

Immobilization of White-Tailed Deer With Telazol, Ketamine, and Xylazine, and Evaluation of Antagonists

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ABSTRACT Telazol–xylazine and ketamine–xylazine are versatile and safe drug combinations that are used frequently for chemical immobilization of cervids. Although neither combination consistently offers rapid induction and recovery, we hypothesized that a combination of Telazol, ketamine, and xylazine (TKX) would provide a safe and effective alternative for immobilization of white-tailed deer (*Odocoileus virginianus*). During a 2-stage study, we evaluated the effectiveness of yohimbine and tolazoline as α_2 -adrenergic antagonists (2005–2006), and characterized the factors that affected chemical immobilization of male deer with a targeted dose of telazol (2.20 mg/kg), ketamine (1.76 mg/kg), and xylazine (0.44 mg/kg), using explosive-charged darts (2007–2010). During the first stage, we randomly assigned deer to antagonist treatments, including a control group that did not receive an antagonist ($n = 8$), a tolazoline (4 mg/kg) treatment ($n = 16$), and a yohimbine (0.11 mg/kg) treatment ($n = 15$). Recovery times ($\bar{x} \pm SE$) were longer ($P = 0.0013$) for control (150.6 ± 21.7 min) and yohimbine (74.5 ± 13.1 min), compared with tolazoline (12.5 ± 12.3 min). Tolazoline resulted in faster and more complete recovery compared with the frequent incomplete antagonism and ataxia observed with yohimbine. During the second stage, 56 immobilization events (2007–2010) with TKX yielded a mean induction time of 7.8 minutes ($SE = 0.44$). Repeated-measures analyses indicated that induction and recovery were affected by body weight, with larger males taking longer to become recumbent ($P = 0.08$), but they recovered more rapidly ($P = 0.003$) following administration of tolazoline. Physiological parameters we measured under anesthesia were within normal ranges for white-tailed deer; however, initial temperature was higher ($\beta = -0.86$) for younger males ($P = 0.014$). Final physiological parameters were closely related to initial measurements, with rectal temperature being the most preserved ($\beta = 0.90$); heart and respiration rate declined ($\beta < 0.60$) during anesthesia. Our results indicate that TKX may be useful for chemically immobilizing white-tailed deer, and we recommend tolazoline as an antagonist for xylazine. © 2012 The Wildlife Society.

KEY WORDS anesthesia, ketamine, *Odocoileus virginianus*, telazol, tolazoline, white-tailed deer, xylazine, yohimbine.

Capture and handling of animals is frequently required for research, and chemical immobilization often is the safest and most effective method (Kreeger and Arnemo 2007). Suitable immobilizing agents should be easy to administer, have a high therapeutic index, require only small volumes for re-

mote delivery, provide short induction times, be reversible, and exhibit no long-term effects (Walsh and Wilson 2002). Currently, few drug combinations meet these criteria for white-tailed deer (*Odocoileus virginianus*). Combinations of telazol–xylazine (TX) and ketamine–xylazine (KX) have been used for a number of cervid species (Jessup et al. 1983, DelGiudice et al. 1989, Millspaugh et al. 1995) and are commonly used for immobilization of white-tailed deer (Mech et al. 1985; Kreeger et al. 1986; Kilpatrick and Spohr 1999; Miller et al. 2003, 2004). Nevertheless, both combinations are a compromise between rapid induction (TX) and rapid recovery (KX).

Telazol is a 1:1 ratio of a cyclohexane dissociative anesthetic, tiletamine hydrochloride, and the benzodiazepine tranquilizer, zolazepam (Spelman et al. 1997, James et al.

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1999, Miller et al. 2004). Cyclohexanes cause the animal to become unconscious and amnesic; however, no antagonists are available for dissociative drugs (Kreeger and Seal 1986). To avoid violent inductions and recoveries when cyclohexanes are used independently, adding alpha₂-adrenergic agonists (e.g., xylazine) provides sedation, analgesia, myo-relaxation, and better inductions and recoveries (Millsbaugh et al. 1995, Walsh and Wilson 2002). Ketamine, another cyclohexane, is frequently used in combination with opioid and alpha₂ agonists to decrease total drug required, improve muscle relaxation, and reduce hyperthermia (Citino et al. 2001, 2002; Grobler et al. 2001; Storms et al. 2006), or as a supplemental drug to prolong anesthesia (Murray et al. 2000).

