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Authors: Delvaux, Hugues, Courtois, Réhaume, Breton, Laurier, and Patenaude, Robert

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RELATIVE EFFICIENCY OF SUCCINYLCHOLINE, XYLAZINE, AND CARFENTANIL/XYLAZINE MIXTURES TO IMMOBILIZE FREE-RANGING MOOSE

Hugues Delvaux,^{1,2} Réhaume Courtois,^{1,4} Laurier Breton,¹ and Robert Patenaude³

¹ Ministère de l'Environnement et de la Faune, Direction de la Faune et des Habitats, Service de la faune terrestre, boîte 92, 11e étage, 675, Boul. René-Lévesque, Est, Québec (Québec), Canada, G1R 5V7

² Present address: 22, rue des Tourterelles, 4121 Neupré, Belgique

³ Ministère de l'Environnement et de la Faune, Jardin Zoologique du Québec, 9141, ave. du Zoo, Charlesbourg (Québec), Canada G1G 4G4

⁴ Corresponding author (e-mail: rehaume.courtois@mef.gouv.qc.ca)

ABSTRACT: We compared the efficiency of succinylcholine chloride, xylazine hydrochloride and carfentanil/xylazine mixtures in immobilizing 364 free-ranging moose (*Alces alces*) between 1987 and 1997 in Québec (Canada). With succinylcholine chloride (0.070, 0.062, 0.051 mg/kg of estimated body weight for calves, juveniles and adults), 63% of the 252 immobilization attempts led to complete immobilization and marking, whereas 7% of the darted animals died of respiratory paralysis during handling. The moose took an average of 13 min to lay down after darting (down time). Injection of xylazine (3.67–4.22 mg/kg) permitted sedation (the animal laid down but got up again when approached) or complete immobilization in 78% of the 40 darted adult moose, the mean down time being 8.7 min. No mortality was noted with this drug but 58% of the marked animals were only sedated. The use of RX821002A (0.058 mg/kg) as an antagonist, permitted a mean recovery time of 2.8 min after intravenous injection. With the carfentanil/xylazine mixtures (0.0071 and 0.181 mg/kg), 96% of the immobilization trials ($n = 72$) led to complete (88%) or partial (8%) immobilization, but 6% of the moose died several days after capture. The mean down time was 6.6 min, and injection of naltrexone (0.709 mg/kg) antagonized the effect of the immobilizing agent within 3.7 min. The respiratory rate was higher ($P < 0.05$) among moose immobilized with xylazine (35/min) than among those immobilized with carfentanil/xylazine mixtures (19/min) but this variation could be related to a longer pursuit time ($z = 3.60$; $P < 0.01$) and higher stress levels during handling. Rectal temperature also was higher with xylazine but the difference was small (39.7 vs. 39.3, $P = 0.03$) and did not differ significantly between the sexes ($P > 0.05$). Considering loss of materials and helicopter flight time due to non-successful marking trials, carfentanil/xylazine mixtures were the least expensive (\$333 Cdn/animal).

Key words: Carfentanil, cost, immobilization, moose, naltrexone, physiological reactions, RX821002A, succinylcholine chloride, xylazine hydrochloride.

INTRODUCTION

The capture of wild animals with the help of chemical agents became a common practice in the mid-1950's, following the development of projectile systems and the availability of efficient drugs (Franzmann et al., 1982). At the end of the 1980's, up to 17 different products were in use to immobilize cervids (Seal and Bush, 1987), and various methods have been developed to capture moose (*Alces alces*) including net gunning from a helicopter (Simard, 1971; Ritchie and Barney, 1972; Roussel and Pichette, 1974; Joyal et al., 1978; Jolicoeur and Beaumont, 1986; Garner and Addison, 1994). Actually, the use of drug darts fired from a helicopter by means of

projectile syringes remains one of the most efficient techniques. Unlike net gunning, this method can be used on antlered animals and in closed habitats.

