Cardiopulmonary effects and induction and recovery characteristics of isoflurane and sevoflurane in foals

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Objective—To compare induction and recovery characteristics and cardiopulmonary effects of isoflurane and sevoflurane in foals.

Design—Prospective crossover study.

Animals—6 healthy foals.

Procedure—Foals were anesthetized twice (once at 1 month of age and again at 3 months of age). Anesthesia was induced by administration of the agent in oxygen through a nasotracheal tube. During maintenance of anesthesia, foals were positioned in dorsal recumbency; intermittent positive-pressure ventilation was performed. Characteristics of induction and recovery were recorded. Cardiopulmonary variables were recorded 10 minutes after anesthetic induction and 15, 30, 45, and 60 minutes later.

Results—All 6 foals were successfully anesthetized with isoflurane and sevoflurane. There were no significant differences between the 2 drugs in regard to characteristics of induction or recovery, and induction and recovery were generally smooth and unremarkable. There were no significant differences between drugs in regard to measured cardiopulmonary variables; however, both drugs caused initial hypotension that resolved over time.

Conclusions and Clinical Relevance—Results suggest that isoflurane and sevoflurane can both be used for general anesthesia of 1- to 3-month-old foals. Significant differences between the 2 agents were not detected for any of the variables measured, suggesting that quality of anesthesia with these 2 agents was comparable. (*J Am Vet Med Assoc* 2002;221: 393–398)

General anesthesia is frequently required for management of medical and surgical conditions in foals. In such cases, anesthesia can be induced with injectable agents, such as ketamine and diazepam, or inhalant agents, such as halothane or isoflurane. Regardless of the induction technique used, anesthesia is most often maintained in foals with inhalant anesthetic agents.[1-3]

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Many authors have recommended that isoflurane, rather than halothane, be used for general anesthesia of foals, because isoflurane has been associated with faster and smoother anesthetic induction and recovery, the depth of anesthesia can be altered more quickly with isoflurane, and isoflurane causes less cardiopulmonary depression.[1-3] More recently, there has been a growing interest in the use of sevoflurane for anesthesia in horses, as various studies[4-10] have shown that sevoflurane has cardiopulmonary effects comparable to those of isoflurane but allows for more rapid induction of and recovery from anesthesia and better control over the depth of anesthesia. These characteristics of sevoflurane are attributable to its lower blood:gas solubility coefficient, which results in more rapid uptake into and removal from the CNS, and may be particularly advantageous in certain patients, especially young animals that should be returned to their dams as soon as possible after anesthesia. To our knowledge, however, there have been no reports of studies comparing use of sevoflurane with use of more common anesthetic agents in foals.

The purpose of the study reported here was to compare induction and recovery characteristics and cardiopulmonary effects of sevoflurane in foals with those of isoflurane and to determine whether there were any advantages to using sevoflurane versus isoflurane in these patients.

Materials and Methods

The study protocol was approved by the University of Saskatchewan Committee on Animal Care and Use. The present study was designed to coincide with a separate study involving 2 minor orthopedic procedures in foals. These surgical procedures were scheduled to be performed at 1 month and 3 months of age. The present study, therefore, was designed so that each foal would be anesthetized once with isoflurane and once with sevoflurane, with the order of treatments randomly assigned. This crossover design allowed each foal to act as its own control and helped to minimize differences in induction and recovery characteristics associated with learned behaviors from previous anesthetic experiences.

Six healthy male Appaloosa or Appaloosa-Quarter Horse cross foals were used in the study. All foals were determined to be healthy on the basis of results of a physical examination. Foals were housed with their dams in accordance with the Canadian Council on Animal Care guidelines and were allowed ad libitum access to hay, foal ration, and fresh water.