Although the addition of ketamine to other immobilizing agents has produced favorable results, TX has outperformed KX, with shorter flight distances (Kilpatrick and Spohr 1999), and it is considered a better combination for white-tailed deer (Murray et al. 2000). Muller et al. (2007) evaluated combinations of ketamine, xylazine, medetomidine, and butorphanol for immobilizing white-tailed deer and concluded that telazol, ketamine, and medetomidine provided the best inductions, physiological parameters, and recoveries. Medetomidine often outperforms xylazine (Walsh and Wilson 2002), but at greater costs for the drug and its antagonist (atipamezole), compared with xylazine (Muller et al. 2007). We hypothesized that a combination of telazol, ketamine, and xylazine (hereafter referred to as TKX) may offer a safe and effective alternative for immobilization of white-tailed deer.

A combination of TKX has been successfully used to immobilize domestic cats (*Felis catus*), sheep (*Ovis aries*), pigs (*Sus scrofa*), and cheetahs (*Acinonyx jubatus*; Thurmon et al. 1988, Ko et al. 1993, Lewandowski et al. 2002, Williams et al. 2002, Cistola et al. 2004), but it has not been evaluated for cervids. The combination may offer advantages to TX or KX immobilization of white-tailed deer, but recovery times for telazol combinations are often lengthy (Miller et al. 2004), especially compared with ketamine combinations (Mech et al. 1985, Storms et al. 2006, Muller et al. 2007). Although no complete antagonists for the cyclohexanes exist, yohimbine and tolazoline may have partial antagonistic qualities (Kreeger and Seal 1986). Yohimbine has been used to reverse xylazine (Hsu and Shulaw 1984), KX (Jessup et al. 1983, Mech et al. 1985), and TX (Millsbaugh et al. 1995) in elk (*Cervus elaphus*) and mule deer (*O. hemionus*), but has proven unsatisfactory for TX in white-tailed deer (Miller et al. 2003). Tolazoline has the lowest affinity for all alpha₂-adrenergic receptor subtypes when compared with yohimbine (Schwartz and Clark 1998), but has been reported as a useful antagonist for KX (Kreeger et al. 1986) and TX (Miller et al. 2004). By including ketamine with TX and reducing the amount of telazol, we hypothesized that recovery times would be reduced.

Our objective was to evaluate TKX and associated antagonists for their effectiveness in chemical immobilization of white-tailed deer. Our study consisted of 2 stages: 1) evaluate the effectiveness of alpha₂ antagonists for TKX (2005–

2006), and 2) determine factors related to induction and recovery, as well as physiological parameters observed during chemical immobilization with TKX (2007–2010) for male white-tailed deer.

METHODS

We conducted this study at the Wildlife and Fisheries Sciences Research Facility at South Dakota State University, Brookings, South Dakota, USA (44°20'N, 96°47'W). The facility encompassed approximately 1.8 ha and was enclosed with 2, 2.4-m high woven-wire fences to prevent contact between captive and wild animals (Vercauteren et al. 2007). We fed deer rations formulated as complete diets of corn, pelleted soy hulls, and alfalfa hay. We withheld rations from deer beginning 12 hours prior to immobilization. We weighed deer <1 week prior to immobilization with a walk-on scale (Adrian J. Paul Company, model 16, Duncan, OK) accurate to 0.45 kg to determine appropriate drug dosage and to control for body weight in analyses. Our procedures were approved by the South Dakota State University Institutional Animal Care and Use Committee (IACUC 02-A038) and complied with guidelines of the American Society of Mammalogists (Sikes et al. 2011).

Our study animals were males of varying age (range: 1.5–11.5 yr) and body weight (range: 60.3–150.1 kg), which we kept in multiple enclosures exclusive to males. We immobilized deer within 3 weeks of peak rutting activity (i.e., mid-Oct to early-Nov). We recognized the potential for confounding effects of reproductive hormones within our study animals and interactions among animals once darted, which could increase stress and delay immobilization. Confinement of adult males within the enclosure likely maximized agonistic interactions among males, thereby lengthening inductions.

During 1–8 November 2005 and 2006 (stage 1), we chemically immobilized captive deer with TKX to evaluate the performance of 2 alpha₂ antagonists, yohimbine hydrochloride and tolazoline hydrochloride. During mid-October 2007–2010 (stage 2), we chemically immobilized deer using TKX to determine which factors influenced induction and recovery times. Throughout the study, we used TKX with a targeted dose of Telazol[®] (2.20 mg/kg; Fort Dodge Animal Health, Fort Dodge, IA), ketamine hydrochloride (1.76 mg/kg; Wildlife Pharmaceuticals, Fort Collins, CO), and xylazine hydrochloride (0.44 mg/kg; Wildlife Pharmaceuticals), which was determined after consultation with veterinarians in our region and was within the range of published dosages (Kreeger et al. 1986, Miller et al. 2004, Muller et al. 2007).

