuroactive steroid; modulates chloride ion transport and binds to GABA receptors	1–2 mg/kg	IM, IV, intranasal	Concerns with apnea, volume required for sedation may be too large to achieve in all sizes of pigs, particularly for IM and intranasal administration.	Mitek[56]; Hampton et al[22]
Azaperone	Inhibition of dopamine and norepinephrine	1–2 mg/kg	IM	Doses >1 mg/kg may cause priapism in boars. Hypotension may be a concern for doses >1 mg/kg. IV administration is not recommended because of potential for excitation.	Van Amstel[55]; Anderson & Mulon[16]
Butorphanol	Opioid receptor agonist and antagonist	0.1–1.0 mg/kg	IM, IV	Usually used to provide sedation as part of a multiple agent protocol.	Mitek[56]; Østevik et al[12]
Dexmedetomidine	α_2-Agonist	10–20 μg/kg	IM	More effective as part of a multiple agent protocol. Cardiovascular effects are more significant at higher doses. May cause vomiting.	Mitek[56]; Carpenter[18]
Diazepam	Benzodiazepine; modulates chloride ion transport via binding to $GABA_A$ receptors	0.1–0.5 mg/kg	IV, PO	IM administration of diazepam is not recommended because of pain from injection and erratic absorption.	Bollen[10]; Carpenter[18]

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Table 1
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Drug	Mechanism of Action	Dose	Route	Comments	Reference
Midazolam	Benzodiazepine; modulates chloride ion transport via binding to $GABA_A$ receptors	0.1–0.5 mg/kg	IM, SC, IV, intranasal	Can be administered intranasally via a catheter with the stylet removed and squirted during inspiration. The volume is challenging to administer intranasally in large pigs. Consider reversal with flumazenil when large doses are used.	Carpenter[18]; Swindle & Sistino[57]
Morphine	Full opioid receptor agonist	0.1–1.0 mg/kg	IM, IV	May cause undesirable excitation in pigs. High doses may cause respiratory depression.	Booth[19]; Mitek[56]
Tiletamine + zolazepam	Tiletamine: a dissociative and an NMDA receptor antagonist Zolazepam: benzodiazepine; modulates chloride ion transport via binding to $GABA_A$ receptors	1–2 mg/kg	IM	Considered for heavy sedation, may result in rough recovery afterward.	
Xylazine	α_2-Agonist	0.5–3.0 mg/kg	IM	Cardiovascular effects are more significant than dexmedetomidine. May cause vomiting.	Anderson & Mulon[16]
Combination of medications					
Midazolam + ketamine + dexmedetomidine	Ketamine: dissociative NMDA receptor antagonist	Midazolam: 0.2 mg/kg Ketamine: 5–20 mg/kg Dexmedetomidine: 0.01–0.02 mg/kg	IM		Mitek[56]

Dexmedetomidine + midazolam + butorphanol	Dexmedetomidine: 0.01–0.04 mg/kg Midazolam: 0.1–0.3 mg/kg Butorphanol: 0.2–0.4 mg/kg	IM	Can substitute xylazine (at 1 mg/kg) for dexmedetomidine.	Carpenter[18]
Azaperone + midazolam	Azaperone: 2–4 mg/kg Midazolam: 0.5 mg/kg	IM	Sedation without analgesia.	Bollen et al[10]
Ketamine + butorphanol + midazolam	Ketamine: 5 mg/kg Butorphanol: 0.2 mg/kg Midazolam: 0.2 mg/kg	IM		Østevik et al[12]

Induction Combinations:

Agent	Mechanism of Action	Dose	Route	Comments	Reference
Acepromazine + ketamine	As listed above	Acepromazine: 0.4 mg/kg Ketamine: 15 mg/kg	IM	Approximate 5 min onset and 15–20 min duration.	Anderson & Mulon[16]
Alfaxalone	As listed above	0.9 mg/kg	IV	Induction was after premedication with: 4 mg/kg alfaxalone; 40 μg/kg medetomidine; and 0.4 mg/kg butorphanol IM.	Bigby et al[58]
Butorphanol	As listed above		IM	Induction for debilitated or compromised patients only.	Kerrie Lion Lewis, Personal Communication, 2021.
Ketamine		n/a	n/a	Not recommended as a sole induction agent. Recommended use involves combination therapy with other agents.	
Midazolam + ketamine	As listed above	Midazolam: 0.3–1.0 mg/kg Ketamine: 10 mg/kg	IM	This combination can cause hypothermia.	Bollen et al[10]; Carpenter[18]; Østevik et al[12]
Diazepam + ketamine	As listed above	Diazepam: 0.2–0.5 mg/kg Ketamine: 5–15 mg/kg	IV, titrated to effect	Anesthesia is prolonged with an additional 2–4 mg/kg of ketamine. High doses of ketamine can lead to increased risk of apnea.	Wheeler et al[29]; Carpenter[18]; Moon & Smith[32]; Østevik et al[12]

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Table 1
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Induction Combinations:

Agent	Mechanism of Action	Dose	Route	Comments	Reference
Propofol	Hypnotic	0.4–5.0 mg/kg	IV, titrated to effect	Cardiorespiratory depression.	Dubois[59]; Lagerkranser et al[60]; Coutant et al[61]; Moon & Smith[32]; Østevik et al[12]
Inhalational Induction (not usually recommend as sole method for induction of anesthesia)					
Isoflurane	CNS depression	3.0%–5.0%	Inhalation	Hypotension and respiratory depression are possible.	Anderson & Mulon[16]; Trim & Braun[6]; Needleman & Videla[62]
Sevoflurane	CNS depression	3.0%–5.0%	Inhalation	Rapid onset and recovery.	Carpenter[18]
Nitrous oxide			Inhalation	Not commonly used. Its use is described for relaxation before induction with isoflurane. Has to be administered with oxygen.	

Maintenance of Anesthesia:

Agent	Mechanism of Action	Dose	Route	Frequency	Comments	Reference
Inhalant						
Isoflurane	CNS depression	0.5%–2%	Inhalational	Entire procedure	Hypotension and respiratory depression are possible, particularly at higher doses.	Anderson & Mulon[16]; Trim & Braun[6]; Needleman & Videla[62]

Sevoflurane	CNS depression	1.0%–3.0%	Inhalational	Entire procedure	Rapid onset and recovery. Hypotension and respiratory depression are possible, particularly at higher doses.	Carpenter[18]
Halothane	CNS depression	n/a	n/a	n/a	No longer recommended because of unavailability and malignant hyperthermia concerns in commercial pigs.	
Injectable						
Fentanyl + propofol	Opioid receptor agonist and anesthetic	Fentanyl: 2.5-20 mic/kg/hr Propofol: 11 mg/kg/h	IV (as continuous infusion)	CRI	Immediate onset.	Anderson & Mulon[16]
Propofol	Hypnotic (anesthetic)	0.4–2.5 mg/kg followed by CRI of 8–12 mg/kg/h	IV	CRI		Lagerkranser et al[60]
Xylazine, ketamine, midazolam		Xylazine: 2 mg/kg Ketamine: up to 20 mg/kg Midazolam: 0.25 mg/kg	IM	Once	10-min onset, approximate 60-min duration.	Anderson & Mulon[16]
Xylazine, ketamine, telazol		Xylazine: 4.4 mg/kg; Ketamine: 2.2 mg/kg; Telazol: 4.4 mg/kg	IM	Once	Short onset, approximately 60-min duration.	Anderson & Mulon[16]
Xylazine, butorphanol, ketamine		Xylazine: 2 mg/kg Butorphanol: 0.2–0.22 mg/kg Ketamine: 5–11 mg/kg	IM	Once	Short onset, approximately 60-min duration. For minor procedures.	Anderson & Mulon[16]; Bollen et al[10]; Calle & Morris[63]

Reversal Agents:

