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DETERMINATION AND EVALUATION OF AN OPTIMAL DOSAGE OF CARFENTANIL AND XYLAZINE FOR THE IMMOBILIZATION OF WHITE-TAILED DEER (*ODOCOILEUS VIRGINIANUS*)

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ABSTRACT: Using an iteration method, optimal hand-injected immobilization dosages of carfentanil/xylazine (CAR/XYL) were determined for 13 adult white-tailed deer (*Odocoileus virginianus*). Deer were temporarily restrained in a squeeze chute and were repeatedly immobilized one to four times at 2–5-wk intervals from December 2002 to March 2003. A fixed ratio of 1 mg CAR:10 mg XYL intramuscularly was used, increasing or decreasing the dosage until the optimal dosage (defined by an induction time<3 min and $PaCO_2$<60 mmHg) was reached for each animal. Inductions were videorecorded and reviewed by observers blinded to drugs and dosages, who rated qualitative aspects of each induction. There were significant (P<0.05) dosage-dependent decreases in induction time, time to first effect, PaO_2, SaO_2, and arterial pH, and significant dosage-dependent increases in $PaCO_2$ and quality ratings. The median optimal dosage (mOD) was 0.03 (range, 0.015–0.06) mg/kg CAR+0.3 (range, 0.15–0.6) mg/kg XYL. Induction times using the mOD were rapid (median 3.0 min [range, 1.8–10.0]), but quality ratings were considered undesirable for nine of 13 deer. Increased rectal body temperatures of 40.6±0.5 C (mean ± SD) were noted in all deer and hyperthermia (T>41 C) was noted in three. There was a positive correlation between body temperature and induction time (r=0.44). Heart rates significantly decreased from 5 to 15 min postinduction and remained decreased at the 20-min reading; there was occasional bradycardia. There was a significant increase in pH from 10 to 20 min postinduction, but metabolic acidemia (pH<7.3) persisted throughout the immobilization periods for all deer. Possible hypoxemia (SaO_2 and SpO_2<90 mmHg but PaO_2>60 mmHg) was present after induction, while hypercapnea ($PaCO_2$>60 mmHg) did not occur. Reversal times with naltrexone and yohimbine were rapid (mean 3.7±1.5 min) and uneventful, with no evidence of renarcotization. Although the median optimal dosage produced rapid inductions, no respiratory depression, complete reversal after antagonist administration, and no renarcotization, negative attributes included elevated body temperatures, acidemia, and undesirable induction qualities.

Key words: Carfentanil, cervid, iteration method, *Odocoileus virginianus,* optimal dosage, white-tailed deer, xylazine.

INTRODUCTION

Opioid agents, including carfentanil citrate, have been widely utilized, often in combination with $alpha_2$ agonists, for the immobilization of captive and free-ranging cervids (Jessup et al., 1984; Bailey et al., 1985; Karesh et al., 1986; Stanley et al., 1988; Haigh, 1991; Caulkett et al., 2000). However, there are few reports of their use in white-tailed deer (*Odocoileus virginianus*). To date, an optimal carfentanil and xylazine immobilization dosage has not been determined for white-tailed deer.

The common practice when using opioids for ungulate immobilization is to use higher rather that lower dosages to avoid excitement and hyperthermia (Haigh, 1990; Haigh and Hudson, 1993). Although several studies have reported the deleterious cardiopulmonary effects of high opioid dosages (Schumacher et al., 1997a, b; Moresco et al., 2001), no study has quantified the relative quality or physiologic effects of immobilizations produced by varying opioid dosages. An optimal dosage of carfentanil/xylazine should produce a rapid, smooth induction and minimal respiratory depression, excitation, and muscle rigidity. The few opioid dose-response studies reported for cervids have determined effective population median doses by using single dosages in each an-

imal (Bailey et al., 1985; Smith et al., 1993). Unlike a crossover study design, however, this approach does not take into account interindividual variation in drug effects.

An alternate technique uses an iteration procedure to determine an optimal immobilization dosage. This procedure determines an optimal dosage in each individual by increasing and decreasing the dosage until predetermined criteria are met, using each animal as its own control. Advantages of this design include an elimination of interindividual physiologic variability, more precise identification of an optimal dosage, and the reduction in number of animals and/or immobilizations required to determine an optimal dosage. The use of this technique for opioid dosage selection has not been reported, although it has been applied to the determination of an optimal medetomidine/ketamine dosage in reindeer (*Rangifer tarandus*; Ryeng et al., 2001a, b).