However, the diversity of available methods and products can lead to confusion when trying to select the best ones. Immobilizing agents can be classified into three main categories: muscular relaxing drugs, sedatives, and anesthetics (Kreeger, 1996) including narcotics (Seal and Bush, 1987). Muscular relaxing drugs block the transmission of the nerve impulses in skeletal muscles. Until recently, succinylcholine chloride was the most frequently used drug of this category. Its main advantages are speed of action, short duration of effect, very low cost, widespread availability

and small volume (Parent, 1981). Its major drawbacks are the very narrow margin of safety and the fact that the animal remains conscious during handling, being therefore affected by auditory, visual, tactile and psychological stimuli (Parker and Haigh, 1982).

Xylazine hydrochloride has a very large safety margin, its lethal level being more than 10 times the normal dosage. The cost is relatively low and its effects are reversible with certain antagonists, such as yohimbine, tolazine, idazoxan and RX821002 (Parent, 1981; Haigh, 1982; Seal and Bush, 1987; Doherty and Tweedie, 1989; Garner and Addison, 1994). Among its drawbacks are the difficulty in correctly estimating the minimal active dose per animal, its inefficiency when animals are strongly stimulated (Parent, 1981; Seal and Bush, 1987; Schwartz et al., 1997), and a lowering of gastrointestinal tonus. Moreover, the large volumes needed to completely immobilize the animal require the use of 10-cc syringes which are less accurate when shot from a helicopter.

The narcotics group includes morphine and its derivatives which act on the central nervous system (Seal and Bush, 1987), among which etorphine, fentanyl and, principally, carfentanil are the most frequently used (Lynch, 1981; Franzmann, 1982; Haigh, 1982). These products are very safe for the animal and can be neutralized by specific antagonists (diprenorphine, naltrexone) which allow rapid recovery. Their concentrations permit the use of small projectile syringes, improving accuracy of the shot. More importantly, they produce a deep level of anesthesia, which permits easy handling of the animals. Unfortunately, these drugs are very dangerous for the handler, the cost is high, they are difficult to obtain and they may cause hyperthermy (Parent, 1981; Franzmann, 1982; Haigh, 1982; Seal and Bush, 1987) or respiratory depression. Parent (1981), Franzmann (1982), Haigh (1982), Parker and Haigh (1982) and Kreeger

(1996) give a more exhaustive description of these immobilization agents.

The reactions of an animal to a given drug are very species-specific and can vary greatly depending on the conditions under which the drug is injected, leading to contradictory results in the scientific literature. This paper compares the efficiency of the three most widely used products to immobilize free-ranging moose in Québec over the last 10 yr. During this period, succinylcholine chloride, xylazine and carfentanil/xylazine mixtures, with or without antagonists, were used. Optimal concentrations, mortality rates and some physiological reactions of the immobilized animals, as well as costs related to immobilization are reported.

MATERIALS AND METHODS

The trials were conducted from 1987 to 1997 at different study sites throughout the province of Québec (Canada; 47°40' to 50°30'N, 66°00' to 78°45'W). Three hundred sixty four moose immobilizations were attempted during the winter for the purpose of collaring with radio transmitters. The moose were located by surveying the study sites by helicopter (Hughes 500C, 500D, Bell 206-B, or Astar 350D, BA or B2) and by locating the track networks in the snow. The weight and age class of the animals were estimated visually from the air. Succinylcholine chloride (20 mg/ml, Anectine, Mallinckrodt, Veterinary, Ajax, Ontario, Canada) was used between 1987 and 1993. Dosage varied depending on sex, estimated age and body weight. Calves received 12–14 mg (mode: males = 14, $n = 27$; females = 13, $n = 14$) whereas 16–20 mg were injected in the case of 1.5-year-olds (mode: males = 18, $n = 16$; females = 18, $n = 4$). Adult males and females were darted with, respectively, 18–27 mg (mode = 25, $n = 56$) and 17–28 mg (mode = 22, $n = 118$) of succinylcholine chloride. Xylazine (300 mg/ml, Rompun, Miles Canada Inc., Etobicoke, Ontario, Canada) was used on adult moose in the winter of 1995. A dosage of 1,500 mg of xylazine for males and 1,300 mg for females was used initially, but was gradually increased to 2,850 mg to obtain complete immobilization of the animals. The effect of xylazine was antagonized by 25–30 mg of a specific antagonist, RX821002A (10 mg/ml, methoxy analogue of Idazoxan, Ultrafine Chemicals, Manchester Science Park, Manchester, UK), injected intravenously. In 1996, 3 mg of