Agent	Mechanism of Action	Dose	Route	Comments	Reference
Atipamezole	α-Receptor antagonist	0.05–0.1 mg/kg; or same volume of dexmedetomidine (0.5 mg/mL)	IM	For reversal of α_2-adrenergic agonists. Typically dosed at the same volume of dexmedetomidine administered.	Mitek[56]; Carpenter[18]
Flumazenil	Benzodiazepine receptor antagonist	0.02–0.05 mg/kg	IV, IM	Useful for reversal of diazepam, midazolam.	Mitek[56]; Papich[64]
Naloxone	Opioid antagonist	0.5–2.0 mg/kg; 0.005–0.04 mg/kg	IV	Opioid reversal. May need to be administered multiple times as necessary. The authors recommend starting with a lower dosage (0.005–0.04 mg/kg) and repeating as necessary.	Mitek[56]; Swindle & Sistino[57]
Yohimbine	α-Receptor antagonist	0.1–0.5 mg/kg	IM, SC	Useful in the reversal of xylazine, dexmedetomidine. IV administration only in emergency situations or if diluted in saline solution.	Kim et al[65]

Abbreviations: CNS, central nervous system; CRI; GABA, γ-aminobutyric acid; IV, intravenously; NMDA, *N*-methyl-D-aspartate; SC, subcutaneously; CRI, constant rate infusion; n/a: not applicable.

MCPs.[17] An agent from the same drug class but with higher potency and duration of action is tiletamine, which is available in combination with zolazepam. Tiletamine-zolazepam is used at low doses (1–2 mg/kg) in MCPs for sedation or at higher doses and in combination with other agents (opioids, α_2-agonists) for induction of anesthesia. Both tiletamine and zolazepam are long-lasting drugs and may result in prolonged or rough recoveries.

Opioids

Opioids are used as sedatives for MCPs either as sole agents, or in combination with other agents. Butorphanol and morphine are the most common opioids used for this purpose. Butorphanol is primarily used as a sedative agent and is combined with: ketamine and xylazine, tiletamine-zolazepam, tiletamine-zolazepam and xylazine, and xylazine.[18] In contrast, morphine has an efficacious analgesic, and a sedative, effect. Nevertheless, a stimulatory effect has been described for some pigs after receiving morphine.[19] Excitatory effects of morphine are more likely if higher doses of morphine are used, particularly as a sole agent. Therefore, animals should be monitored after administration of morphine for increased activity. Opioids can typically be reversed by injections of naloxone.[20]

Alfaxalone

One of the newer agents available for MCPs is alfaxalone.[21] Alfaxalone is a neuroactive steroid that works by modulating chloride ion transport and binding to γ-aminobutyric acid receptors.[22,23] This agent is used for sedation and immobilization purposes, but unlike opioids and α_2-agonists, it is not thought to provide analgesia. Because of the risk of apnea, particularly after intravenous (IV) administration of alfaxalone or when used at higher doses, endotracheal intubation, oxygen support, and ventilation support may be necessary. Recent research has demonstrated sedative effects of alfaxalone after intranasal administration (1–2 mg/kg) in the miniature breed of Yucatan swine; however, considering the low concentration of alfaxalone, the use of this route is limited by the volume that is needed to achieve the sedative effects.[22] The authors recommend a combination of alfaxalone with a benzodiazepine administered IM to achieve preanesthetic sedation.

Azaperone

Azaperone is a neuroleptic agent with the ability to tranquilize or immobilize pigs in a dose-dependent manner.[16] Salivation, hypothermia, sensitivity to noise, and hypotension have been reported in pigs administered azaperone.[16] Priapism is another adverse effect of azaperone when administered in high doses to intact boars.[16] Azaperone has no intrinsic analgesic properties, and if analgesia is desired, it should be combined with analgesic agents.

