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BIRTH, MORPHOLOGIC, AND BLOOD CHARACTERISTICS OF FREE-RANGING WHITE-TAILED DEER NEONATES

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ABSTRACT: Winter severity is a primary factor influencing deer survival and reproduction in northern climates. Prolonged, harsh winters can adversely affect body condition of does, resulting in depressed morphologic development of neonates. In this study, we captured 59 white-tailed deer (*Odocoileus virginianus*) neonates (28 in 2001 and 31 in 2002), following two distinctly different winters, one severe and the other historically mild. Vaginal implant transmitters allowed exact age to be determined for 73% of the neonates; new hoof growth was used to estimate age (days) of the other 27%. Birthdate and morphologic measurements of neonates (i.e., birth mass, new hoof growth, hoof length) were compared by sex and capture year. For known-age neonates (n=43), there was a year-by-sex interaction effect (P=0.01) on birthdate, being later for females during spring 2001 compared with 2002, which was consistent with a significant (P=0.03) year-by-sex interaction for total hoof length (22.3 mm [SE=0.9] and 20.3 [SE=0.8] for females and males in 2001; 19.9 [SE=1.0] and 22.1 [SE=1.0] for females and males in 2002). Interestingly, there was no effect of year on birth mass or birthdate of known-age neonates. A year-by-sex interaction (P=0.04) was determined for birthdates of estimated age (≤7 days) neonates (n=16), with females born earlier than males in 2001 and later than males in 2002. Dam age had an apparent effect on birthdates of known-age neonates, as fawns born to dams ≤5 yr old were born later (P=0.01) than fawns born to dams >5 yr old (2 June and 26 May, respectively). Capture year had little effect on 20 hematologic and serum characteristics examined; however, there were significant (P<0.05) sex effects on red blood cell (RBC) counts, serum cholesterol, and cortisol concentrations, and a year-by-sex effect (P=0.04) on triglycerides. Mean corpuscular volume (MCV) was the only blood characteristic that differed (P<0.01) between years, with higher values occurring in spring 2001. We report a range of reference values for blood constituents that have not been previously documented for free-ranging neonates. Overall, winter severity appeared to have little effect on birth, morphologic, or blood characteristics of neonates. Documenting reference values for free-ranging, known-age neonates is of particular importance to enhancing our understanding of their rapid physiologic development, the concomitant changes in mean values of their blood constituents, and the natural variability that appears to be associated with those values. Our findings suggest caution should be exercised when applying physiologic models derived in captivity to free-ranging deer populations.

Key words: Blood characteristics, deer neonates, morphologic development, *Odocoileus virginianus,* reproduction, white-tailed deer, winter severity.

INTRODUCTION

Typically, winter conditions in northern climates affect the nutritional welfare of white-tailed deer (*Odocoileus virginianus*) in a way that negatively impacts population performance through decreased survival and reproductive success (Mech et al., 1971; Nelson and Mech, 1986a; DelGiudice et al., 2002). Diminished nutrient quality and declining food availability as winter conditions become severe force deer to rely increasingly on fat and endogenous protein (Torbit et al., 1985; DelGiudice et al., 1990c). Studies of captive, pregnant does have demonstrated that nutritional restriction induces higher pre- and postnatal losses compared with when nutrition is adequate (Verme, 1962, 1979). Further, malnourished captive does have had longer gestational periods, a reduced incidence of twinning, fawns of low birth masses, and marked decreases in neonate survival (Verme, 1963, 1965, 1969; Langenau and Lerg, 1976). Reduced skeletal development (i.e., body length, hind-foot length) has also been observed in fawns born to malnourished does (Verme, 1963). Blood characteristics of captive neonates have been reported to vary with the nutritional status of their doe. Sams et al. (1995) reported that erythrocyte indices (mean corpuscular volume [MCV], mean corpuscular hemoglobin [MCH], and mean corpuscular hemoglobin concentration [MCHC]) and certain serum chemistries (serum urea nitrogen [SUN], SUN: creatinine ratio, glucose, cholesterol) were lower in newborn fawns from captive does fed a low-protein diet.