carfentanil (3 mg/ml, Wildnil, Wildlife Laboratories, Inc., Fort Collins, Colorado, USA) mixed with 50–150 mg of xylazine was used. This mixture, administered to both males and females, was antagonized with 300 mg of naltrexone (50 mg/ml, Trexonil, Wildlife Laboratories, Inc.) injected intravenously (Schmitt and Dalton, 1987). The same products and dosages were used in 1997, except that only one fourth of the naltrexone was injected intravenously, the rest being administered intramuscularly.

The immobilizing products were injected with a projectile syringe, that were usually shot from a helicopter. However, several animals were driven towards a shooter on the ground. A .50-caliber Extra Long Range Projector rifle (Cap-Chur, Palmer Chemical and Equipment Company, Douglasville, Georgia, USA) was usually used with 5 to 10-cc capacity syringes for succinylcholine chloride and xylazine, and 3-cc syringes for the carfentanil/xylazine mixtures.

A topical antibiotic was applied to the wound of immobilized animals, along with an intramuscular injection of a broad spectrum antibiotic and a vitamin E/selenium supplement. During the winters of 1995 to 1997, cardiac and respiratory rates, as well as the rectal and tympanic temperatures of the animals were measured and recorded before and after handling in order to detect any possible stress related to the capture. The age of the marked animals was estimated by tooth wear examination. Blood samples also were taken for hematological and serological studies.

Whenever possible, the terminology of Schwartz et al. (1997) was used to describe product efficiency and the animals' reactions following injection, namely the terms pursuit time: time elapsed from the initial engagement with the animal to the injection of the immobilizing agent; down time: time elapsed from the injection of the immobilizing agent to the moment the animal laid down; immobilized time: time from laying down until the animal was standing; recovery time: time elapsed from the injection of the antidote to the rising of the animal; sedation: animal lays down but duration of immobilization is not long enough to allow marking or marking is very difficult; immobilization: duration of immobilization is sufficient for easy marking; no reaction: product injected into the animal, yet no reaction is observed or product was incorrectly injected.

Differences between sex, age and product were tested using the Kruskal-Wallis test or analysis of variance depending on the number of comparisons, the number of variables and the normality of the data (Snedecor and Cochran, 1971). Spearman rank correlations were

used to evaluate the links between the dosage of drug, time of pursuit and physiological condition of the animals. The χ^2 test was used to compare the animals' reactions following the injection of immobilizing agents. A 5% significance level was maintained. All calculations were processed using the SAS statistical software (Statistical Analysis Systems, SAS Institute, Inc., Cary, North Carolina, USA).

RESULTS

Marking success, dosage, down time, immobilization time and recovery time

The effective doses of succinylcholine chloride varied among moose categories ($\chi^2 = 39.39$, $P < 0.01$), and were 0.070 mg/kg of estimated body weight for calves, 0.062 mg/kg for juveniles, and 0.051 mg/kg for adults. Adult females received a slightly lower dose per animal as compared to males ($z = 3.12$, $P < 0.01$) due to their lower estimated body weight. Mean dosage for adults was 22.5 mg/animal (Table 1). The mean down time of the immobilized moose was approximately 13 min, and did not differ significantly with age or succinylcholine chloride dose ($P > 0.05$). Animals were immobilized for a mean period of approximately 33 min, a duration that does not differ significantly with respect to age or dose of immobilizing agent. Nevertheless, juvenile males reacted a little faster ($z = 2.39$, $P = 0.02$) than did juvenile females. Similarly, males, both adult and juvenile, remained immobilized for a longer period than did their respective female counterparts ($z = 2.57$, $P = 0.09$). The animals that were not properly immobilized received similar doses (22.7 ± 0.5 , $n = 68$, $P > 0.05$) as did the successfully immobilized animals.