On the day of surgery, foals were weighed and muzzled 1 hour prior to induction of anesthesia. Mares were sedated with 12.5 mg of acepromazine maleate and 5 mg of detomidine hydrochloride, IV. No sedatives or tranquilizers were administered to the foals, but foals were allowed to remain in the presence of their sedated dams until after induction of anesthesia. Foals were gently restrained, and the midcervical

region of the neck was clipped and aseptically prepared. Lidocaine hydrochloride was infiltrated SC over the jugular vein, and an 8-F venous introducer[a] was inserted in the vein to facilitate subsequent positioning of a 7-F 110-cm balloon catheter[b] that would be used for cardiopulmonary monitoring during anesthesia. Foals were nasotracheally intubated with a lubricated 10- or 11-mm silicone endotracheal tube, as described.[11]

For induction of anesthesia, foals were gently restrained, and the nasotracheal tube was connected to a semiclosed circle system with a calibrated, precision, out-of-circuit, agent-specific vaporizer. Oxygen (100%) was delivered at a rate of 40 ml/kg/min (18 ml/lb/min), and the vaporizer was set to deliver the maximum concentration of anesthetic (isoflurane,[c] 5%; sevoflurane,[d] 7%). Foals were allowed to breathe spontaneously during anesthetic induction, and a sidestream, calibrated gas analyzer[e] was used to continuously monitor inspired and expired volatile anesthetic gas concentrations.

The following values were recorded during anesthetic induction: number of breaths taken until the foal became recumbent, time to recumbency, maximum inspired anesthetic gas concentration, and maximum expired anesthetic gas concentration. In addition, an induction score ranging from 1 to 3 (1 = smooth induction with minimal excitement or struggling of the foal; anesthetic induction was safe for foal and handlers; 2 = moderate excitement or struggling of the foal; handling is more difficult; minimal risk of injury for foal and handlers; and 3 = marked excitement or struggling of the foal; potential for injury to foal or handlers) was assigned by a single individual (EKR) who did not know which inhalant anesthetic agent was being used. Relative maximum inspired and expired anesthetic gas concentrations during anesthetic induction were calculated by dividing the maximum inspired or expired anesthetic gas concentration by the reported **minimum alveolar concentration (MAC)** for isoflurane (1.31%[12]) or sevoflurane (2.31%[6]) in adult horses. No attempts were made to determine MAC in the foals in the present study.

Once foals were recumbent, they were positioned in dorsal recumbency on a padded surgical table. Anesthesia was maintained by altering the vaporizer setting as necessary to maintain a light plane of anesthesia (as determined by presence of a slow palpebral reflex and absence of ocular nystagmus and purposeful movement). The fresh gas flow rate was decreased to 10 ml/kg/min (4.5 ml/lb/min). An IV catheter[f] was aseptically placed in the contralateral jugular vein, and lactated Ringer's solution was administered at a dosage of 5 to 10 ml/kg/h (2.3 to 4.5 ml/lb/h), IV. Butorphanol tartrate (0.1 mg/kg [0.05 mg/lb], IV) was administered to provide intraoperative analgesia. Intermittent positive-pressure ventilation was initiated; ventilation parameters were altered as necessary to maintain $PaCO_2$ between 45 and 55 mm Hg during maintenance of anesthesia.

The skin over the lateral metatarsal artery was clipped and aseptically prepared for placement of a catheter[g] for direct monitoring of arterial pressure. The catheter was connected to a pressure transducer via noncompliant plastic tubing primed with heparinized saline solution. The transducer was connected to a physiologic monitor,[h] and **systolic arterial pressure (SAP)**, **mean arterial pressure (MAP)**, and **diastolic arterial pressure (DAP)** were continuously monitored. The transducer was zeroed with the point of the shoulder as a reference point.