PREMEDICATION

Most premedication protocols for MCPs are similar to the previously described agents used for sedation. These protocols usually include multiple agents to achieve the maximum effect with minimum adverse effects. In some references, addition of an anticholinergic, such as atropine, has been recommended to reduce salivation and bronchial secretions before surgery. However, anticholinergics should not be administered simultaneously with α_2-agonists, because the initial bradycardia induced by α_2-agonists is a physiologic reflex in response to increased peripheral blood pressure. Some example premedication protocols include: butorphanol, midazolam, and

xylazine; butorphanol, midazolam, and medetomidine; or butorphanol, midazolam, and tiletamine-zolazepam.[6] An in-depth list of premedication protocols is provided in **Table 1**.

EPIDURAL ANESTHESIA

In MCPs, epidural anesthesia should be considered as an adjunct for procedures caudal to the thorax[20] involving the pelvic limbs and abdomen. In overconditioned animals, identifying the epidural space is challenging. Epidural anesthesia has improved the anesthetic plane in commercial pigs undergoing herniorrhaphy with injectable agents.[24] Lidocaine (2 mg/kg), bupivacaine (1 mg/kg), morphine (0.1–0.15 mg/kg), and xylazine (0.2 mg/kg) have been used for epidural anesthesia in pigs.[25–27] When considering formulations of morphine (or other medications) for epidural use, it is important to select a preservative-free formulation, because many preservatives have been associated with inflammation in other mammalian species when administered epidurally.[28]

INDUCTION

Although injectable agents are used for induction of anesthesia in MCPs, inhalational agents can also be used in premedicated animals to induce anesthesia. Induction of anesthesia in unsedated animals is not recommended because it may result in excitatory effects and cardiorespiratory compromise. Induction is achieved with a facemask and an oxygen flow rate of 3 to 4 L/min and 3% to 4% isoflurane. Standard veterinary anesthesia masks are used for MCPs, and for larger pigs, masks for induction are fashioned from gallon-sized jugs by cutting off the bottom and fixing the gas connection hose to the original opening. Drug dosages for induction and maintenance are located in **Table 1**.

ENDOTRACHEAL INTUBATION

Following induction, endotracheal intubation provides an efficient method of ventilatory support during anesthesia. A secured and sealed ETT also prevents the risk of aspiration pneumonia in the case of regurgitation. However, the anatomy of the pig can lead to some major challenges in intubation. Mainly, the jaws do not open widely, the soft palate is long, and the epiglottis frequently is trapped on top of the soft palate and needs to be repositioned. In addition, the trachea of the pig is narrow in diameter relative to body size. Pigs have a large ventral diverticulum located caudal to the glottis that can catch the ETT. Lateral laryngeal ventricles can also cause challenges for a successful intubation. A long-bladed laryngoscope is often necessary for intubation of pigs. Care should be taken to select an appropriately sized ETT, because too large of a tube can lead to trauma. ETT diameters of 6.5 to 14 mm have been recommended for MCPs.[6] **Table 2** shows a range of ETT sizes relative to body weight.

For intubation, with the pig in sternal recumbency, and after the administration of induction agents when the jaws are relaxed, the epiglottis should be released from the soft palate to visualize the glottis. The glottis should be sprayed with 0.5 to 1 mL of 2% lidocaine. An introducer or stylet is passed through the glottis and intubation attempted over the stylet. It is not uncommon for the ETT to enter the larynx and become trapped (usually at the laryngeal diverticulum). If this occurs, the tube should be rotated 90° and gently advanced again, with care to not force the tube to avoid trauma. With curved polyvinyl chloride ETT, intubation is facilitated by passing the tube down the glottis while the outward curvature of the tube is at either the 3- or

Table 2
Endotracheal tube sizes with associated weight ranges for miniature companion pigs presented to the Farm Animal Hospital at the University of Tennessee (2010–2021)

Endotracheal Tube Size (ID-mm)	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10
Patient Weight (kg)	3.0–6.8	6.4–9.6	5.0–10.0	17.3–21.4	11.4–36.5	35–78	52.0–113	46.0–122.0	35.0–69.0	60.0–160.0	86.4–164.0	108.2–117.0

9-o'clock position to avoid entrapment of the tip of the tube in the laryngeal diverticulum. Laryngeal edema from trauma, regurgitation, aspiration, or perforation of the larynx are common complications during and after intubation.[29–32] Clinicians should be aware of these complications and favor restarting the intubation process rather than applying more pressure for challenging intubations. **Figs. 6** and **7** demonstrate intubation.