We evaluated the validity of a modified iteration method for the determination of an optimal hand-injected dosage of carfentanil (CAR) and xylazine (XYL) for immobilization of white-tailed deer and evaluated the physiologic and qualitative aspects of immobilizations produced by this dosage.

MATERIALS AND METHODS

This study was conducted from December 2002 to March 2003 at the Daniel B. Warnell School of Forest Resources Whitehall Deer Research Facility, University of Georgia, Athens, Georgia 30602, USA (33°53′N, 83°21′W). Protocols were approved by the University of Tennessee (UT-ACUC 1227) and the University of Georgia (UGA-ACUC A2002-10062-0) Animal Care and Use Committees. Deer were housed in 0.4–0.8-ha wooded outdoor pens and fed 18.5% protein ration (Antler King Trophy Products, Inc., Black River Falls, Wisconsin, USA), with fresh water and legume hay provided ad libitum in addition to grasses, legumes, and leafy browse in the pens. Average ambient temperatures for the study dates ranged from 1.1 to 10.0 C. Deer were moved to individual 3- × 6-m indoor stalls, with porous visual barriers covering walls, 48–120 hr prior to each immobilization. Food was removed from each stall 12–16 hr before immobilizations.

Thirteen deer (five males, eight females), with a median age of 2.5 (range, 1.5–4.5) yr and a median prestudy body weight of 53.6 (range, 35.9–75.0) kg, were included in this study. Seasonal weight loss occurred in all deer over the course of the study, with median body weight decreasing to 44.5 (range, 36.4–73.2) kg.

For each immobilization, each deer was moved to a drop-floor squeeze chute designed for white-tailed deer, with a built-in electronic scale. While in the chute, body weight was recorded and immobilizing drugs, combined in a single syringe, were administered by hand injection in the left caudal epaxial musculature, using a 3.8-cm, 20-gauge needle.

Deer were immobilized with CAR (3 mg/ml, Wildnil®, Wildlife Laboratories, Inc., Fort Collins, Colorado, USA) and XYL (20 mg/ml, X-Ject SA®, Phoenix Scientific, Inc., St. Joseph, Missouri, USA) administered at dosages described below. The drug dosage for the first immobilization was calculated based on the prestudy body weight for each deer, and subsequent dosages were calculated based on the weight obtained during the previous session.

Immediately after drug injection, deer were released into a 15- × 20-m observation pen. Time (minutes) from injection until first effect (TE, defined by stumbling, gait alteration, or dysphoria) and time from injection until recumbency without being able to rise (induction time [TI]) were recorded. Once recumbent and approachable, deer were positioned in sternal recumbency, with the head elevated. The eyes were lubricated with ophthalmic ointment (Paralube Vet Ointment, Pharmaderm, Melville, New York, USA) and a towel was placed over the eyes to reduce visual stimulation.

Heart rate (HR, measured by thoracic auscultation), respiratory rate (RR, measured by observation of thoracic movements), and relative arterial oxygen hemoglobin saturation (SpO_2), measured using a pulse oximeter (SurgiVet V3402, SIMS BCI, Inc., Waukesha, Wisconsin, USA) probe on the lingual, rectal, preputial, or vulvar mucosa, were recorded at 5, 10, 15, and 20 min postrecumbency. Rectal temperature was measured using a digital thermometer (Apex Medical Corp., Sioux Falls, South Dakota, USA) at 10 and 20 min postrecumbency.

Blood was collected anaerobically from the auricular or metatarsal artery at 10 and 20 min postrecumbency into a heparinized syringe, which was placed immediately into an ice-water bath. Samples were analyzed within 30 min of collection using a portable automated blood gas analyzer (IRMA® SL Series 2000 Blood

TABLE 1. Criteria for quality rating scores of three parameters for inductions of white-tailed deer (*Odocoileus virginianus*) with a carfentanil/xylazine combination.