The distal port of the balloon catheter in the jugular vein was connected to a pressure transducer, and the catheter was advanced until the balloon tip was wedged in the pulmonary artery. Correct placement was confirmed by observation of characteristic waveforms. The balloon was deflated, and the catheter was secured in this position. The distal port of the catheter was used to monitor **mean pulmonary arterial pressure (MPAP)**, and the proximal port was used to measure **central venous pressure (CVP)** and to inject 5% dextrose solution for determination of **cardiac output (CO)**. The thermistor of the catheter was connected to a CO computer[i] and was used to measure CO and core temperature. Cardiac output was determined with a thermodilution technique at end-expiration; the ventilator was turned off prior to injection of dextrose solution. Ten milliliters of room temperature 5% dextrose solution was injected at a constant rate via the proximal catheter port to measure CO. Five measurements were performed in close succession (< 3 minutes), and the high and low values were discarded. The remaining 3 values were averaged, and the mean value was recorded.

Heart rate (HR) was recorded directly from the physiologic monitor. **Stroke volume (SV)** was calculated by dividing CO by HR. **Stroke index (SI)** and **cardiac index (CI)** were calculated by dividing SV and CO by body weight. Systemic vascular resistance was derived from measured data.

Heparinized blood samples were obtained from the lateral metatarsal artery for measurement of PaO_2, $PaCO_2$, pH, and bicarbonate (HCO_3^-) concentration. Samples were immediately analyzed with a blood gas analyzer.[j] Blood gas values were corrected for body temperature. Minute ventilation was measured with a Wright respirometer[k] inserted between the endotracheal tube and the anesthetic circuit.

Data were collected 10 minutes after foals became recumbent (baseline) and 15, 30, 45, and 60 minutes later. Body temperature, HR, **respiratory rate (RR)**, SAP, MAP, DAP, CVP, CO, PaO_2, $PaCO_2$, pH, HCO_3^- concentration, and minute ventilation were measured at each time, except that samples for blood gas analyses were collected only at baseline and 30 and 60 minutes later. After data were collected at the 60-minute time point, surgery was performed on the foals.

At the conclusion of the surgical procedure, positive-pressure ventilation was discontinued, and foals were disconnected from the anesthetic circuit and allowed to breathe room air. They were moved to a padded recovery stall and placed in left lateral recumbency. The nasotracheal tube was removed when the swallow reflex returned. Each foal was assisted during anesthetic recovery by 2 experienced handlers who did not know which inhalant anesthetic agent had been used. Foals were gently restrained in lateral recumbency until deemed awake and strong enough to attempt to stand. Once standing, foals were supported as necessary and allowed to walk, with assistance if necessary. Once they had recovered sufficiently, foals were returned to their dams. Total surgery time and total anesthesia time were recorded for each foal.

The following values were recorded during anesthetic recovery: time to first movement, time to swallowing, and time to standing. In addition, a recovery score ranging from 1 to 3 (1 = smooth recovery with minimal excitement or struggling of the foal; anesthetic recovery was safe for foal and handlers; 2 = moderate excitement or struggling of the foal; handling is more difficult; minimal risk of injury for foal and handlers; and 3 = marked excitement or struggling of the foal; potential for injury to foal or handlers) was assigned by a single individual (EKR) who did not know which inhalant anesthetic agent had been used.

Statistical analyses—Examination of descriptive statistics suggested that data for each of the measured variables were normally distributed. Accordingly, paired *t* tests were used to compare induction and recovery characteristics obtained when foals were anesthetized with sevoflurane with results obtained when foals were anesthetized with isoflurane. A 2-way ANOVA followed by the Bonferroni test was used to compare cardiopulmonary data between agents. Within a drug treatment, cardiopulmonary effects over time

were compared by use of a repeated-measures 1-way ANOVA with Bonferonni test. All analyses were performed with standard software[l,m]; values of $P < 0.05$ were considered significant. Data were reported as mean ± SD.

Results

Five foals were randomly assigned to be anesthetized with sevoflurane first (at 1 month of age) and isoflurane second (at 3 months of age), and 1 was randomly assigned to be anesthetized with isoflurane first and sevoflurane second. Mean ± SD body weight of the foals during anesthesia with sevoflurane was 92.3 ± 34.8 kg (203.1 ± 76.6 lb). Mean body weight of the foals during anesthesia with isoflurane was 127.8 ± 22.0 kg (281.2 ± 48.4 lb).

