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COMPARISON OF ISOFLURANE AND SEVOFLURANE FOR ANESTHESIA IN BEAVER

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ABSTRACT: We compared the hemodynamic and respiratory effects, recovery time, and cost of two gas inhalants (isoflurane and sevoflurane) for anesthetic induction and maintenance of beaver (*Castor canadensis*) during surgery to implant radio transmitters in the peritoneal cavity. Heart rate, respiratory rate, relative hemoglobin saturation with oxygen (SpO_2), and body temperature were measured every 5 min for the first 45 min, and arterial blood gas was measured once, 25 min into the anesthetic procedure. Induction for either agent was smooth and rapid. Heart rate and respiratory rate both decreased during the procedure though neither was lower than baseline values reported in the literature for beaver. Relative hemoglobin saturation with oxygen, body temperature, and blood gas variables did not differ between each anesthetic regime. Both inhalants caused slight respiratory acidosis. Recovery time from anesthesia was highly variable (1–178 min) but did not differ statistically between drugs. Sevoflurane costs ($22.30/60 min) were much higher than isoflurane costs ($3.50/60 min). We recommend isoflurane or sevoflurane for anesthetic induction and maintenance of beaver because of the lack of physiologic differences.

Key words: Anesthesia, beaver, inhalants, isoflurane, sevoflurane, surgery.

INTRODUCTION

The choice of anesthetic regime for immobilizing wild animals must balance animal welfare with logistic constraints associated with fieldwork. Inhalation anesthetics are generally preferred over injectable agents because they offer rapid induction, better control over the depth and duration of anesthesia, more predictable physiologic responses, and rapid recovery (Sedgwick, 1986). However, inducing anesthesia in wild animals with inhalants can be more expensive, requires sophisticated equipment, and is generally limited to smaller animals that can be safely restrained without first being anesthetized with an injectable anesthetic (Kreeger et al., 1998).

Beaver (*Castor canadensis*) are medium sized semi-aquatic mammals that are easy to restrain without the use of tranquilizers. The need to immobilize beavers can vary from short procedures like gender determination, phlebotomy, or cutaneous biopsies to longer procedures like surgically implanting radio transmitters. Several protocols have been use to anesthetize beavers. Injectable protocols include: ketamine alone or ketamine with acepromazine or xylazine (Patenaude and Genest, 1977; Lancia et al., 1978; Davis et al., 1984; MacArthur, 1989; Smith et al., 1991). Injectable drugs combined with inhalation agents include: ketamine, ketamine-xylazine, or ketamine-diazepam used with halothane or isoflurane (McKean, 1982; Gilbert and Gofton, 1982; Swain et al., 1988; Greene et al., 1991; Smith et al., 1991; Eisele et al., 1997). Use of inhalants as the sole inducing agent for beaver in laboratory or field situations is uncommon and has not been reported.

We compared two inhalants, isoflurane and sevoflurane. Isoflurane is commonly used for anesthetizing domestic animals and humans and occasionally used for immobilizing smaller wild animals (Belant, 1995; Gaynor et al., 1997; Kreeger et al., 1998). It has a relatively low blood-gas solubility coefficient (1.4), which allows for rapid induction and recovery and enables rapid change in anesthetic depth (Seal and Kreeger, 1987). Eisele et al. (1997) used isoflurane for anesthetic maintenance of beaver after induction with ketamine in a hospital setting.

Sevoflurane is a newer inhalant more commonly used for domestic animals and humans than for wildlife (Gaynor et al., 1997). In dogs, sevoflurane is characterized by more rapid induction and recovery and more rapid change in depth than isoflurane anesthesia because of its lower blood-gas solubility coefficient (0.6) (Jones, 1990). Theoretically, rapid adjustment to the anesthetic plane, should allow more rapid recovery, which would decrease the time a wild animal is kept in captivity. In humans, sevoflurane is popular for anesthetizing children because it causes less respiratory irritation than halothane, enflurane, or isoflurane (Doi and Ikeda, 1993).

We compared the recovery time, cardiovascular and respiratory effects, and cost of isoflurane and sevoflurane anesthesia in beaver during surgical implantation of radio transmitters into the peritoneal cavity. We also describe the equipment, techniques, and logistic challenges associated with the use of inhalants for anesthetizing beavers under field conditions.

MATERIALS AND METHODS

We used Hancock traps (Hancock Trap Co., Custer, South Dakota, USA) and snares (Gregerson #3 with a 40 cm stop) to capture beavers from September through November of 1997 and 1998 on the Green and Yampa Rivers in northwestern Colorado (USA; 40°45′N, 108°32′W). Animals weighing over 16 kg were selected for surgical implantation of transmitters and transported in a large cage from the river to a trailer. If we suspected the animal was cold, then we housed it in a warm enclosure for several hours prior to surgery.