Quality rating score	Criteria for score
Excitability	
3	Very calm; no excitation during induction
2	Mild excitement; procedure-related stress evident but calming with onset of drug effects
1	Marked excitement; frantic/racing behavior, minimally or not reduced with onset of drug effects
0	Extreme excitement; frantic, reckless, or violent behavior, apparently increased by onset of drug effects
Muscle rigidity	
3	Complete muscle relaxation with onset of drug effects
2	Minimal and sporadic muscle rigidity and fasciculations
1	Marked intermittent muscle rigidity or fasciculations when recumbent
0	Extreme or continuous muscle rigidity or fasciculations when recumbent
Overall quality	
3	Rapid, smooth, optimal induction
2	Relatively rapid and smooth but could be improved
1	Rough or extended unacceptable induction
0	Extremely rough, lengthy, potentially dangerous induction

Analysis System, Diametrics Medical, Inc., St. Paul, Minnesota, USA), calibrated to a human oxygen-dissociation curve, and used with corresponding BG cartridges (Diametrics Medical, Inc.). Arterial pH, PCO_2, and PO_2 were measured directly and automatically corrected to the measured body temperature, while arterial oxygen saturation (SaO_2) was calculated by the instrument.

After 20 min postrecumbency, specific opioid and $alpha_2$ antagonists were combined in a single syringe and administered by hand injection in the left caudal semimembranosus muscle, using a 3.8-cm, 20-gauge needle. Naltrexone (NAL, 50 mg/ml, Trexonil®, Wildlife Pharmaceuticals Wildnil®, Wildlife Laboratories, Inc.) was administered at 100 times the CAR dose, and yohimbine (YOH, 5 mg/ml, University of Tennessee Veterinary Teaching Hospital Pharmacy, Knoxville, Tennessee, USA) was administered at 0.15 mg/kg. The time from antagonist injection until standing (reversal time [TR]) was recorded. When each deer was safely ambulating in the observation pen, it was returned to its stall for continued recovery. Deer were observed hourly during daylight hours and periodically during the night for 48 hr following each immobilization.

Videotapes of the induction phase of all immobilizations were reviewed by two observers (board-certified veterinary anesthesiologists), who were blinded to dosages and drugs employed. Three qualitative parameters of the induction phase for each immobilization were rated: excitability, muscle rigidity, and overall quality. Each parameter was assigned a numeric scale (Table 1). Ratings from both observers were summed and reported as a combined total quality score, giving each immobilization a potential maximum quality rating score of 18. A desirable induction was empirically defined as having a quality rating sum≥12.

Iteration study design

Each deer was immobilized repeatedly until an individual optimal dosage (iOD) was attained (1–4 times). A rest (washout) period, ranging from 2–5 wk, was allowed between successive immobilizations. The attributes of an optimal dosage were defined as TI<3.0 min and $PaCO_2$<60 mmHg (at both 10- and 20-min postrecumbency measurements). All dosages of CAR and XYL used were held to a constant ratio of 1 mg CAR:10 mg XYL. An initial dosage (d_1) of 0.015 mg/kg CAR+0.15 mg/kg XYL was selected.

If TI for the first immobilization was ≥3.0 min, the dosage for the second immobilization (d_2) was doubled ($d_2=2\times d_1=0.03$ mg/kg CAR+0.3 mg/kg XYL). If TI was ≥3.0 min for d_2, the dosage for the third immobilization (d_3) was again increased ($d_3=3\times d_1=0.045$ mg/kg CAR+0.45 mg/kg XYL). If TI was still ≥3.0 min for d_3, the dosage for the fourth