Induction—No complications developed during anesthetic induction in any of the foals. There was no breath-holding during induction with either agent, and for both agents, quality of induction was judged to be acceptable. For all variables examined, values obtained during anesthetic induction with sevoflurane were not significantly different from values obtained during anesthetic induction with isoflurane (**Table 1**).

Relative maximum inspired and expired concentrations during induction (ie, maximum concentration expressed as a multiple of the MAC) were similar for the 2 agents, suggesting that equipotent doses of the drugs were being delivered by the circuit. In addition, induction scores were similar. During anesthesia with sevoflurane, 1 of 6 foals was assigned an induction score of 3. Similarly, during anesthesia with isoflurane, 1 of 6 foals was assigned an induction score of 3. No foals or handlers were injured during anesthetic induction.

Maintenance—Mean ± SD total anesthesia times (isoflurane, 134.3 ± 15.1 minutes; sevoflurane, 142.8 ± 19.3 minutes) were similar for the 2 agents. There were no adverse incidents that necessitated intervention. Relative expired anesthetic gas concentrations (ie, expired gas concentration divided by MAC) during maintenance of anesthesia ranged from 0.9 to 1.1 for both agents.

Throughout the maintenance period, mean HR ranged from 63 to 73 beats/min (**Table 2**). No significant changes in HR over time were detected, nor were any arrhythmias recorded. Arterial blood pressures were not significantly different between drugs at any

Table 1—Characteristics of anesthetic induction with isoflurane and sevoflurane in 6 foals at 1 and 3 months of age

Variable	Isoflurane	Sevoflurane	*P* value
Relative maximum inspired concentration	1.81 ± 0.33	1.56 ± 0.59	0.32
Relative maximum expired concentration	1.17 ± 0.22	1.16 ± 0.34	0.98
Time to recumbency (min)	2.10 ± 0.50	2.50 ± 0.95	0.44
Breaths to recumbency	45 ± 13	73 ± 32	0.10
Induction score	1.67 ± 0.81	1.50 ± 0.83	0.74

Data are given as mean ± SD.
Relative maximum inspired and expired anesthetic gas concentrations were calculated by dividing maximum inspired or expired anesthetic gas concentration by the reported minimum alveolar concentration for isoflurane (1.31%) or sevoflurane (2.31%) in adult horses.
Possible induction scores ranged from 1 to 3; *See* text for details of scoring criteria.

Table 2—Cardiovascular indices during maintenance anesthesia with sevoflurane and isoflurane in 6 foals at 1 and 3 months of age

	Anesthesia time				
Variable	Baseline	15 min	30 min	45 min	60 min
Heart rate (beats/min)					
Sevoflurane	73 ± 10	69 ± 9	72 ± 11	72 ± 13	73 ± 12
Isoflurane	64 ± 11	63 ± 13	65 ± 11	67 ± 13	68 ± 13
Systolic arterial pressure (mm Hg)					
Sevoflurane	67 ± 11	82 ± 27	107 ± 18*	110 ± 30*	112 ± 23*
Isoflurane	80 ± 13	81 ± 13	96 ± 28	113 ± 29	127 ± 23*
Mean arterial pressure (mm Hg)					
Sevoflurane	44 ± 7	56 ± 22	78 ± 18*	82 ± 24*	84 ± 18*
Isoflurane	46 ± 8	53 ± 11	69 ± 27	85 ± 28*	96 ± 21*
Diastolic arterial pressure (mm Hg)					
Sevoflurane	31 ± 6	41 ± 18	62 ± 15*	67 ± 21*	69 ± 16*
Isoflurane	30 ± 6	38 ± 9	55 ± 25	69 ± 25*	78 ± 20*
Central venous pressure (mm Hg)					
Sevoflurane	1 ± 4	–1 ± 3	0 ± 4	2 ± 5	2 ± 5
Isoflurane	–1 ± 1	0 ± 2	–1 ± 1	0 ± 2	2 ± 4
Cardiac index (ml • min^{-1} • kg^{-1})					
Sevoflurane	101 ± 25	100 ± 19	117 ± 35	110 ± 45	107 ± 30
Isoflurane	96 ± 31	93 ± 17	94 ± 25	99 ± 28	116 ± 32
Stroke index (ml • kg^{-1})					
Sevoflurane	1.4 ± 0.3	1.5 ± 0.2	1.6 ± 0.3	1.5 ± 0.4	1.1 ± 0.3
Isoflurane	1.4 ± 0.2	1.4 ± 0.2	1.4 ± 0.3	1.4 ± 0.3	1.7 ± 0.4
Systemic vascular resistance (dyn • s • cm^{-5})					
Sevoflurane	399 ± 131	519 ± 218	605 ± 95	656 ± 180	697 ± 207
Isoflurane	324 ± 50	373 ± 93	470 ± 130	553 ± 154	540 ± 148