We administered TKX using explosive-charge darts with gel collars and 1.25-inch needles (Pneu-dart Inc., Williamsport, PA) fired from a CO₂ powered rifle (Dan-Inject[®], Fort Collins, CO). We commonly rounded the TKX dose up to the nearest 0.10 ml because a finer resolution would be unrealistic in a field setting. Upon administering TKX, we monitored each animal to determine time to sternal and lateral recumbancy. We defined sternal

recumbancy as the time required for the animal to lie down, with the inability to rise. We noted lateral recumbancy when an animal placed its head to the ground and did not respond to external stimuli. We recorded degree of induction exhibited by each animal after animals were approached for processing using ordinal scores: 0 = lateral recumbancy, complete immobilization without response to any stimuli; 1 = lateral recumbancy, slight response to stimuli (eye or ear movement), but inability lift head; 2 = sternal recumbancy, ability to erect head, but unable to stand, dazed, and unsteady; and 3 = maintained ability to rise and walk in an ungainly manner.

Once recumbent, we blindfolded deer to reduce stress and protect their eyes. We monitored respiration (breaths/min), heart rate (beats/min), and rectal temperatures ($^{\circ}$ C) of immobilized deer. When rectal temperatures exceeded 40° C we applied cold water to the head, chest, and abdomen to facilitate cooling. We recorded physiological parameters of each deer upon approach, shortly after lateral recumbancy (hereafter initial measurement), and immediately prior to administering an antagonist (hereafter final measurement). While each deer was immobilized, we acquired morphological measurements, collected blood, and removed antlers.

During 2005 and 2006, we randomly assigned deer to antagonist treatments: a control group that did not receive an antagonist ($n = 8$), a tolazoline treatment ($n = 16$) that received 4 mg/kg of tolazoline (100 mg/ml, Tolazoline[®]; Wildlife Pharmaceuticals), and a yohimbine treatment ($n = 15$) that received 0.11 mg/kg of yohimbine (2 mg/ml, Yobine[®]; Lloyd Laboratories, Shenandoah, IA). We assigned antagonist doses based on previous research on white-tailed deer (Hsu and Shulaw 1984; Mech et al. 1985; Miller et al. 2004, 2009). We recorded time of antagonist administration, removed blindfolds, and then monitored animals from a distance to avoid human interference and promote natural recovery. Although no antagonist was given to the control group, we recorded the time when we would have normally administered antagonists to provide a comparable recovery time. We recorded time required for each animal to be capable of standing and walking with coordination. If animals experienced incomplete recovery or recurring effects from anesthesia, we recorded recovery time when the animal fully recovered from the effects of TKX.

During the final 4 years of study (2007–2010), we immobilized all deer with TKX and antagonized with tolazoline (4 mg/kg). In addition to recording physiological parameters (e.g., initial and final temperature, pulse, and respiration), we determined nutritional condition of each male using ultrasonography. We measured maximum depth (± 0.1 cm) of rump fat cranial to the cranial process of the tuber ischium and parallel to the spine using electronic calipers with a portable ultrasound device (Aloka 210; Aloka, Inc., Wallingford, CT) and a 5-MHz linear transducer following protocols developed for mule deer (Stephenson et al. 2002, Cook et al. 2010). Because rump fat thickness was never < 0.3 cm, body condition scores were not necessary to estimate ingesta-free body fat (IFBFat; Cook et al. 2007). Given

their similarities in morphology and fat deposition, we assumed that equations developed to estimate IFBFat for mule deer would be sufficient for white-tailed deer. Therefore, we used a combination of body weight and rump fat thickness to estimate IFBFat following Cook et al. (2010).

Statistical Analyses

Prior to analyzing differences in recovery time among antagonist treatment groups (2005–2006), we removed individuals with an induction score of 3 ($n = 3$) and those that received supplemental agonist ($n = 2$), which provided a standardized test of antagonist treatments. To evaluate differences in age, weight, characteristics of anesthesia, and recovery among antagonist treatments, we used repeated-measures analysis of variance (ANOVA; PROC MIXED, SAS v. 9.2; SAS Inc., Cary, NC) with an autoregressive error structure and a lag of 1 to account for repeated sampling of some individuals (Neter et al. 1996). Subsequently, we used Bonferroni corrections to maintain overall experiment-wise error for multiple comparisons among antagonist treatment groups (Zar 1999).