MAINTENANCE

The method used for maintenance of anesthesia for MCPs is determined by factors including the availability of the equipment and drugs, duration of the proposed procedure, and underlying condition of the animal. Generally, maintenance of anesthesia is achieved by inhalational anesthesia, total IV anesthesia (TIVA), or a combination of inhalational and injectable anesthetics in partial IV anesthesia (PIVA). The most commonly used method for maintenance of anesthesia is with inhalation agents, and this is used when a moderate to long duration of anesthesia is intended. Inhalation anesthetics are beneficial because they provide a more controlled plane of anesthesia[16]; however, almost all of the inhalational anesthetics cause a dose-dependent cardiorespiratory depression and lack analgesic effects. For swine patients of up to 140 kg, a small animal anesthetic machine system is adequate.[33] Isoflurane (1%–3%) and sevoflurane (2%–4%) are commonly used inhalant anesthetics in pet pigs.[18,34] Nitrous oxide administered by a mask has been described for calming an MCP before mask induction with isoflurane.[18]

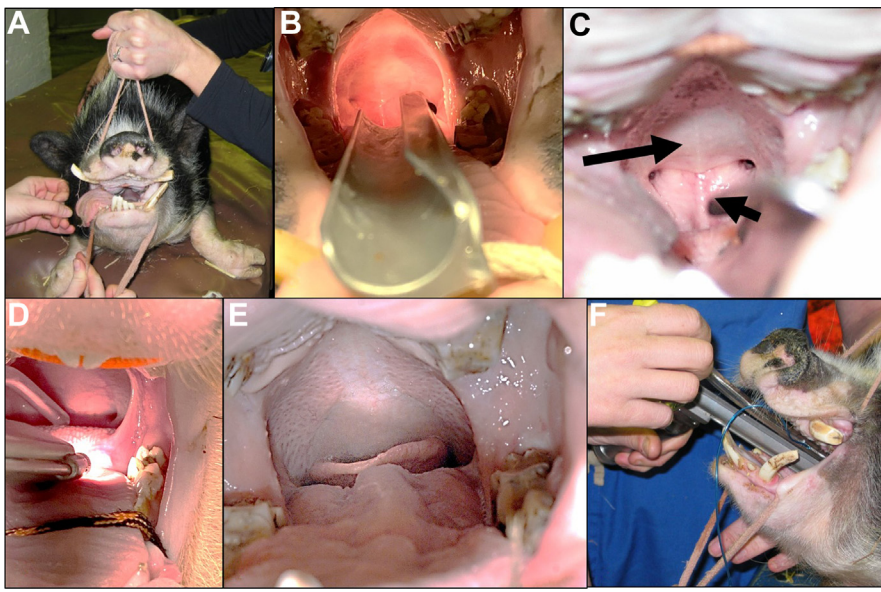

Fig. 6. Endotracheal intubation in a pig. (*A*) Animal is positioned in sternal recumbency and the jaws are gently pulled open using two appropriately sized fine ropes. (*B*) Initial placement of the laryngoscope. (*C*) Intraoral view of the epiglottis (*short arrow*) and the soft palate (*long arrow*). The tip of the epiglottis is commonly displaced dorsal to the soft palate. (*D*) Releasing the displaced epiglottis with a blunt stylet. (*E*) The tip of the epiglottis is visible after it is released using a blunt stylet. (*F*) After visualization of the glottis assisted by a laryngoscope, endotracheal tube is inserted.