In 78% of the 40 attempts, injection of xylazine led to immobilization ($n = 14$) or sufficient sedation to allow marking ($n = 16$). The dose injected was gradually increased from 1,230 to 2,850 mg/animal due to insufficient sedation during the first trials. The mean dose injected was 4.0 mg/kg of body weight while the mean down time was 8.7 min; no significant difference was noted between the sexes ($P > 0.05$).

TABLE 1. Dosage of succinylcholine chloride, xylazine hydrochloride and carfentanil/xylazine mixtures, pursuit time, down time and immobilized time of moose captured between 1987 and 1997 in Québec.

	Dosage of immobilizing agents		Pursuit time (min)	Down time (min)	Immobilized time (min)
	mg/animal	mg/kg ^a			
Succinylcholine chloride	22.5 ± 0.2 (106) ^b	0.051 ± 0.001 (106)	6.8 ± 0.8 (100)	13.0 ± 0.4 (106)	32.7 ± 1.6 (92)
Xylazine hydrochloride	1,749.3 ± 102.8 (30)	4.00 ± 0.24 (30)	13.1 ± 2.5 (28)	8.7 ± 1.5 (26)	47.1 ± 64 (18)
Carfentanil/	3.0 ± 0.0 (69)	0.0071 ± 0.0001 (69)	6.3 ± 1.0 (63)	6.6 ± 0.4 (55)	30.1 ± 1.3 (60)
Xylazine mixture	76.8 ± 4.3 (69)	0.181 ± 0.0100 (69)			

^a mg/kg of estimated body weight.

^b $\bar{x} \pm SE (n)$.

On average, the animals were immobilized for 47.1 min. The antagonist RX821002A was injected intravenously in 18 moose at a mean dose of 0.058 mg/kg of body weight for a mean recovery time of 2.8 min (Table 2). Animals that were only sedated and got up before handling was completed did not receive the antagonist and therefore mean recovery time for these animals was not estimated. The injected doses did not differ significantly ($\alpha = 0.75, P = 0.45$) between animals that were not immobilized and those that were successfully immobilized. The mean pursuit time was about 2 min shorter for those animals that were only sedated, but the down time was the same.

Close to 96% of the 72 animals that received a carfentanil/xylazine mixture were completely immobilized or sufficiently sedated to be collared. Despite weight differences, the same doses of carfentanil (3 mg) were administered to both males and females but doses of xylazine varied from 50 to 150 mg/animal. Mean doses were 0.007 mg/kg for the carfentanil and 0.181 mg/kg for the xylazine. The mean down time was 6.6 min whereas immobilization lasted for an average of 30.1 min. All of the immobilized animals received 300 mg of naltrexone (0.709 mg/kg) in order to antagonize the effect of the immobilizing agent. On average, the animals recovered within 3.7 min (Table 2).

Moose reactions

Reactions following injection of the immobilization agents did not differ between the sexes (succinylcholine chloride: $\chi^2 = 2.058$; xylazine: $\chi^2 = 0.870$; carfentanil/xylazine: $\chi^2 = 1.07$; $P > 0.05$) but did differ between the products ($\chi^2 = 91.95, P < 0.01$) (Fig. 1). With succinylcholine chloride, 63% of the injected animals were immobilized and 7% died of respiratory paralysis. Besides the very narrow margin of safety with succinylcholine chloride, the longer-than-average pursuit time could partly explain the deaths. In 43% of the cases where an animal died, pursuit time

TABLE 2. Dosage of RXS21002A and naltrexone respectively used as antagonist of xylazine and carfentanil, and recovery time of adult moose immobilized between 1995 and 1997 in Québec.

	Dosage of antagonist		Recovery time (min)
	mg/animal	mg/kg ^a	
RXS21002A	25.4 ± 1.6 (18) ^b	0.058 ± 0.004 (18)	2.8 ± 0.6 (17)
Naltrexone	300.0 ± 0.0 (69)	0.709 ± 0.010 (69)	3.7 ± 0.2 (68)

^a mg/kg of estimated body weight.