For the second stage of our study, we evaluated factors that influenced chemical immobilization using TKX and physiological parameters observed under anesthesia using linear mixed models (PROC MIXED; SAS) with an autoregressive error structure and a lag of 1 to account for repeated sampling of some individuals during 2007–2010 (Neter et al. 1996). We first examined predictor variables for multicollinearity with Pearson's correlation and did not include in the same model pairs of variables with $r > |0.50|$ (Neter et al. 1996). We began modeling with the global model containing all predictor variables that we hypothesized would influence the response variable, and reduced that model using a stepwise process with backward elimination and $\alpha = 0.10$ for entry and retention in the model. We evaluated logical interaction terms using the same approach, with $\alpha = 0.10$ for retention in the model. We examined residual and $Q-Q$ plots to identify violations of assumptions of linear models.

For time to sternal and lateral recumbancy, we evaluated the influence of body weight, age, IFBFat, and TKX dose relative to body weight (TKX ml/kg). For initial and final physiological parameters observed during anesthesia, we evaluated the influence of body weight, age, IFBFat, time to sternal recumbancy, and TKX dose relative to body weight, as well as other physiological parameters measured during anesthesia, including temperature, respiration, and heart rate. Finally, we evaluated the relationship of recovery time and final temperature, respiration, and heart rate, as well as body weight, age, IFBFat, and time from TKX to antagonist administration.

RESULTS

During 2005–2006, we immobilized 39 deer with a mean induction score of 0.25 (SE = 0.079) by remote delivery of telazol ($\bar{x} = 2.41$ mg/kg, SE = 0.063), ketamine ($\bar{x} = 1.92$ mg/kg, SE = 0.051), and xylazine ($\bar{x} = 0.48$ mg/kg, SE = 0.013). Time to sternal recumbancy ($\bar{x} = 8.65$ min, SE = 0.47) and lateral recumbancy

(\bar{x} = 12.11 min, SE = 0.50), time between TKX and antagonist administration (\bar{x} = 47.31 min, SE = 2.43), TKX dose relative to body weight (\bar{x} = 2.40 ml/kg, SE = 0.063), and body weight (\bar{x} = 102.80 kg, SE = 2.93) were all similar (all $F_{2,8} < 1.15$, all $P > 0.23$) between antagonist treatments. Age among males assigned to treatment groups differed ($F_{2,8} = 5.13$, $P = 0.037$); males in the control group (LS means; \bar{x} = 3.78 yr, SD = 1.61) were younger than males in the tolazoline (\bar{x} = 4.56 yr, SE = 0.58) and yohimbine (\bar{x} = 4.80 yr, SE = 0.59) treatments. Time to recovery differed markedly ($F_{2,8} = 17.14$, $P = 0.0013$) among α_2 -antagonist treatment groups; recovery time was significantly shorter for the tolazoline than yohimbine treatments (Table 1). Notably, 8 of the 15 (53%) animals that were administered yohimbine experienced incomplete recovery and recurring anesthesia.

During 2007–2010, we chemically immobilized 56 deer by remote delivery using single doses of telazol (\bar{x} = 2.33 mg/kg, SE = 0.036), ketamine (\bar{x} = 1.86 mg/kg, SE = 0.029), and xylazine (\bar{x} = 0.47 mg/kg, SE = 0.0072) with a mean induction score of 0.13 (SE = 0.073). Time to sternal recumbancy (\bar{x} = 7.81 min, SE = 0.44), lateral recumbancy (\bar{x} = 10.81 min, SE = 0.50), and recovery (\bar{x} = 12.33 min, SE = 1.49) using TKX and tolazoline during this second phase of our study were similar to that observed during 2005–2006 (all $F < 2.7$, all $P > 0.11$). Despite no difference in the amount of TKX administered relative to body weight, our repeated-measures analysis indicated the only factor with an influence on induction times was body weight. A slight, but positive relationship with sternal ($F_{1,21} = 3.36$, $P = 0.081$) and lateral ($F_{1,21} = 3.02$, $P = 0.099$) recumbancy indicated that larger males generally had longer inductions. Similarly, despite administration of tolazoline in direct relation to body weight (4 mg/kg), body weight was related negatively to recovery time ($F_{1,20} = 11.26$, $P = 0.0031$); larger males recovered more rapidly than smaller males (Fig. 1).