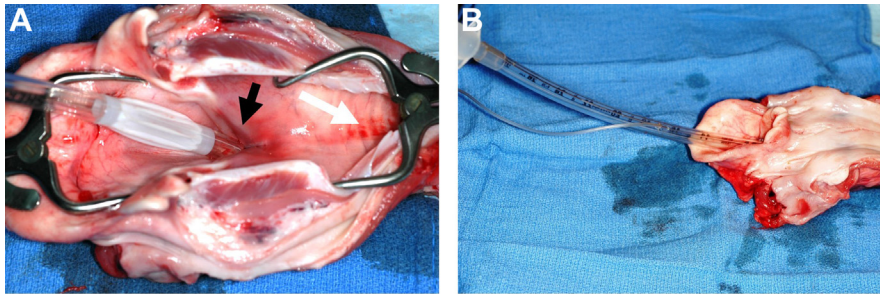

Fig. 7. Endotracheal intubation demonstration in a porcine cadaveric specimen. (*A*) If the endotracheal tube is inserted with the tip directed downward, it will most likely face the laryngeal diverticulum (*black arrow*) and will not enter the trachea (*white arrow*) as desired. (*B*) Inserting the endotracheal tube into the larynx while the tube curvature faces downward and the tip of the tube faces upward results in a successful endotracheal intubation.

Halothane is not commonly used, primarily because of the association with its use and development of malignant hypothermia in production pigs, although other inhalational anesthetics also have the potential for triggering malignant hyperthermia (MH) if the animal has the genetic predisposition.

Injectable protocols for TIVA are reported for MCPs, but these are typically recommended for minor procedures up to 20 minutes in length. Routine procedures in MCPs, such as castration, can take longer compared with other veterinary species (44 minutes in one study).[35] When planning anesthetic protocols in MCPs, one should weigh the benefits of intubation with the relative ease of an injectable protocol, because the use of injectable protocols without airway support and monitoring of the patient could be problematic for longer procedures or in compromised patients. The authors occasionally use TIVA protocols in intubated animals that may not tolerate the adverse effects of inhalational anesthetics, even at low doses (eg, animals with sepsis). With an appropriate combination of drugs, endotracheal intubation, and proper anesthetic monitoring, TIVA protocols are also used for longer procedures (60–90 minutes). PIVA protocols usually provide better homeostatic stability without significant delay in anesthetic recovery and are applied to most MCPs undergoing general anesthesia.

PERIANESTHETIC MONITORING

Anesthetic monitoring for MCPs should include electrocardiogram, pulse oximetry, temperature, capnography, and blood pressure where possible. Hypoventilation has been reported in MCPs undergoing anesthesia.[6] Using mechanical or intermittent manual ventilation resolves hypoventilation and hypoxemia (oxygen saturation by pulse oximetry of <95%). Hypotension with mean arterial pressures of less than 65 mm Hg or systolic arterial pressures of less than or equal to 85 mm Hg can also occur frequently in MCPs and may require intervention with dopamine or dobutamine (1–10 μg/kg/min continuous rate IV infusion for either), colloids, or fluid support.[6,36,37] In addition, the authors frequently use ephedrine (0.05–0.1 mg/kg, preferably IV) to improve blood pressure. Ephedrine's blood pressure boosting effect usually lasts for 10 to 20 minutes. Monitoring of circulatory function is critical for cases undergoing anesthesia for different underlying conditions, such as gastrointestinal disturbances, because the stoic nature of MCPs frequently leads to clients presenting their animals

to veterinary hospitals after some degree of circulatory compromise has occurred.[38] Hypothermia is a frequent complication from anesthesia in MCPs.[6] Normal rectal temperatures of some MCP breeds, such as Vietnamese pot-bellied pigs (37.6 ± 0.8°C, 99.7 ± 1.5°F), may be lower than those reported for other pigs, and the temperature could be different based on diurnal variations.[39] Heat support can usually be performed using different methods, such as electrical heating mats (HotDog, Augustine Surgical Inc, Eden Prairie, MN), forced warm air heating devices (Bair Hugger, 3M, Maplewood, MN), or recirculating warm water blankets.[25,36]