Data are given as mean ± SD.
*Significantly ($P < 0.05$) different from baseline value.
Anesthesia was induced by administration of anesthetic agents through a nasotracheal tube; baseline values were collected 10 minutes after foals became recumbent. Foals were maintained with intermittent positive-pressure ventilation.

Table 3—Respiratory and blood gas indices during maintenance anesthesia with sevoflurane and isoflurane in 6 foals at 1 and 3 months of age

	Anesthesia time				
Variable	Baseline	15 min	30 min	45 min	60 min
Respiration rate (breaths/min)					
Sevoflurane	14 ± 2	13 ± 1	13 ± 2	12 ± 2	12 ± 1
Isoflurane	12 ± 1	12 ± 1	12 ± 1	13 ± 2	12 ± 2
Minute ventilation (L/min)					
Sevoflurane	14.9 ± 5.2	15.5 ± 5.5	15.2 ± 5.8	15.3 ± 6.0	14.0 ± 5.4
Isoflurane	17.8 ± 1.3	17.8 ± 1.9	16.5 ± 2.5	17.6 ± 3.4	17.1 ± 2.3
Pa_{O_2} (mm Hg)					
Sevoflurane	257 ± 110	ND	270 ± 105	ND	272 ± 64
Isoflurane	253 ± 72	ND	303 ± 78	ND	246 ± 96
Pa_{CO_2} (mm Hg)					
Sevoflurane	56 ± 9	ND	49 ± 5	ND	48 ± 3
Isoflurane	51 ± 5	ND	51 ± 3	ND	50 ± 3
Arterial pH					
Sevoflurane	7.33 ± 0.05	ND	7.38 ± 0.03	ND	7.38 ± 0.02
Isoflurane	7.35 ± 0.02	ND	7.36 ± 0.01	ND	7.36 ± 0.01
Bicarbonate (mmol/L)					
Sevoflurane	29 ± 0.9	ND	29 ± 1.2	ND	28 ± 1.0
Isoflurane	28 ± 1.4	ND	28 ± 1.2	ND	29 ± 1.4

ND = Not determined.
See Table 2 for remainder of key.

Table 4—Characteristics of recovery from anesthesia with isoflurane and sevoflurane in 6 foals at 1 and 3 months of age

Variable	Isoflurane	Sevoflurane	*P* value
Time to first movement (min)	3.2 ± 2.3	4.1 ± 1.5	0.43
Time to swallowing (min)	4.8 ± 2.5	4.6 ± 1.1	0.87
Time to standing (min)	12.5 ± 4.5	9.2 ± 1.5	0.18
Recovery score	1.67 ± 0.51	1.33 ± 0.81	0.36

Data are given as mean ± SD.
Possible recovery scores ranged from 1 to 3; *See* text for details of scoring criteria.

time point. However, with sevoflurane, SAP, MAP, and DAP were all significantly increased, compared with baseline pressures, at 30, 45, and 60 minutes. With isoflurane, SAP and MAP were significantly increased at 45 and 60 minutes, and DAP was significantly increased at 60 minutes. There were no significant differences in CVP, CI, SI, or SVR between drugs or over time.