Initial rectal temperature, heart, and respiration rate averaged 38.9° C (SE = 0.12), 49 beats per minute (SE = 1.82), and 49.5 breaths per minute (SE = 3.58). Initial temperature was related negatively to age ($\beta = -0.86$, $F_{1,16} = 7.54$, $P = 0.014$) and positively to heart rate ($\beta = 0.05$, $F_{1,16} = 29.19$, $P < 0.001$). Model predictions indicated that initial temperature decreased 1° C as age of males increased from 1.5-year old to 11.5-year old; whereas, an increase in heart rate of 70 beats

Table 1. Mean dose, sample size, and recovery times for captive male white-tailed deer immobilized with telazol (\bar{x} = 2.37, SE = 0.44 mg/kg), ketamine (\bar{x} = 1.90, SE = 0.35 mg/kg), and xylazine (\bar{x} = 0.47, SE = 0.09 mg/kg), and randomly assigned to α_2 -adrenergic antagonist treatments, 2005–2006, South Dakota, USA.

Alpha ₂ antagonist	Dose (mg/kg), mean ± SE	n	Recovery (min), LS mean ± SE ^a
Control	None	8	150.61 ± 21.66 A
Tolazoline HCl	3.84 ± 0.57	16	12.46 ± 12.33 B
Yohimbine HCl	0.11 ± 0.01	15	74.53 ± 13.12 C

^a Means with the same letter within columns are similar ($P > 0.05$) following a Bonferroni correction.

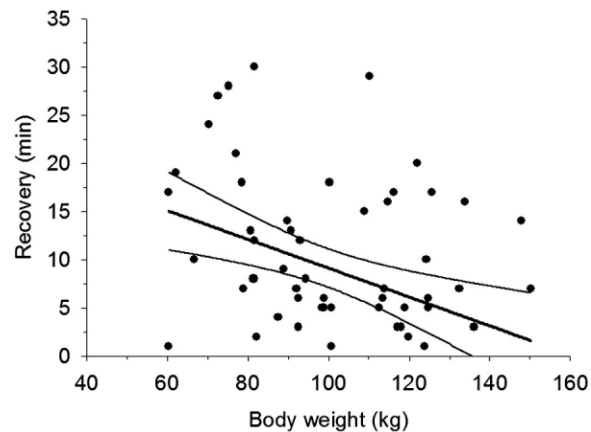


Figure 1. Predicted ($\pm 95\%$ CI) effect of body weight on recovery time following administration of tolazoline (4 mg/kg) for 53 captive male white-tailed deer, during mid-October 2007–2010, Brookings, South Dakota, USA.

per minute led to a predicted increase in initial temperature of 2° C. In addition, initial heart rate was positively associated with initial rectal temperature ($\beta = 7.31$, $F_{1,16} = 40.46$, $P < 0.001$). Initial respiration rate of individual males was not related to any other characteristic ($P > 0.10$).

After processing (\bar{x} = 43.40 min, SE = 1.41), final temperature, heart, and respiration rate averaged 38.6° C (SE = 0.13), 46.8 beats per minute (SE = 1.63), and 43.3 breaths per minute (SE = 3.67), respectively. Final physiological measurements were influenced by their initial values. Temperature was largely maintained during anesthesia ($\beta = 0.90$, $F_{1,19} = 146.63$, $P < 0.001$; Fig. 2a), compared with heart rate ($\beta = 0.52$, $F_{1,17} = 34.22$, $P < 0.001$) and respiration ($\beta = 0.57$, $F_{1,17} = 22.76$, $P = 0.001$), which declined during anesthesia relative to initial values (Fig. 2b and c).

During the course of our study, 21 (18.1%) immobilization events required supplemental drugs. Of those individuals, 14 (66.7%) darts were expelled upon impact, 3 (14.3%) failed to discharge, 1 (4.7%) male was attacked and gored by another male, and 3 (14.3%) were unexplained. In contrast, only 2 (2.1%) darts were expelled for males that did not require supplemental drugs. The proportion of expelled and failed darts (0.81) within the group that required supplemental TKX was the most likely explanation for failed immobilization. Time to sternal (\bar{x} = 7.3 min, SE = 0.72) and lateral (\bar{x} = 10.8 min, SE = 1.51) recumbancy following the second darting attempt was nearly identical (both $F < 0.97$, both $P > 0.33$) to individuals that were immobilized with the first darting attempt. We removed those 21 individuals from other analyses because our objectives were to evaluate the effectiveness of TKX and those individuals did not provide a representative sample, mostly because of the problems we encountered with remote delivery.