We anesthetized 29 beavers (16 in 1997 and 13 in 1998). The anesthetic procedure began by putting the beaver into a burlap sack. We placed a large canine gas-inhalant mask directly over the sack, covering the beaver's nose and mouth. The mask was connected to a portable anesthesia system (77 Anesthesia, Fort Collins, Colorado) having multi-gas capability. Anesthesia was induced with either 7% sevoflurane (Ultane, Abbott Laboratories, North Chicago, Illinois, USA) using a sevoflurane specific vaporizer (Sevotec 3, Ohmeda, Liberty Corner, New Jersey, USA) or 5% isoflurane (Aerrane, Ohmeda) using an isoflurane-specific vaporizer (Fortec 3, Ohmeda) in 5 l/min of oxygen. We arbitrarily selected sevoflurane for the first surgery and then alternated inhalants thereafter. To minimize human exposure to the anesthetic agents we used an activated charcoal gas scavenger and performed surgeries in area with good air circulation. No pregnant women participated in the anesthetic procedures.

During induction, the animal was periodically rocked from side to side to test for responsiveness. When no response was detected, the mask was removed to take the beaver out of the burlap sack and then reapplied directly to its nose and mouth. We did not endotracheally intubate animals because field technicians were not trained to perform this procedure. The anesthesia vaporizers were adjusted to maintenance level, which varied during surgery from 1.5%–5% in 1 l/min of oxygen for both drugs. During the procedure we frequently attempted to lower the percent of gas being administered to maintain the beaver in as light an anesthetic plane as possible. If a beaver moved its legs or body during the procedure, we increased the concentration of anesthetic until the animal stopped reacting.

The surgical procedure involved making a mid-line abdominal incision, located midway between the xyphoid process and cloaca. The abdominal cavity was opened by cutting along the linea alba for a length of 5 cm. Blood samples were obtained and the transmitter was placed inside the peritoneal cavity and allowed to float freely. Routine three layer abdominal closure was performed using absorbable suture material (no. 00) for the linea alba and subcutaneous layer, and stainless steel staples for the skin.

We attached a pulse oximeter (Nellcor, N-20PA, Hazelwood, Missouri, USA) to the upper or lower lip of each beaver to estimate relative hemoglobin saturation with oxygen (SpO_2) and heart rate. We inserted a temperature probe 2.5 cm into the cloaca to monitor body temperature, and counted the number of breaths during a 15 sec period to monitor respiration rate. Heart rate, respiratory rate, temperature, SpO_2, and vaporizer setting were recorded at 5 min intervals for the first 45 min that animals were under anesthesia. For animals anesthetized in 1998 (seven with isoflurane and six with sevoflurane) we sampled intestinal arterial blood for blood gas analysis (IRMA Blood Analysis System, Diametrics Medical, St. Paul, Minnesota, USA) about 25 min into the procedure. At the end of the surgery we took morphometric measurements, applied ear tags, and administered 100,000 units of procaine penicillin. We then turned off the gas anesthetic, removed the mask, and placed the animal on its

back inside a covered cage. Time to resumption of righting reflex was recorded as recovery from anesthesia. We provided water to individuals after full recovery, allowed them to recover from 6 to 8 hr, then released them at the site of capture. The Colorado State University Animal Care and Use Committee approved our trapping, handling and surgical protocol (#97-018A-04).

We calculated the monetary cost of each inhalant by multiplying the mean amount of inhalant used by its retail cost. Relative SpO2, heart rate, respiratory rate, and body temperature followed repeated measures designs (Winer, 1971) and were analyzed as mixed linear models (e.g., McLean et al., 1991; Wolfinger et al., 1991). In this model drug type, time (5 min intervals) and drug×time interactions were fixed effects with animals, nested within drug type, a random effect. SAS PROC MIXED (SAS Institute Inc., 1999), with a restricted maximum likelihood estimation procedure (REML) and an autoregressive order 1 covariance structure, was used to perform the calculations (Littell et al., 1996). All other variables, measured once per subject, were analyzed using a two-sample *t*-test. We pooled data across drugs and performed a simple linear regression to model mean spontaneous resumption of righting reflex on the body mass of individuals. For all statistical tests we considered $P<0.05$ as statistically significant and report means with ±1 SE.