Controlled ventilation maintained Pa_{CO_2} within our projected range during maintenance of anesthesia, and values for Pa_{O_2}, pH, and HCO_3^- concentration were all maintained within acceptable ranges (**Table 3**). There were no significant differences in these variables between drugs or over time.

Recovery—For all variables examined, values obtained during recovery from anesthesia with sevoflurane were not significantly different from values obtained during recovery from anesthesia with isoflurane (**Table 4**).

Discussion

Results of the present study suggest that isoflurane and sevoflurane can both be used for general anesthesia of 1- to 3-month-old foals. We did not detect any significant differences between the 2 agents in regard to any of the variables measured, which suggests that quality of anesthesia with these 2 agents was comparable. However, initial arterial hypotension was detected with both drugs. Therefore, anesthetic depth and cardiovascular indices (HR, heart rhythm, and arterial blood pressure) should be closely monitored during the early anesthetic period, and supportive treatment should be given if necessary.

In the present study, we chose to induce anesthesia with the inhalant anesthetic agents alone so that we could evaluate the effects of these drugs without confounding associated with use of injectable anesthetic agents. Nasotracheal intubation was easily performed in these foals with minimal restraint, and induction of anesthesia was smooth, regardless of whether isoflurane or sevoflurane was used, with only 1 foal assigned an induction score of 3 with each agent. Other authors have found this technique to result in smooth induction, without the potential for struggle in foals that object to placement of a mask or the smell of the agent.[11]

During anesthetic induction, the fresh gas flow was set to deliver oxygen at a rate of 40 ml/kg/min in an attempt to lower the time constant of the circuit, encourage uptake of the anesthetic agent, and decrease rebreathing of diluted gas concentrations. This fresh gas flow rate was 3 to 4 times the flow rate we had planned to use for maintenance of anesthesia in the foals. The anesthetic induction technique was consistent with techniques used for adult horses.[13]

The MAC of an inhalant anesthetic agent is the alveolar concentration required to prevent purposeful movement in response to a painful stimulus in 50% of a population. It has previously been reported that MAC values for various anesthetic agents in foals are similar to those in adult horses.[3] For this reason, we used reported values for MAC of isoflurane (1.31%[12]) and sevoflurane (2.31%[6]) in adult horses when calculating relative maximum inspired and expired anesthetic gas concentrations in this study. Mean relative maximum inspired gas concentrations for isoflurane (1.56) and sevoflurane (1.81) were similar, suggesting that equipotent doses of the anesthetic agents were delivered. More importantly, mean relative maximum expired gas concentrations at the time of recumbency for isoflurane (1.17) and sevoflurane (1.16) were nearly identical, suggesting that relative doses of drugs received by the foals were not significantly different. Interestingly, the mean relative maximum expired concentration of sevoflurane (1.16) in these foals was similar to the reported value at the time of recumbency in adult horses (1.10) in which anesthesia was induced with sevoflurane delivered by mask.[6]

Times to recumbency were not significantly different between drugs in the present study, and both agents provided for rapid, smooth induction of anesthesia in 2 to 3 minutes, on average. These anesthetic induction times were shorter than those previously reported for isoflurane (4 minutes)[2]; however, in that study, the investigators used a step-up approach to delivering the agent, rather than immediately setting the vaporizer to deliver the maximum concentration, as was done in the present study.

In the present study, although mean number of breaths to recumbency was lower when isoflurane was used, a significant difference was not detected between isoflurane and sevoflurane. In addition, it is not clear whether number of breaths to recumbency is a useful method for comparing effects of anesthetic drugs. Respiratory rate can vary for many reasons, including age and degree of excitement. Although we did not measure tidal volume or minute ventilation during induction in these foals, we suspect that these measurements would have been more useful for comparing agents than recording the number of breaths required to induce recumbency.