DISCUSSION

Combinations of TX and KX frequently have been used for chemical immobilization of white-tailed deer; however, both

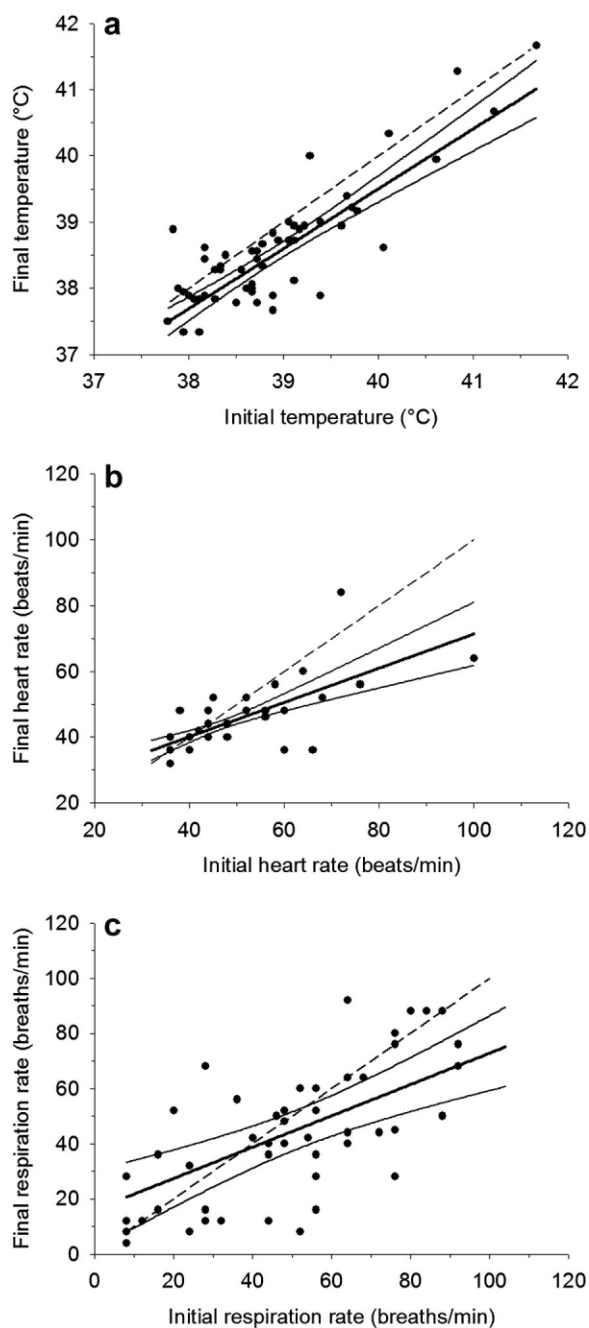


Figure 2. Predicted ($\pm 95\%$ CI) relationship between temperature (a), pulse (b), and respiration (c) measured following lateral recumbancy (initial) and the same parameter measured following processing (final), but prior to administering an antagonist for 53 captive male white-tailed deer, during mid-October 2007–2010, Brookings, South Dakota, USA. Dashed lines represent the linear relationship with a slope of 1.0 if each physiological parameter was maintained under anesthesia.

combinations have shortcomings. Ketamine–xylazine is adequately reversed (Mech et al. 1985), but it lacks the rapid induction of TX (Kilpatrick and Spohr 1999, Miller et al. 2003). Telazol–xylazine is apparently not well antagonized because recovery times were extensive using yohimbine (112.0 min), atipamazole (89.7 min), and tolazoline (52.6 min; Miller et al. 2004). Practitioners are often forced to compromise rapid induction with smooth and rapid recovery when selecting immobilant combinations for

white-tailed deer. A combination of TKX provided comparable induction times to other combinations (i.e., TX and KX), favorable physiological properties under anesthesia, and more rapid and smoother recovery when antagonized with tolazoline relative to most drug combinations administered to white-tailed deer.