^b $\bar{x} \pm SE (n)$.

ranged from 24 to 28 min, whereas only 5% of the other immobilized animals were pursued for such a duration ($\chi^2 = 13.3$, $P < 0.01$). During immobilization, the majority ($\approx 80\%$) of moose immobilized with succinylcholine chloride displayed normal behavior, being calm with head raised high. Males, females, and calves showed similar behavior ($\chi^2 = 8.39$, $P > 0.05$).

Xylazine resulted in immobilization in only 35% of the trials. Few darted animals showed no reaction (8%) but 58% were only sedated. No mortality was directly related to that drug. An adult male died several days after its capture but the necropsy suggested that the death probably resulted from physiological complications due to the animal's very poor physical condition.

Carfentanil/xylazine mixtures were the most effective drugs as only 4% of the animals showed no reaction after darting. With the mixtures used, 96% of the immobilization trials led to marking. Correct immobilization represented 82% of the tri-

als whereas 8% of the darted animals were only sedated and 6% died several days after capture. The four deaths comprised three females that showed evidence of capture myopathy while a 1.5-year-old male developed foreign body pneumonia.

Some physiological reactions are available for the xylazine and the carfentanil/xylazine mixtures (Table 3). Analysis of variance shows that females have a higher respiratory rate than do males ($F = 8.61$; $P = 0.05$). The principal difference between the two products also is related to the respiratory rate which is higher among animals immobilized with xylazine ($F = 40.15$, $P < 0.01$), a phenomenon that could be due to longer pursuit time ($z = 3.60$, $P < 0.01$) or increased stress during handling under partial sedation. We did note a decrease in the animal's respiratory rate with an increased dosage of xylazine ($r = -0.56$, $P < 0.05$) suggesting improved clinical effect under increased level of sedation. Rectal temperature was however

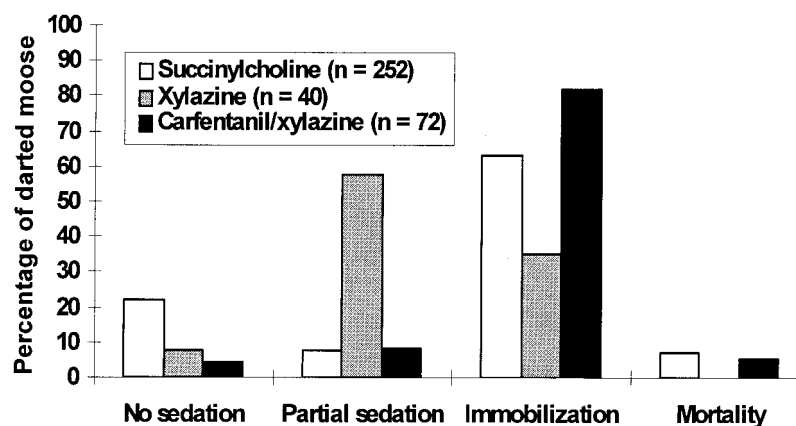


FIGURE 1. Moose reaction after injection of immobilizing agents in Québec between 1987 and 1997.

TABLE 3. Physiological condition of adult moose captured between 1995 and 1997 in Quebec using Xylazine hydrochloride or carfentanil/xylazine mixtures.

	Xylazine		Carfentanil/xylazine	
	Males	Females	Males	Females
Respiratory rate (/min)	28.3 ± 7.4 (6) ^a	40.2 ± 6.7 (7)	18.0 ± 0.5 (28)	20.2 ± 0.7 (44)
Cardiac rate (/min)	—	—	70.9 ± 2.0 (22)	74.8 ± 1.3 (28)
Rectal temperature (C)	39.6 ± 0.2 (11)	39.7 ± 0.2 (11)	39.5 ± 0.1 (23)	39.1 ± 0.1 (38)
Tympanic temperature (C)	—	—	38.3 ± 0.1 (19)	37.9 ± 0.1 (18)

^a $\bar{x} \pm SE (n)$.

negatively correlated to the respiratory rate ($r = -0.65$, $P = 0.03$) so it remains possible that a higher respiratory rate could be necessary to help control body temperature. Rectal temperature was higher in animals immobilized with xylazine ($\bar{x} \pm SE = 39.7 \pm 0.1$, $n = 22$) than in those immobilized with carfentanil (39.3 ± 0.1 , $n = 61$) but the difference was small ($F = 4.82$, $F = 0.031$). It was not possible to establish the same correlation between the dose of the carfentanil/xylazine mixtures injected and the respiratory rate or the rectal temperature because the doses of carfentanil did not vary throughout the experiment.