All inhalant anesthetics cause dose-dependent cardiopulmonary depression.[2,6-8,10,12] Cardiopulmonary effects of isoflurane in foals and adult horses and cardiopulmonary effects of sevoflurane in adult horses have been studied[2,6-8,10]; however, to our knowledge, the effects of sevoflurane in foals have not been reported previously.

Cardiovascular changes observed in this study reflect those that may occur during mechanical ventilation. We elected to control ventilation during maintenance anesthesia of these foals to ensure delivery of the anesthetic agents and maintain Pa_{CO_2} within a narrow range. Arterial P_{CO_2} > 70 mm Hg may result in increases in CO and blood pressure secondary to catecholamine release,[14] and variations in depth of anesthe-

sia may alter sympathetic tone. Thus, intermittent positive-pressure ventilation was used to minimize variations in measured cardiovascular variables associated with variable depth of anesthesia and hypoventilation-associated hypercarbia. Although intermittent positive-pressure ventilation may affect the cardiovascular system by decreasing venous return to the heart,[15] we considered the effects to be equivalent between the 2 anesthetic drugs, as there were no significant differences between drugs in regard to ventilation conditions.

Knowing that the foals were exposed to comparable levels of each anesthetic agent, as evidenced by similar relative expired gas concentrations, we feel confident that the drugs were administered at equipotent doses. Heart rates were found to be similar between treatments, with mean values ranging from 63 to 73 beats/min, which is consistent with previous reports[3] of HR in anesthetized foals. Heart rates and rhythm were stable during maintenance anesthesia, which has also been found in adult horses anesthetized with these 2 agents.[7,8]

Sevoflurane has been found to decrease blood pressure, CO, and SVR similarly to isoflurane in adult horses.[8] In these foals, baseline SAP, MAP, and DAP were low, and under normal clinical conditions, intervention would have been instituted to support the patients had these values been measured. However, during the next 30 to 60 minutes, blood pressure values increased into acceptable ranges with both agents. This improvement in blood pressure has also been seen in adult horses anesthetized with these agents.[7,10] In both of these previous studies, blood pressure was initially low after mask induction but increased over time.

Arterial blood pressure may increase as a result of an increase in CO, SVR, or both. In these foals, there were no measured changes in CI or SI over time that could account for the observed increases in arterial blood pressure. There were also no significant differences in these indices between drugs. Foals have been reported to have CI up to 2 times the CI in adult horses, with values in awake foals near 170 ml/kg/min.[3] Awake adult horses have been reported to have CI of approximately 75 ml/kg/min,[16] and CI during anesthesia with isoflurane or sevoflurane and controlled ventilation were between 25 and 35 ml/kg/min.[10] Foals in the present study had mean CI between 93 and 117 ml/kg/min during anesthesia, which would approximate the 30 to 50% decrease, compared with values in awake animals, in anesthetized adult horses under similar conditions.

Blood pressure could have also increased as a result of progressive vasoconstriction, measured as an increase in SVR. We did observe an increase in SVR over time with both agents, but at no time was SVR significantly different from baseline with either drug. Increases in SVR have been reported in adult horses during maintenance of anesthesia with controlled ventilation.[10] Foals reportedly have lower SVR than adult horses[1,3]; however, values in the present study were higher than those reported for adult horses anesthetized with these agents.[10] Others have shown that sevoflurane causes minimal decreases in SVR with increased drug concentrations and have suggested that sevoflurane has minimal vasodilating effects on blood vessels.[7]

Although we attempted to collect data when foals were hemodynamically stable, we retrospectively suspect that baseline data (10 minutes after recumbency) may have been collected when foals were not yet in a steady state of anesthesia. This could help to explain the relatively greater degree of cardiovascular depression at baseline. Clinically, we have often observed that foals become hypotensive at the beginning of an anesthetic episode, but that these changes become less severe as anesthesia progresses. We suspect that even though relative expired gas concentration at baseline was similar to that at other data collection times, foals may have been at an unstable plane of anesthesia when baseline values were recorded.