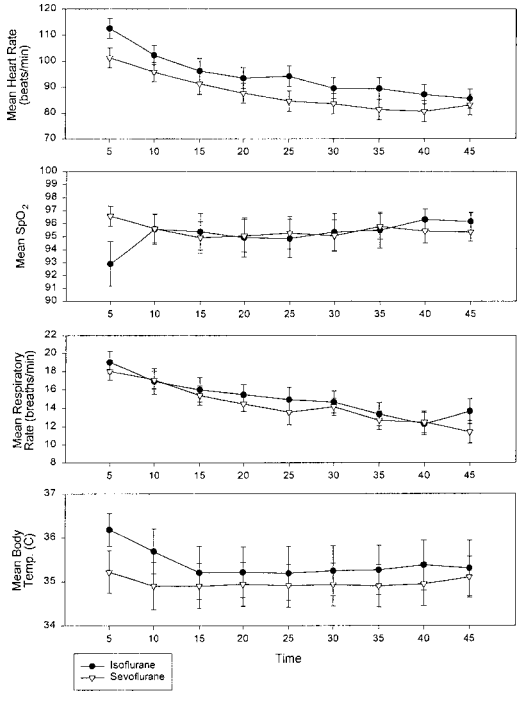

FIGURE 1. Mean heart rate, hemoglobin saturation with oxygen (SpO_2), respiration, and body temperature of beavers recorded at 5 min intervals for the first 45 min that animals were under anesthesia. Fifteen and fourteen beavers were anesthetized with isoflurane and sevoflurane, respectively.

RESULTS

Mass of beaver anesthetized with isoflurane was less (20.3±0.68 kg) than that of beaver anesthetized with sevoflurane (21.9±0.52 kg), though the difference was not statistically significant ($t=-1.91$, $df=27$, $P=0.069$). Time to perform the surgical procedure was similar between isoflurane (39.1±3.3 min) and sevoflurane (38.1±3.0 min) groups. Time under anesthesia was also similar: isoflurane (65.4±4.0 min) and sevoflurane (66.6±4.7 min). Mean resumption of righting reflex for beaver anesthetized with isoflurane was nearly 14 min less (42.7±12.8 min) than beaver anesthetized with sevoflurane (56.3 min±16.1), but was not statistically different ($t=-0.66$, $df=27$, $P=0.512$). Mean righting reflex was not correlated with body mass ($F_{1,27}=0.30$, $P=0.590$)

Mean heart rate calculated over the first 45 min of the procedure was higher for beaver anesthetized with isoflurane (93.9±4.0 beats/min [bpm]) compared to that of beaver anesthetized with sevoflurane (87.7±3.9 bpm; $F_{1,98}=5.71$, $P=0.019$). Respiratory rate, body temperature, and relative SpO_2 were not different between groups (Fig. 1). Heart rate ($F_{8,202}=7.63$, $P<0.001$) and respiratory rate ($F_{8,210}=3.43$, $P=0.001$) both decreased over time and the decreases were similar for each drug (Fig. 1). Results of blood gas measurements were similar for beavers breathing isoflurane and sevoflurane (Table 1). Only base excess (BE) was marginally different between treatments (Table 1).

The mean vaporizer setting during maintenance of anesthesia was 2.2% and 3.1% for isoflurane and sevoflurane, respectively. For a 60 min procedure isoflur-

TABLE 1. Mean arterial blood-gas variables for beavers anesthetized with isoflurane ($n=7$) and sevoflurane ($n=6$) in fall 1999. Blood was sampled approximately 25 min after induction from an artery along the small intestine.

Variable[a]	Isoflurane	SE	Sevoflurane	SE	*P*
pH	7.27	0.08	7.31	0.03	0.73
pCO_2 mmHg	69.86	5.02	65.95	4.79	0.59
pO_2 mmHg	217.27	46.71	259.1	44.32	0.53
Na+ meq/l	135.27	4.29	131.72	1.85	0.49
K+ meq/l	3.69	0.35	2.98	0.17	0.12
iCa meq/l	1.13	0.06	1.12	0.04	0.85
Hct %	29.14	1.52	28.83	0.66	0.86
HCO_3 meq/l	28.17	2.02	32.28	0.77	0.10
BE meq/l	−0.014	2.31	5.38	1.14	0.07
TCO_2 meq/l	30.31	2.07	34.30	0.80	0.12
sO_2 %	97.29	1.34	98.32	1.30	0.60
Hb g/dl	9.87	0.50	9.80	0.22	0.91

[a] pCO_2=partial pressure of carbon dioxide; pO_2=partial pressure of oxygen; iCa=ionized calcium; Hct=hematocrit; BE=base excess; TCO_2=total carbon dioxide; sO_2=oxygen saturation; Hb=hemoglobin.

ane and sevoflurane cost approximately $3.50 and $22.30, respectively. Purchase price of a portable anesthesia machine was $1,700.