Both xylazine and carfentanil/xylazine mixtures were used under various meteorological conditions. Ambient air temperatures ranged from -18 to 10 C ($n = 40$) with xylazine and -30 to 13 C ($n = 67$) with the carfentanil/xylazine mixtures. No significant correlation was noted between rectal and ambient temperature with xylazine ($r = 0.06$, $P = 0.83$) but the correlation was highly significant with the carfentanil/xylazine mixture ($r = 0.33$, $P = 0.010$) even if we tended to limit the length of pursuit during warm weather ($r = -0.25$, $P = 0.05$). This suggests that the pursuit must be as short as possible on warmer days.

The behavior after injection of the antidote is available for xylazine and carfentanil/xylazine mixtures. Most (84%) of the 19 animals immobilized with xylazine and antagonized with RX821002A left walking (11 individuals) or running (5) whereas three animals demonstrated abnormal be-

havior such as staggering, tongue hanging or lowered ears. Tongue hanging was also the rule during immobilization with xylazine. The reversal of the carfentanil/xylazine mixtures with naltrexone also seemed acceptable as 85% of the animals left walking (60 of 72) and running (1); nine moose left staggering and two others displayed tongue hanging.

Rectal and tympanic temperatures were not correlated ($r = 0.21$, $P = 0.22$), a situation probably related in large part to the difficulty of correctly measuring tympanic temperature in the field.

Costs of utilization

Besides personnel time, which was not estimated, total cost of immobilizing free-ranging moose depends on three major components: the immobilizing agent, the antidote, and the flight time necessary to dart the animal and follow it until it lays down. Flight time proved to be the most expensive component. Surprisingly, the cost of the antidote came in second, followed by that of the immobilizing agent (Table 4). Succinylcholine chloride is inexpensive ($\$0.16/\text{animal}$) but the cost of its utilization is relatively high due to loss of flight time consecutive to long down time and many cases of partial or no sedation and mortality. Xylazine does not cost very much per animal ($\$27.00$) but its antidote is somewhat expensive ($\$55.00/\text{animal}$); xylazine also requires major flight time to recover moose that are only sedated. The carfentanil/xylazine mixtures ($\$52.00/\text{animal}$) and particularly its antidote ($\$113.00/\text{moose}$) are the most expensive drugs, but

TABLE 4. Mean cost per moose immobilized with succinylcholine chloride, xylazine hydrochloride and carfentanil/xylazine mixtures.

	Immobilizing agent (Cdn \$)	Antagonist (Cdn \$)	Helicopter ^a		Sub-total (Cdn \$)	Total ^b (Cdn \$)
			Time (min)	Cost (\$)		
Succinylcholine chloride	0.2 ± 0.1 (157) ^c	—	20.2 ± 0.7 (145)	236 ± 8 (145)	236 ± 8 (145)	426
Xylazine	27 ± 1 (31)	55 ± 3 (19)	21.6 ± 2.7 (25)	252 ± 32 (25)	347 ± 47 (16)	481
Carfentanil/xylazine	52 ± 0 (69)	113 ± 0 (69)	12.8 ± 1.2 (55)	150 ± 14 (55)	314 ± 14 (55)	333

^a Helicopter costs were estimated at \$700/h.

^b Including costs related to unsuccessful marking trials (no reaction, sedation not deep enough to allow marking, deaths).

^c $\bar{x} \pm SE (n)$.

a very high success rate of immobilization permits a moderate total cost due to a 36 to 40% reduction in flight time.

Finally, in field work, one must take into account the costs related to unsuccessful marking trials which are high, being 45, 28 and 6% of the total cost for succinylcholine chloride, xylazine and the carfentanil/xylazine mixtures, respectively. Among the three products employed, xylazine and succinylcholine chloride were the most expensive ones at \$481.00 and \$425.00 respectively per effective (live) marked animal. The carfentanil/xylazine mixtures cost about 30% less (\$333.00/animal) due to a much lower proportion of unsuccessful trials.