The cardiovascular effects of butorphanol were considered to be negligible in these foals. In previous research, administration of butorphanol at a dose of 0.1, 0.2, or 0.4 mg/kg (0.05, 0.09, or 0.18 mg/lb), IV, was found to have negligible effects on HR, blood pressure, and CO in adult horses and ponies.[17,18] In ponies, a transient decrease in blood pressure was observed following IV administration of butorphanol but was considered insignificant.[18] Whether administration of butorphanol to these foals may have contributed to the observed initial hypotension is not clear from our data.

Recovery from anesthesia was smooth and predictable with both agents, and we did not detect any significant differences between drugs in regard to time to first movement, time to swallowing, or time to standing. Mean time to standing with sevoflurane (9.2 minutes) was similar to times previously reported for adult horses (8 to 10 minutes),[6,7] whereas mean time to standing with isoflurane (12.5 minutes) was similar to results of a previous study[2] of isoflurane in foals (14.7 minutes). All foals were reintroduced to their dams within 15 minutes after termination of anesthesia.

Recovery scores and times in the present study may have been affected by the method used for anesthetic recovery. In our clinic, we typically allow foals that weigh up to 150 kg (330 lb) to recover from anesthesia by gently restraining them in lateral recumbency until they are considered to be awake enough to make a successful attempt to stand. At that time, the foal is permitted to make an attempt and is assisted to remain standing by supporting its head and tail. In this study, individuals who were unaware of which anesthetic agent had been used were involved in assisting the foals during anesthetic recovery. Thus, although this method may have prolonged the time to standing, it should not have affected comparisons between agents, as consistent subjective signs were used to assess when foals were awake enough to make an attempt to stand. In addition, the only recovery time variable that may potentially have been affected was time to standing, since times to first movement and swallowing were unlikely to be affected by the presence of handlers.

Characteristics of anesthetic recovery may also have been affected by the use of butorphanol for provision of analgesia in this study. The effects of butorphanol in foals have not been thoroughly evaluated, but butorphanol can be used at a dose of 0.1 to 0.2 mg/kg, IV or IM.[1] In adult horses and ponies, butor-

phanol causes various degrees and durations of analgesia and may be associated with sedation or excitement, depending on the individual animal, the dose, and the route of administration.[17-18] In these foals, butorphanol was administered at a low dose (0.1 mg/kg, IV) approximately 2 hours prior to recovery. On the basis of previous research on the duration of clinical effects in horses,[17-19] it is unlikely that butorphanol at this dose would markedly affect recovery after this time.

One drawback of the present study was the small number of foals that could be used, limiting the power of comparisons. For the present study, we calculated, on the basis of published data on induction and recovery times with isoflurane and sevoflurane in horses,[2,6,10] that we would need between 5 and 20 animals in each group for sufficient power to detect meaningful differences between agents.

[a]Percutaneous Sheath Introducer Kit, Baxter Corp, Toronto, ON, Canada.
[b]Swan-Ganz Catheter, Baxter Corp, Toronto, ON, Canada.
[c]Isoflurane, Technilab Inc, Mirabel, QC, Canada.
[d]Sevorane, Abbott Laboratories, St Laurent, QC, Canada.
[e]Poet IQ, Criticare Systems Inc, Waukesha, Wis.
[f]Angiocath, Becton Dickinson, Sandy, Utah.
[g]Surflo, Terumo Medical Corp, Elkton, Md.
[h]PB240, Puritan Bennett Corp, Wilmington, Mass.
[i]Hemodynamic profile computer model SP 1445, Spectromed Inc, Oxnard, Calif.
[j]iStat portable clinical analyzer, iStat Corp, East Windsor, NJ.
[k]Wright Respirometer Haloscale Infanta, Ferraris Development & Engineering Co, London, England.
[l]Statistix, version 1.0, Analytical Software, Tallahassee, Fla.
[m]Prism, GraphPad Software Inc, San Diego, Calif.

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