DISCUSSION

There was no statistical difference in recovery time between drugs, in part because recovery varied greatly for beavers anesthetized with both drugs, which limited our ability to detect a difference. Variation in recovery time was not correlated to body mass. It is possible that variation in recovery time was due to differences in the amount of anesthesia each animal received, though we attempted to maintain each animal at a light surgical plane of anesthesia by monitoring physiologic signs and responsiveness to stimulation, and then adjusting the amount of anesthesia based on these signs. However, if an animal was unresponsive it was difficult to determine how deeply they were anesthetized. It is possible that some animals were in a deeper anesthetic plane than others and took longer to recover. A more precise method of comparing depths of anesthesia between groups would have been to use an inhalation agent specific analyzer which could measure expired gas concentrations. This was not practical in the field setting of this study. Alternatively, our measurement of righting reflex may not be an accurate assessment of recovery. In several cases we noticed animals that were awake and aware but remained on their backs or rolled partially on their side, which we did not count as recovered. Eisele et al. (1997) reported the same passive behavior and difficulty measuring resumption of righting reflex. For both drugs, all beaver appeared recovered within 4 hr and were released the same day.

Beaver were responsive to changes in the amount of anesthetic administered, enabling us to control the depth of anesthesia. For example, there were 10–12 occasions when a beaver reacted to the surgical procedure (e.g., movement of legs). In these cases we stopped the procedure, increased the percentage of anesthetic administered by 0.5%–1%, and waited 30–60 sec before testing again for reaction to stimulation. In all cases the individual did not react to the painful stimulus when it was resumed. The rapid change in depth of anesthesia demonstrates the utility of using inhalant anesthetics. Although we did not quantify reaction time to changes in the amount of anesthetic administered, there did not appear to be differences between isoflurane and sevoflurane.

A reported benefit of sevoflurane in hu-

mans is that it causes less irritation and therefore provides smoother induction (Patel and Goa, 1996). Beavers showed little reaction to either inhalant, beyond a few attempts to shake their head when the mask was applied. This could mean that the gases did not cause much irritation or it could be that animals were stressed from handling and we were unable to accurately assess the ease of induction.

Heart rates for free-ranging beaver range from 60–70 bpm (resting) to 110–120 bpm (active) (Gilbert and Gofton, 1982; Swain et al., 1988). Beaver anesthetized with isoflurane and sevoflurane initially had heart rates similar to active beaver (110–120 bpm) which decreased to about 80–90 bpm by the end of the surgery (Fig. 1). The cause for the decline in heart rates is likely due to drug impacts on cardiac physiology. The consistently lower heart rates of beaver anesthetized with sevoflurane were probably clinically insignificant because they were within range of heart rates reported for free-ranging beaver. Gaynor et al. (1997) reported similar differences in heart rates for polecats (*Mustela eversmanni*) anesthetized with isoflurane and sevoflurane.

Respiratory rate did not differ between drugs, but like heart rate showed a continual decline through the procedure and stabilized at approximately 12–14 breaths per min (Fig. 1). This decline is consistent with changes in respiratory rate in other species. Changes in respiratory rate are not indicative of adequacy of ventilation or depth of anesthesia (West, 1985).

Arterial blood gas values are imperative for assessing adequacy of acid-base status, ventilation, and oxygenation (Gaynor et al., 1997). The mean pH of the beaver's blood under both isoflurane and sevoflurane indicated that animals were slightly acidemic likely as a result of significant hypoventilation (elevated partial pressure of CO_2 in arterial blood [$PaCO_2$]). It is not clear if the elevated $PaCO_2$ was the result of the decrease in respiratory rate or was due to a decrease in tidal volume. This is consistent with the effects of sevoflurane and isoflurane in other species (Gaynor et al., 1997). There were no other significant changes in acid–base status. Oxygenation, based on SpO_2 and blood gas values, was adequate for animals breathing virtually 100% oxygen.

At the time of our study sevoflurane was nearly seven times more expensive to use than isoflurane. However, the cost of sevoflurane is likely different for other practitioners and may drop in the future. Because of the lack of differences between physiologic and hemodynamic responses, we recommend using either sevoflurane or isoflurane for anesthetic induction and maintenance of beaver.

Kreeger et al. (1998) compared the injectable drug combination of ketamine-medetomidine to isoflurane for immobilizing black-footed ferrets (*Mustela nigripes*) in the field and offered the following criticisms: precision-calibrated vaporizers require high levels of maintenance and were not very portable and inhalation delivery systems required a great deal of training. We believe these criticisms may be justified in situations when anesthetic procedures are short (i.e., <30 min) and do not involve a surgical procedure. In situations requiring prolonged anesthesia, we recommend inhalation anesthetics because of the superior control over the depth of the anesthetic plane. Furthermore, if the issues of portability can be overcome, gas anesthesia may be advantageous for shorter procedures on beaver because recovery from insoluble inhalant agents is generally rapid and requires no additional reversal agents.

Regardless of the type of anesthetic used, we recommend wildlife biologists receive adequate training in the materials and methods needed to safely induce and monitor animals under anesthesia. This training was extremely valuable for assuring the health of the animals and maintaining the integrity of the research. In our study all 29 surgeries were successful with no known complications.

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