DISCUSSION

Succinylcholine chloride was a widely used immobilizing agent, but it was progressively abandoned due to its difficulty in usage (Parent, 1981; Parker and Haigh, 1982). The animal's weight must be correctly estimated, and an overdose of this depolarizing muscle relaxing agent inevitably causes death by asphyxiation, as the movements of the diaphragm cease. Moreover, Ballard and Tobey (1981) report that pursuing pregnant females by helicopter in order to inject succinylcholine chloride could increase the cases of fetal mortality. Conversely, when the dosage is insufficient, the animal lies down but gets up again when the marking team approaches. Finally, the ethics of succinylcholine chloride utilization can be questioned because animals remain conscious during handling and nearly 40% of the darted animals do not become immobilized on the first attempt and must be darted again to remove the syringes and to inject antibiotics to prevent possible infections.

The doses we used for the moose correspond to those reported by other researchers, except for the calves who required higher doses/kg due to a faster metabolism than did the adults. Reported unsuccessful efforts with succinylcholine chloride range from 16 to 33% whereas

mortality rates varied between 2 and 26%, most of which being around 5% (Bergerud et al., 1964; Houston, 1969; Nielson and Shaw, 1967; Jolicoeur and Beaumont, 1986), as in our study. Down time however, was longer in our study than in other studies (9.0–9.5 min; Bergerud et al., 1964; Houston, 1969). The costs of succinylcholine chloride itself are minute, the largest proportion being associated with aircraft use. Very little reference in the literature is made to the cost of marking with this drug. Thirty years ago, Nielson and Shaw (1967) reported a cost of only \approx \$62.00/animal.

The appropriate dose of xylazine is not well known. This probably explains why it is primarily used in combination with other immobilizing agents (Franzmann et al., 1982). In the literature, the reported doses vary from 2.2 to 3.0 mg/kg (Franzmann, 1982; Doherty and Tweedie, 1989; Schwartz et al., 1997). However, we used a dose of 4.0 mg/kg of body weight. Even at this dosage level, the majority of the animals were only sedated and not immobilized. The adequate dosage would be about 6.5 mg/kg of estimated body weight, a quantity requiring 12-cc syringes which implies major ballistic problems.

Xylazine works very well with penned moose, provided the environment is calm and the handlers wait 10 to 15 min after the animal lays down to assure complete sedation before handling (Schwartz et al., 1997). Moreover, it can be effectively countered with tolazoline (Schwartz et al., 1997), RX82100 (Doherty and Tweedie, 1989) or RX821002A (this study). However, in our field experiment xylazine proved to be the least efficient product. Despite the injection of twice the xylazine quantity suggested for captive animals, the moose overrode the sedative effect of this drug when subjected to external stimulation (pursuit and the noise of the helicopter). These animals laid down but stood up again as soon as the marking team approached, even if they moved slowly and quietly. In the field, this product poses

similar ethical problems as does succinylcholine chloride.

Franzmann (1982) observed a mean down time of 10.5 min with xylazine, a value similar to ours (8.7 min), whereas Doherty and Tweedie (1989) mention a down time of 5.1 min. The relatively long down time for this drug led to higher helicopter costs. The only description of the physiological parameters after xylazine injection is provided by Doherty and Tweedie (1989). These authors measured a mean cardiac frequency of 45 pulses/min. Neither body temperature nor respiratory rates were noted. In our trials with xylazine, respiratory rates were 1.5 to 2 times those obtained with the carfentanil/xylazine mixture, and animals were too agitated to correctly measure cardiac rates. This information provides just one more illustration of the difficulty of using xylazine in the field.

RX821002A seems to be one of the best antidote for xylazine, as compared to tolazoline, idazoxan, or yohimbine. The recovery time was quick (\bar{x} = 2.8 min) and similar to that reported by Doherty and Tweedie (1989) with idazoxan (1.6 min). RX821002A is more efficient than tolazoline which takes about 15 to 20 min to antagonize xylazine (Schwartz et al., 1997). Yohimbine proved to be inefficient in neutralizing xylazine in moose (Schwartz et al., 1997) but Garner and Addison (1994) obtained the reversal of a xylazine and ketamine mixture in 1 to 71 min on females immobilized in spring.