OTHER PERIANESTHETIC COMPLICATIONS

Malignant Hyperthermia

In addition to the previously mentioned common adverse effects of general anesthesia (hypothermia, hypotension, and hypoventilation), MH is a genetic condition caused by an altered ryanodine receptor gene and may be seen in pigs undergoing general anesthesia. Predominant clinical signs of MH include a significant and rapid rise in the body temperature and hypercapnia because of a surge in muscle activity. This condition is predominantly described in domestic pig breeds, such as the Landrace, Piétrain, and Yorkshire.[40] MH is not thought to occur commonly in MCPs, although a suspected case has been reported.[41] This case involved a 7-week-old pig anesthetized with isoflurane that was successfully treated with whole-body cooling and administration of dantrolene sodium.[41] This pig was never tested for the presence of the MH gene, so it is not confirmed if this was truly MH. One should recognize the importance of temperature monitoring while under inhalational anesthesia in these cases, because MH may occur.

Pneumothorax

Pneumothorax has been reported in a pair of Vietnamese pot-bellied pigs as a result of high airway pressures during mechanical ventilation.[42] The rupture of pulmonary bullae has also been associated with pneumothorax in MCPs.[43] Pneumothorax is managed by the application of indwelling chest tubes and suction.[43]

Concerns with Fentanyl Transdermal Patches

Fentanyl transdermal patches are used as a sustained-release analgesic formulation for pigs, potentially maintaining concentrations for as long as 72 hours after application. However, clinicians should be aware that patches can become dislodged in pigs and can present a risk to the patient if swallowed.[25,44] The authors have found that covering the patch with dynamic pressure tape, such as Elastikon, and stapling the tape to the skin can be necessary to prevent dislodgement. Even with these additional security measures, pigs have been able to remove fentanyl patches.[25,44] In one case report, a fentanyl patch was ingested by a production pig and presented with dysphoria, panting, and vocalization. This progressed to depression and recumbency.[44] In that case, the pig was successfully treated with an injection of naloxone (0.012 mg/kg).[44] Clinicians should also keep in mind that the potential for release from a fentanyl transdermal patch may be longer than the short half-life of naloxone, so multiple injections could be necessary if fentanyl absorption is ongoing from the patch. Another consideration is that if a fentanyl patch is to be used in conjunction with the procedure, vigilance is warranted to ensure that the patch is not in direct contact with a heating device because this increases the release of the drug, which may result in an overdose.

Other Considerations

Obesity is common in MCPs and can complicate anesthetic events. Drugs may be administered in adipose tissue instead of IM and may take longer to reach full effect or may last longer than desired. One should consider this when deciding whether to administer additional doses of injectable sedative or anesthetic drugs, because it may result in an overdose. These pigs can also have difficulty thermoregulating during recovery from anesthesia, and lipid embolism has been identified as a cause of perisurgical mortality in obese pet pigs.[45] Obese pigs have also been reported to have increased resistance to airflow, and inspiratory flow limitation,[46] so respiratory monitoring is crucial in these cases. Use of the American Society for Anesthesia scoring system should be considered for planning procedures for MCPs, but in a recent study, American Society for Anesthesia scores were not correlated with the likelihood of complications during MCP anesthesia.[37] This may have been caused by a small number of pigs used in that review.

Additional considerations for pet pigs undergoing general anesthesia include complications associated with surgery. Excessive hemorrhage has been reported in uterine and ovarian surgeries,[47] and identifying and collecting donor blood from pigs is challenging.