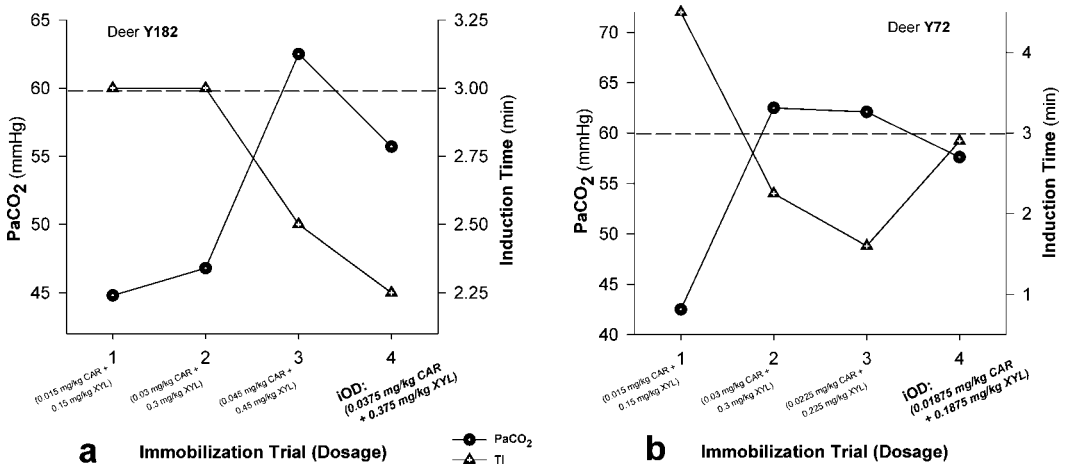

FIGURE 1. Two examples of the iteration method used to determine an individual optimal immobilization dosage (iOD) of carfentanil/xylazine for two white-tailed deer (*Odocoileus virginianus*). Deer were immobilized sequentially until both induction time (TI) and $PaCO_2$ values were less than a predefined threshold ($PaCO_2$<60 mmHg and TI<3.0 min), represented by the dashed line in each graph. The iOD for each deer was that used in the fourth trial.

immobilization (d_4) was again increased ($d_4=4\times d_1=0.06$ mg/kg CAR+0.6 mg/kg XYL). If for any immobilization, $PaCO_2\geq 60$ mmHg, the subsequent dosage was decreased to half of the sum (i.e., the midpoint) of the current and next-lowest dosage. For each deer, the first dosage meeting the optimal dosage criteria was considered to be the iOD, and no further immobilizations were performed (Fig. 1). For one deer, the first dosage evaluated was the iOD.

After the iOD dosage was determined for each deer, a median optimal immobilization dosage (mOD) was calculated, which was equivalent to the second dosage employed for all deer requiring more than one immobilization. This mOD was then evaluated in the one deer having not yet received it.

Statistical analyses

Statistical analyses were performed using computerized software (SAS Institute, Cary, North Carolina, USA) for all tests. All testing was done at the $P<0.05$ significance level. All parameters were examined for normality ($W>0.9$) using the Shapiro-Wilk test, then either means (±SD) or medians (range) were calculated. Because no curvilinearity was detected, regression analysis was used to evaluate the relationship between each parameter and CAR/XYL dosage. All parameters were compared among individuals to assess variation and among the CAR/XYL dosages used for each individual to assess the relationship to dosage, using multisource regression. Proc GLM models included various combinations of the effects of individual deer, gender, time, and regression on dosage. Comparisons were also made for each parameter between the iOD and the mOD for each deer and for the population mean/median values. Temporal trends for multiple (5-, 10-, 15-, and 20-min time points) measurements were determined and compared using a repeated-measures mixed-model analysis of variance. Proc GLM regression models were also used to evaluate the relationship between these temporal trends and CAR/XYL dosage ($r^2>0.8$ indicated a linear relationship). Pearson correlations among variables were determined using the CORR Procedure.

RESULTS

Optimal dosage determination

The modified iteration method successfully identified an optimal immobilization dosage (OD) of CAR/XYL for all deer. The initial dosage (0.015 mg/kg CAR+0.15 mg/kg XYL) was optimal for one deer. For seven deer, the second dosage (0.03 mg/kg CAR+0.3 mg/kg XYL) was optimal. Two deer required three immobilizations to define an optimal dosage: for one deer, the second dosage produced $PaCO_2>60$ mmHg, therefore, the third dosage was decreased to 0.0225 mg/kg CAR+0.225 mg/kg XYL; for the second deer, the second dosage produced TI>3.0 min, therefore, the third dosage was increased to

0.045 mg/kg CAR+0.45 mg/kg XYL. Two deer required four immobilizations to identify an optimal dosage (Fig. 1).

There were linear relationships between the dosage of CAR/XYL and each parameter except SpO_2. Gender had no significant effect on TI, body temperature, or pH values. There were significant interindividual (deer) variations for TI, TE, HR, RR, and PaO_2. Despite these interindividual variations, there were significant dosage-dependent decreases in TI, TE, PaO_2, SaO_2, and pH and a significant dosage-dependent increase in $PaCO_2$. Body temperatures were positively correlated with TI for all dosages (r=0.51). Time-related changes (within each immobilization) were not significantly affected by dosage.