Carfentanil seems to have few detrimental effect on moose physiology. The mortality rate mentioned in different studies remains less than 10% (Franzmann et al., 1984b; Olterman et al., 1994). This drug can be used alone at 3–5 mg per adult moose with a rapid down time of about 5 min and few mortalities (6.5%; Franzmann, 1982). Seal et al. (1985) suggest 3–4 mg of carfentanil in conjunction with 100–175 mg of xylazine to prevent muscle hypertonicity. Schwartz et al. (1997) suggest a mixture of 3 mg of car-

fentanyl and 200 mg of xylazine. We used 3 mg of carfentanyl and 50–150 mg of xylazine with excellent results. This mixture can be administered with 3-cc syringes which improves the ballistics, and reduces loss of material and pursuit time. During immobilization, animals remain in sternal position and stay calm which is important to increase the security of personnel and the safety of the animals. Moreover, quick down time (<7 min) allows for reasonable helicopter costs compared to those reported in other studies (\$500/animal, Olterman et al., 1994). One important point is that the carfentanyl/xylazine mixtures generally produce immobilization even when moose are darted in poorly vascularized tissues. However, in such cases, a long down time (15–45 min) is to be expected.

Naltrexone injection led to a quick recovery (3.7 min). We used the same dose as described in Schmitt and Dalton (1987) and obtained similar results. Seal et al. (1985) reported a longer recovery time (25–150 min) after the injection of naloxone and diprenorphine indicating that these antidotes are less effective. For the best results, we suggest the use of naltrexone with $\frac{1}{4}$ of the dose injected intravenously and $\frac{3}{4}$ injected intramuscularly to permit a longer reversal effect and avoid any long term recycling of the immobilizing agents.

The increase in rectal temperature is a good indicator of the stress level experienced by an immobilized animal (Franzmann and Arneson, 1974; Franzmann et al., 1984a; Schmitt and Dalton, 1987). Sedgwick (1979) considers that the homeostatic mechanism regulating temperature begins to fail at temperatures above 41 C. Temperatures exceeding 42 C generate cardiac problems or capture myopathy which usually leads to death. In our study, no animal immobilized with xylazine or the carfentanyl/xylazine mixtures reached the critical temperature of 41 C and mean temperatures were similar to that reported with fentanyl (Haigh et al., 1997). Similarly, no abnormal variations in

either cardiac or respiratory rates were observed during moose handling, indicating normal physiological reactions of moose to these drugs.

Cardiac and respiratory rates as well as body temperature were not correlated to the length of pursuit, but ambient temperature seemed to influence rectal temperature. To limit any potential negative impact, we suggest targeting a chase time of 5 min. This time must be respected in difficult situations (moose in poor physical condition or stressed, difficult terrain, surrounding temperatures >0 C, etc.) but the pursuit can be extended to 10 min under normal conditions. However, each case is unique, and the marking team has to show good judgment during the pursuit.

Management implications

Considering the 10 criteria of Franzmann (1982) for evaluating the ideal immobilization agent, we consider that the injection of 3 mg of carfentanyl and 50 mg of xylazine per animal, and the reversal of this mixture with 300 mg of naltrexone, of which $\frac{1}{4}$ is injected intravenously, is the best combination for efficiently immobilizing free-ranging moose. This mixture is rapidly absorbed by moose; its concentration permits the use of small 3-cc syringes, giving better ballistics; the moose are tolerant of the mixture and demonstrate few side effects; anesthesia is generally deep; the effects of this product are reversible with naltrexone; and finally, this mixture has more acceptable total costs as compared to the two other compounds. The most important drawbacks of the carfentanyl/xylazine mixtures are their potential lethality in humans and the strict license and usage controls. However, these mixtures can be used safely when adequate procedures are implemented (MLCP, 1986) and scrupulously followed during the preparation of syringes and the handling of the moose.

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