RECOVERY

During recovery, MCPs should be placed in sternal recumbency to allow for appropriate oxygenation. Oxygen supplementation during recovery via a face mask may be necessary if there is any risk for hypoxemia. Temperature should be monitored frequently, and external heat sources are frequently needed. Cold animals tend to shiver, which in turn increases their oxygen demand significantly. Because of the variability in drug absorption, delayed or prolonged absorption and action of injectable agents can occur. Pigs are obligate nasal breathers and should be monitored postextubation for any signs of upper airway obstruction. MCPs should be recovered in padded, temperature-controlled areas for comfort and to assist with any potential lingering hypothermia from anesthesia. Caution should be used when recovering pigs on straw, shavings, or blankets because of the risk of swallowing the material. Ingested blankets have been reported as gastrointestinal foreign objects that resulted in obstruction in MCPs.[36,48]

AUTHORS' RECOMMENDATIONS

In the authors' practice, the most common combination of sedative/anesthetic drugs used for MCPs include IM administration of ketamine (5–10 mg/kg), xylazine (0.5–1 mg/kg), and midazolam (0.1–0.2 mg/kg). The lower doses are usually used for sedation purposes and the higher are intended for anesthetic premedication/induction. In the latter scenarios, usually within 10 minutes after IM administration of the combination into the cervical muscles (caudoventral area to the auricle), animals demonstrate profound sedation and endotracheal intubation is possible. Alternative combinations may include a mixture of alfaxalone (1–2 mg/kg) with xylazine (same doses as previously mentioned) or dexmedetomidine (5–10 μg/kg), and midazolam (at same doses as previously mentioned). After heavy sedation is achieved with either combination, an attempt at intubation is performed. However, if the jaws are not fully relaxed or if swallowing is observed, inhalational anesthetics (isoflurane or sevoflurane) at low doses (2%–3% and 3%–4%, respectively) are administered via a tight-fitting facemask for about 5 minutes before intubation is attempted again.

For maintenance of anesthesia, the authors' preferred method is using PIVA with low concentrations of isoflurane or sevoflurane (1%–1.5% or 1.5%–2%, respectively) in combination with IV infusion of injectable anesthetics or analgesics. Examples of the latter group include ketamine (1–3 mg/kg/h) and lidocaine (3–6 mg/kg/h). PIVA techniques usually provide better cardiovascular stability compared with the use of inhalational anesthetics alone, particularly in animals with systemic comorbidities.

Drug Regulatory Considerations

When administering drugs to MCPs, it is important to keep in mind that even though they are pets, from a regulatory perspective, there is no difference between them and a commercial pig intended for food production, because this designation is based on species. Although not common, there are documented instances of MCPs entering the food chain in the United States.[49] Because of this, clinicians should provide language advising for drug withdrawal periods. Regulatory agencies, such as the Food Animal Residue Avoidance Databank (United States: www.farad.org; Canada: www.cgfarad.usask.ca), are consulted in such cases. With the role of the MCPs as pets, the authors have found that the following statement can be used to convey this message to the client, without concerns of implying their pet will be used for food production.[25,36]

> *While we understand that your MCP is a pet, we are legally obligated to inform you that there is a withdrawal period for the medications administered. Please contact us if you need this information.*

FUTURE DIRECTIONS FOR SEDATION AND ANESTHESIA

There are several considerations for sedation and anesthesia of MCPs that could be focused on given the increasing popularity of these animals as companions. For instance, trazodone is a serotonin antagonist and reuptake inhibitor that is used for anxiety and sedation in multiple species.[50] Trazadone anecdotally has been used for sedation in MCPs,[51] but investigation of clinically efficacious dosages and safety is lacking. If safe for MCPs, trazodone could be used as a sedative agent, but more investigation is necessary, because the drug is hepatotoxic in dogs and cardiotoxic in other species.[52–54] Similarly, gabapentin is anecdotally mentioned as a sedative in MCPs, but currently there are no studies evaluating its efficacy.

SUMMARY

Because of the increasing popularity of MCPs in North America, there will continue to be a demand for veterinary services to support their medical needs. Therefore, a thorough understanding of sedation and anesthesia of these patients is critical to respond to the increasing demand for these animals' veterinary care and health. Practitioners should be familiar with the agents used for sedation and anesthesia and the importance of anesthetic monitoring and recovery in MCPs.

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