The quality ratings reported by the blinded observers indicated significant dosage-dependent increases in the quality of inductions, despite significant interindividual variation. Nonetheless, all but one deer were adequately immobilized to perform all study procedures at each dosage evaluated. Gender, body temperature, TI, or pH had no significant effects on the quality ratings. Renarcotization was not observed in any deer during the 48-hr period following immobilization.

Characteristics and comparison of iOD and mOD

The iODs ranged from 0.015 mg/kg CAR+0.15 mg/kg XYL to 0.06 mg/kg CAR+0.6 mg/kg XYL. Gender did not have a significant effect on the iOD determined. The calculated mOD was 0.03 mg/kg CAR+0.3 mg/kg XYL. This dosage was equal to the iOD for seven of 13 deer, and 12 of 13 deer had been immobilized with the mOD during the course of the iteration procedure.

After receiving the mOD injection, all deer showed first signs of effects in ≤1.6 min, and 10 of 13 deer were recumbent in <3.0 min. Mean quality ratings for the iOD and mOD inductions were both considered undesirable (<12; Table 2). All deer at the iOD and 12 of 13 deer at the mOD were lightly to deeply anesthetized, with palpebral reflexes occasionally intact, although the degree of muscle relaxation varied. Some deer required light manual restraint in the initial few minutes of handling. One deer, for which iOD was 0.06 mg/kg CAR+0.6 mg/kg XYL, was recumbent but not handleable at 10 min postinjection when given the mOD; physiologic data were unobtainable and antagonist agents were administered before 20 min postrecumbency. A significant decrease in HR relative to the initial measurement was seen at 15 min postrecumbency and, thereafter, with occasional marked bradycardia (HR<60 beats/min; Fig. 2, Table 2). Decreased respiratory rates and pale, mildly cyanotic mucous membranes were occasionally present but true bradypnea (<6 breaths/min) was not observed. Increased body temperatures (T>39 C) were noted in all deer immobilized with both the iOD and mOD. Hyperthermia (T>41 C) was noted in three of 13 deer immobilized with both the iOD and mOD. Gender had a significant effect on both body temperature and TI, with males given the mOD having lesser values for both. There was a positive correlation between body temperature and TI (r=0.44).

A significant increase in pH relative to the 10-min measurement was seen at 20 min postrecumbency, but mild to marked acidosis (pH<7.3) was present throughout the immobilization periods for both the iOD and mOD (Fig. 3, Table 2). Possible hypoxemia was indicated by SaO_2 and SpO_2 (<90 mmHg) but not by PaO_2 (<60 mmHg) values throughout the immobilizations for both the iOD and mOD. Hypercapnea ($PaCO_2$>60 mmHg) did not occur (Fig. 3, Table 2). Respiratory rates were positively correlated with $PaCO_2$ values (r=0.39), while respiratory rates were negatively correlated with SaO_2 values (r=−0.31).

Reversal with NAL and YOH was complete and rapid (3.7±1.5 min), with consistent changes in behavior (vocalizing, ear twitch) and increased respiratory rates preceding recovery. All deer were ambulating properly within minutes after standing.

TABLE 2. Anesthetic and physiologic values for the determined individual (iOD)[a] and calculated herd median (mOD)[b] optimal dosages of a carfentanil/xylazine combination for the immobilization of white-tailed deer (*Odocoileus virginianus*). Values are reported as either means (±SD) or medians (range).