Although inductions for males have been reported to be longer than for females (DelGiudice et al. 1989, Miller et al. 2003, Hastings et al. 2009), induction time (sternal recumbancy) for male white-tailed deer during 2005–2006 (8.7 min) and 2007–2010 (7.8 min) were comparable to time to sternal recumbancy observed for female white-tailed deer immobilized with TX (8.5 min; Murray et al. 2000), KX (range: 7.0–13.5 min; Mech et al. 1985, Kreeger et al. 1986, DelGiudice et al. 2001, Muller et al. 2007), medetomidine/ketamine (range: 5.8–11.2 min; Millsbaugh et al. 2004, Muller et al. 2007), and butorphanol, azaperone, and medetomidine (BAM; range: 8.3–10.2 min; Mich et al. 2008, Miller et al. 2009). Inductions were shorter with a higher dose of telazol (4.5 mg/kg) in a TX combination (range: 2.4–3.0 min; Miller et al. 2003), but high concentrations of telazol markedly prolonged recovery (>52 min; Miller et al. 2004).

During 2005–2010, we encountered difficulties with remote delivery; 21 deer required a supplemental dose of TKX to induce anesthesia. For those individuals, $>80\%$ of the first darts failed or were expelled on impact. Although failed immobilization following the first darting attempt could have been caused by dose failure, absent or inadequate injection of TKX from expelled darts was most likely the primary cause. Induction time following the second darting attempt was nearly identical ($P > 0.33$) to that observed for individuals successfully immobilized with a single attempt, which would be expected if the initial dart failed. We used darts with a gel collar to minimize tissue damage from darting (Cattet et al. 2006); however, because 14% of the darts were expelled on impact and thus required an additional darting attempt, we recommend the use of barbed darts.

Xylazine interferes with the ability of deer to properly thermoregulate; immobilized animals are susceptible to capture-induced hyperthermia, depending on environmental conditions (Young 1979, Nielsen 1999). Rectal temperatures $>41^{\circ}\text{C}$ put an animal at risk of cell damage and require intervention (Nielsen 1999, Kreeger and Arnemo 2007). During our study, the temperature of 3 animals immobilized with TKX exceeded 41°C . High initial temperature likely was a result of physical exertion that occurred when darted males were pursued by other males in our facility. One male in our study was gored by another and had an initial rectal temperature of 42°C . Despite those instances, initial rectal temperatures (38.9°C) and those immediately prior to antagonist administration (38.6°C), were comparable to or less than mean values reported for other drug combinations with white-tailed deer (range: 39.2 – 42.1°C ; Miller et al. 2003, 2009; Storms et al. 2005, 2006; Muller et al. 2007).

Respirations for immobilized animals can be as low as 5–6 breaths per minute, with depth of respiration being equally

concerning (Kreeger and Arnemo 2007). Average initial and final respiration rates for deer in our study were 49.5 and 43.3 breaths per minute, respectively, which was greater than the range in respiration rates of 19–45 reported for white-tailed deer in other studies (Kreeger et al. 1986; Miller et al. 2003, 2009; Storms et al. 2005, 2006; Muller et al. 2007). We were unable to directly assess oxygen hemoglobin saturation; however, hemoglobin saturation of white-tailed deer immobilized with similar drug combinations was satisfactory (Miller et al. 2003, Muller et al. 2007). Respiration rates of deer immobilized with TKX were greater than in most studies, which should have yielded satisfactory levels of hemoglobin saturation. Average heart rate of deer in our study (initial: 49.0; final: 46.4 beats per min) was within the range reported for white-tailed deer immobilized with other drug combinations (range: 42.0–72.0 beats per min; Kreeger et al. 1986; Miller et al. 2003, 2009; Storms et al. 2005, 2006; Mich et al. 2008).

Young animals often require more drugs per unit body weight for effective immobilization (Kreeger and Arnemo 2007); however, drug dosage (ml/kg) and age of males from 1.5-year old to 11.5-year old were not related to induction times in our study. Young males were, however, more likely to have higher temperatures upon recumbancy than were older males. Physiological parameters were not related to induction time, which has been reported for impala (*Aepyceros melampus*; Meyer et al. 2008). We did find evidence ($P < 0.10$) that heavier males had longer times to sternal and lateral recumbancy. Wildlife practitioners should be prepared to alleviate potential issues with hyperthermia in young animals and recognize the additional time required for induction of heavier individuals.

Final physiological parameters measured an average of 43.4 minutes after darting and immediately prior to administering the antagonist, were closely related to their respective initial measurement. Rectal temperature was the physiological parameter most preserved while individuals were immobilized, whereas heart and respiration rate declined relative to their initial measurement (Fig. 2). Based on limited research, declining heart rate and respiration with maintained temperature seem to be common (Millspaugh et al. 2004, Walter et al. 2005, Storms et al. 2006, Muller et al. 2007, Mich et al. 2008), except during low ambient temperatures when rectal temperatures decline ($\leq -8.5^\circ\text{C}$; DelGiudice et al. 2001).