Dosage	iOD (n=13)	mOD (n=13)
Time to first effect (min)	1.2 (±0.4)	1.1 (±0.4)
Induction time (min)	2.5 (±0.3)	3.0 (1.8–10.0)
Reversal time (min)	3.4 (2.0–6.7)	3.7 (±1.5)
$PaCO_2$ (mmHg)		
10 min	50.9 (±6.9)	53.0 (±8.6)
20 min	50.7 (±7.4)	50.1 (±8.2)
PaO_2 (mmHg)		
10 min	71.7 (±15.0)	71.1 (±14.3)
20 min	81.3 (68.5–98.3)	82.2 (47.1–161.6)
SaO_2 (%)		
10 min	79.1 (±11.6)	78.6 (±9.9)
20 min	84.6 (±9.9)	85.0 (±10.2)
pH		
10 min	7.19 (±0.09)	7.18 (±0.07)
20 min	7.24 (±0.07)	7.25 (±0.04)
SpO_2 (%)		
10 min	85.8 (±6.6)	84.0 (±5.9)
20 min	90.5 (70.0–98.0)	88.8 (±7.4)
HR[c]		
5 min	61.7 (±15.4)	62.3 (±17.2)
10 min	62.5 (±12.5)	61.1 (±13.5)
15 min	58.2 (±11.6)	56.4 (±9.8)
20 min	54.1 (±10.6)	53.2 (±10.9)
RR[d]		
5 min	23.4 (±10.2)	22.4 (±9.2)
10 min	23.4 (±11.6)	22.7 (±10.9)
15 min	20.8 (±4.0–36.0)	21.0 (4.0–36.0)
20 min	20.0 (±9.2)	19.3 (±8.8)
Temperature (C)		
10 min	40.6 (±0.57)	40.6 (±0.50)
20 min	40.6 (±0.68)	40.6 (±0.65)
Quality rating	9.2 (±3.5)	9.3 (±2.90

[a] Range, 0.015 mg/kg carfentanil (CAR)+0.15 mg/kg xylazine (XYL) to 0.06 mg/kg CAR+0.6 mg/kg XYL.
[b] 0.03 mg/kg CAR+0.3 mg/kg XYL.
[c] HR = heart rate (beats/min).
[d] RR = respiratory rate (breaths/min).

DISCUSSION

Determining an optimal dosage of an immobilization drug regimen requires the selection of quantifiable dosage-dependent parameters that can be optimized by manipulating the dosage. Induction time is important when immobilizing deer, especially free-ranging deer, because it is related to the distance that the deer may travel before becoming recumbent and thus to the incidence of injury, hyperthermia, or escape (Haigh, 1990; Ryeng et al., 2001a). Induction times have been evaluated in relation to opioid dosage in only a few cervid species (Meulemann et al., 1984; Stanley et al., 1988).

Undesirable effects of carfentanil in ungulates include excitability and hyperther-

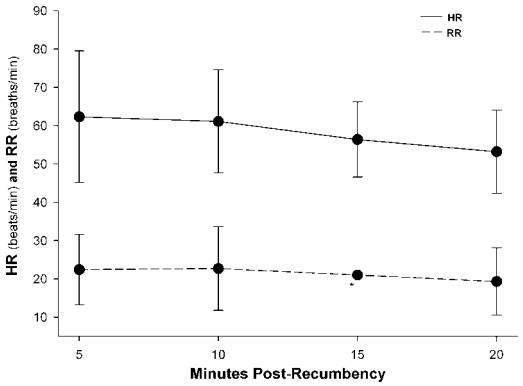

FIGURE 2. Physiologic effects of the median optimal dosage (mOD[a]) of carfentanil/xylazine in white-tailed deer (*Odocoileus virginianus*) (n=13). Values are plotted as means (±SD) or medians (*). Heart rates (HR) were significantly (P<0.05) decreased at both 15 and 20 min postrecumbency compared with the 5-min measurement.

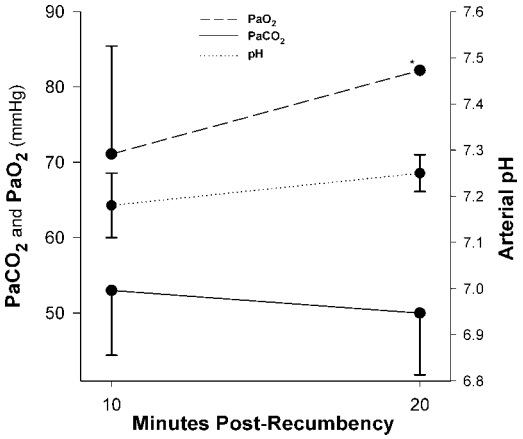

FIGURE 3. Effects of the mean optimal dosage (mOD) of carfentanil (0.03 mg/kg)/xylazine (0.3 mg/kg) on arterial blood gas measurements of white-tailed deer (*Odocoileus virginianus*) (n=13). Values are plotted as means (±SD) or medians (*). pH was significantly (P<0.05) increased at 20 min postrecumbency relative to the 10-min measurement.

mia at lower dosages and respiratory depression and muscle rigidity or tremors at higher dosages (Haigh, 1990; Schumacher et al., 1997a, b; Moresco et al., 2001). Excepting respiratory depression, these effects may be mitigated by the addition of an alpha$_2$ agonist, most commonly xylazine, with or without reduction of the opioid dosage (Klein and Klide, 1989; Haigh, 1990). In the present study, an optimal dosage of CAR/XYL was defined as meeting two criteria, selected to address clinical concerns, including short induction time (TI<3.0 min) and a lack of respiratory depression ($PaCO_2$<60 mmHg).

Previously, Ryeng (2001a) reported that Aitken procedures (mathematical models based on iteration [repetition]) were reliable when applied to the determination of an optimal immobilization dosage of a medetomidine/ketamine combination in reindeer. The iteration model was constructed to locate the intercept between a straight line and a function with a minimum number of iterations. In a dosage-response study, the varying drug dosage represents the function, whereas the desired effect represents the straight line (Ryeng et al., 2001a). This design produces a convergence between drug dosage and the optimally defined criteria with a minimum number of immobilizations because not all dosages are evaluated in all animals, in contrast with a crossover design. In the present study, each deer was immobilized one to four times before the optimal dosage was identified; a total of 33 immobilizations were performed to evaluate seven dosages in 13 deer. Using a traditional crossover study design, 91 immobilizations would have been required to evaluate these same seven dosages.

The success of this iteration procedure depends on a linear relationship between drug dosage and criteria parameters; lacking this, varying the dosage will not dependably locate the optimal effect window. This study successfully identified optimal dosages for all deer and demonstrated a CAR/XYL dosage-dependent linear relationship for both selected criteria, validating the selection of the iteration method. Other dosage-dependent parameters in this study included TE, PaO_2, SaO_2, and arterial pH, which could also have been used as criteria.

The few studies of CAR/XYL immobilization of deer reported immobilization dosages ranging from 0.01 to 0.05 mg/kg

CAR and 0.3–1.0 mg/kg XYL, with most of these being empirically chosen (Jessup et al., 1984; Karesh et al., 1986; Caulkett et al., 2000). The median optimal dosages determined in this study were within these ranges. A ratio of approximately 1 mg CAR:10 mg XYL has been investigated in bongo antelope (*Tragelaphus eurycerus isaaci*) (Schumacher et al., 1997a). This ratio was also used in the present study and was held constant for all immobilizations to ensure a consistent synergistic effect and to eliminate variation in the degree of effect of CAR with respect to XYL. Both drugs were administered in the same syringe by a single intramuscular injection to, in part, mimic conditions of field administration.

As expected, there was a range of identified iODs; three deer had iODs lower than and three deer had iODs greater than the mOD. Despite this variation, the mean/median anesthetic and physiologic effects of the iOD did not significantly differ from those of the mOD.

Initial effects, such as ataxia, stumbling, and dysphoria, that would likely decrease postdarting movement in a field immobilization situation were noted in 1.6 min for all deer using the mOD. Inductions were dependably rapid, with all but one deer becoming recumbent in <3.75 min. These findings agree with induction times previously reported for CAR/XYL in deer and other ruminants (Haigh, 1991; Schumacher et al., 1997a; Caulkett et al., 2000). Subjectively, there were variably excitable, ataxic, and moderately rough induction phases for all CAR/XYL dosages evaluated, but these were more common with lower dosages. Occasionally, deer were markedly dysphoric and ataxic while simultaneously running and pacing, although no deer sustained serious injuries as a result of any immobilization procedure.

The decrease in HR and moderate to marked bradycardia (<60 beats/min) over the course of the CAR/XYL immobilization period was not of clinical concern for the 25–35-min immobilization period, and there was no significant effect on RR. In other ruminants, there have been inconsistent effects of CAR or CAR/XYL on HR but consistent decreases in RR (Caulkett et al., 1994; Schumacher et al., 1997a, b; Moresco et al., 2001).