Although induction times are important in anticipating flight distances by deer in field situations, partially anesthetized deer or those that experience incomplete antagonism are subject to increased risk of predation, hyper- or hypothermia, and other accidents. Xylazine combinations are commonly antagonized with yohimbine, but results have been inconsistent (recovery range: 1–165.5 min; Jessup et al. 1983; Hsu and Shulaw 1984; Mech et al. 1985; Wallingford et al. 1996; Miller et al. 2003, 2004). We observed ataxia, frequent resedation, and lengthy recoveries (74.5 min) for deer immobilized with TKX and reversed with 0.11 mg/kg of yohimbine. Lengthy recovery times for yohimbine in our study may have been partially caused by the relatively low dose; however, increasing the dose of

yohimbine was unlikely to result in a 6-fold decrease in recovery times to approach the performance of tolazoline. Increasing the dose of yohimbine from 0.12 mg/kg to 0.30 mg/kg to reverse TX reduced recovery by only 32% (Miller et al. 2003, 2004), and doubling the yohimbine dose had a negligible effect in 2 other studies (Jessup et al. 1983, Mech et al. 1985).

Tolazoline was demonstrated to have a greater antagonizing ability for xylazine combinations in white-tailed deer (Kreeger et al. 1986, Miller et al. 2004, Muller et al. 2007) and other ungulates (Sontakke et al. 2009). Recovery was smooth and rapid for deer antagonized with tolazoline (12.5 min), and tolazoline performed favorably when telazol concentration was reduced by adding ketamine to the mixture. Mean recovery time with tolazoline (4 mg/kg), when telazol was administered at 2.3 mg/kg in TKX, was >4 times shorter than the average recovery reported by Miller et al. (2004), when telazol was administered at 4.5 mg/kg in TX. Miller et al. (2004) immobilized females and injected tolazoline one-half intravenously and one-half intramuscularly, but we do not believe these differences were enough to explain the >4 -fold difference in recovery time we observed. Furthermore, we did not observe apnea or other adverse effects caused by our dosages of α_2 antagonists or by intravenous administration (Read et al. 2000, Mortenson and Robison 2011). Our recovery times with tolazoline were within the range of recovery times reported for deer immobilized with KX (range: 1.25–13.5 min; Kreeger et al. 1986, Muller et al. 2007), were similar to or less than those observed with telazol–ketamine–medetomidine immobilized deer antagonized with atipamezole (10.3–17.1 min; Millspaugh et al. 2004, Muller et al. 2007), and were less than for white-tailed deer immobilized with TX and reversed with atipamezole (89.7 min; Miller et al. 2004).

Deer that received tolazoline were capable of walking and running with coordination, and showed few residual signs of immobilization. Following administration of yohimbine, individuals would often stand within 2–10 min, but would then lie down and relapse into an immobilized state, making them more vulnerable. Yohimbine reversed deer typically stood rigidly with lowered head and drooped ears another 1–3 hours, with frequent ataxia.

MANAGEMENT IMPLICATIONS

Our results indicated that TKX warrants application as a safe and effective combination for chemically immobilizing white-tailed deer. The drug combination has a high therapeutic index (Kreeger et al. 1986, Murray et al. 2000, Walter et al. 2005), produced safe induction and recoveries, and was adequately and rapidly antagonized with tolazoline. Costs of TKX for a 100-kg animal were approximately \$27.00 (Wildlife Pharmaceuticals and Fort Dodge Animal Health), which is comparable to other combinations reported for white-tailed deer (Miller et al. 2003, Muller et al. 2007).

Our results, along with those provided by Miller et al. (2004), demonstrated poor efficacy for yohimbine antagonism of xylazine combinations in white-tailed deer, especially

those containing telazol. The mean cost for antagonizing a 100-kg animal was \$5.50 (5.5 ml) for yohimbine and \$2.67 (4 ml) for tolazoline (Wildlife Pharmaceuticals). Tolazoline also provided a smooth recovery at a substantially more rapid rate compared to yohimbine. We suggest further evaluation of TKX with free-ranging animals to verify our results with captive white-tailed deer and recommend tolazoline as a partial antagonist for xylazine combinations.

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