The frequent high temperatures and occasional hyperthermia measured during immobilizations was of concern and has also been noted for carfentanil immobilizations in several other species as well (Karesh et al., 1986; Delvaux et al., 1999; Caulkett et al., 2000). Lower body temperatures were correlated both with greater CAR dosage and with shorter induction times in two reports (Bailey et al., 1985; Karesh et al., 1986). Additionally, hyperthermia has frequently been considered to be associated with increased excitement and running prior to recumbency (Karesh et al., 1986; Caulkett et al., 2000). In this study, body temperature was also positively correlated with induction time but was not correlated with CAR/XYL dosage, despite induction times being significantly dosage related. The hyperthermia did appear to be associated with the degree of excitement in the squeeze chute. It is possible that stressors present in this study (manual restraint in the squeeze chute, human presence within the flight distance, and restricted movement during the induction phase) caused higher temperatures than would be seen in a field situation. The lack of significant correlation between temperature and quality ratings, however, would contradict this hypothesis. In the one animal with a temperature of 42.1 C, therapy to correct hyperthermia was considered but not administered because of the brief immobilization period, the cool ambient temperature, and the animal's apparent physiologic stability. Rather, the deer was promptly reversed and recovered uneventfully, with no adverse effects observed postimmobilization.

The acidemia produced by the mOD of CAR/XYL was of predominantly metabolic (eight deer) or mixed (equivalent metabolic and respiratory components, three

deer) forms at 10 min postrecumbency, whereas at 20 min, there were increased respiratory components, with predominantly metabolic acidemia in five deer and mixed forms in six deer. In one deer, the acidemia was of a predominantly respiratory form at 20 min postrecumbency. Interestingly, the most profound acidemia (pH: 7.03 and 7.16 at 10 and 20 min postrecumbency) was almost completely metabolic in nature, with $PaCO_2$ values of 41.2 mmHg and 33.8 mmHg at 10 and 20 min postrecumbency for that deer. Analyses of initial 10-min arterial blood samples indicated that seven of the deer had clinically significant base deficits (>10 mEq/L); however, the 20-min blood gas analyses showed that all but two of these deer had partially compensated (base deficit<8 mEq/L).

While PaO_2 values indicated adequate oxygenation (>60 mmHg) for both iOD and mOD immobilizations, both SaO_2 and SpO_2 values indicated hypoxemia (<90 mmHg). Oxygen saturation values are calculated by the machine based on a human oxygen-hemoglobin dissociation curve, whereas PaO_2 values are a direct measurement and thus more reliable. Pulse oximetry readings (SpO_2) generally overestimated the SaO_2 readings for both iOD and mOD immobilizations but paralleled the general oxygenation trends. The causation of acidemia, hypercapnea, and hypoxemia by CAR/XYL and CAR has been reported previously (Caulkett et al., 1994, 2000; Schumacher et al., 1997a, b; Moresco et al., 2001) and was generally attributed to respiratory depression. The contrasting finding of metabolic acidemia in this study may be attributable to the occasionally marked excitement, struggling, and pacing prior to the deer becoming immobilized. The lessening of the acidemia as the immobilization period progressed supports this hypothesis.

In addition to high body temperatures and metabolic acidemia, negative effects of immobilizations with the mOD included undesirable quality of inductions. The positive correlation between CAR/XYL dosage and induction quality supports previous findings of decreased excitability with higher opioid dosages in other ungulates (Haigh, 1990) and suggests that desirable induction quality could potentially have been achieved, albeit likely at the expense of cardiopulmonary safety.

A potential confounding factor when performing dosage studies with opioids is decreased sensitivity of the animal to drug effects (tolerance) after repeated immobilizations. Deer in this study were given a washout period of 2–5 wk between immobilizations. The finding of linear CAR dosage-dependent relationships for TI, TE, and all blood gas parameters makes the development of tolerance unlikely under the conditions of this study. Further, the lack of effect of CAR dosage on the presence or absence of temporal trends for any parameter implies that the deer responded similarly to CAR/XYL for each immobilization.

The optimal dosage defined by this study may not be applicable to field immobilization. Effective dosages of opioid and nonopioid immobilization drugs have been determined to be greater for dart administration than for hand injection (Meulemann et al., 1984; Smith et al., 1993; Ryeng et al., 2001a). Additionally, artificial stressors present in this study, as mentioned above, would not be present in a field situation and may alter the dosage of drugs that would be adequate for immobilization. Additional study is needed to determine whether the optimal CAR/XYL dosage identified in this study is applicable to and safe for field immobilization of white-tailed deer.

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