The aforementioned studies have enhanced our understanding of nutrition as a possible mechanistic link between winter conditions and reproductive success, and they have generated useful reference values for birth, morphologic, and blood characteristics of captive white-tailed deer. But there has been only limited study of these relations in free-ranging deer because, until recently, locating and capturing deer neonates in northern forests was very difficult (Kunkel and Mech, 1994; Carstensen et al., 2003). Consequently, we have less of an understanding of the combined influence of natural diets, activity, and energy budgets of pregnant does, and environmental conditions on these characteristics. However, with recent refinements of vaginal implant transmitters facilitating marked improvement in white-tailed neonate capture (Bowman and Jacobson, 1998; Carstensen et al., 2003), a next logical step in this area of study was to document reference values of free-ranging deer neonates, preferably following winters that varied in severity. From our 2-yr study, we report birth, morphologic, and blood characteristics of free-ranging white-tailed deer neonates following a severe winter and a historically mild winter.

MATERIALS AND METHODS

Study site

The 1,865-km study area was in north central Minnesota (USA). Elevations ranged between 400 and 475 m above sea level. This area included the spring-summer-fall ranges of adult does that had been radio-collared on winter range as part of an ongoing, long-term study of winter severity, reduced thermal cover, and survival of female white-tailed deer (DelGiudice and Riggs, 1996; DelGiudice, 2002; DelGiudice et al., 2002). Within the study area were four winter trapping sites (46°52′–47°15′N, 93°45′–94°07′W) along the eastern and southern boundaries of the Chippewa National Forest. The four sites ranged from 10 to 22 km^2 and vegetative composition was similar (DelGiudice, 1998). Deciduous and mixed coniferous-deciduous stands dominated the upland areas, and conifer swamps were most prevalent on the lowlands. In the first 10 yr of that study, 66–89% of >240 radio-collared does migrated seasonally, typically moving 11–16 km to a spring-summer-fall range during March–May (DelGiudice, 1997).

Spring-summer-fall range size for these does (including fawning areas) was 162–243 ha (M. Carstensen Powell, unpubl. data). Small towns, private residences, and occasional small farms occurred within the study area, which was a mosaic of federal (i.e., Chippewa National Forest), state, county, commercial, and private lands and timber stands. Common predators in the study area included gray wolves (*Canis lupus*), black bears (*Ursus americanus*), red fox (*Vulpes vulpes*), bobcats (*Lynx rufus*), and fishers (*Martes pennanti*) (Fuller, 1989).

Winter 2000–01 was a severe winter with significantly colder mean minimum ambient temperatures in December and February than winter 2001–02 (−21.9 and −23.2 C vs. −10.1 and −14.7 C; National Oceanic and Atmospheric Administration, 2001, 2002; DelGiudice, 2002). Snow depths were consistently greater in winter 2000–01, reaching a maximum of 81 cm in late February and early March. Snow depths never exceeded 30 cm in winter 2001–02.

The Minnesota Department of Natural Resources (MNDNR) calculates a winter severity index (WSI) by accumulating one point for each day with an ambient temperature ≤–17.8 C and one point for each day with snow depth ≥38 cm during 1 November–31 May. The maximum WSIs for winters 2000–01 and 2001–02 were 153 (70 temperature and 83 snow days) and 45 (39 temperature and six snow days) (DelGiudice, 2002).

Deer capture and handling

During winters 2000–01 and 2001–02, we confirmed pregnancy using a portable dop-tone ultrasound (Pocket-Dop II, Imex Medical Systems, Inc., Golden, Colorado, USA) and inserted vaginal implant transmitters (Model M3940, Advanced Telemetry Systems, Isanti, Minnesota, USA) into 25 adult (≥1.5 yr old) female white-tailed deer, captured by Clover trap (Clover, 1956) and net-gunning from helicopter (Wildlife Capture Services, Marysvale, Utah, USA) during each winter as part of companion studies (Carstensen and DelGiudice, 2002; DelGiudice, 2002; Carstensen Powell, 2004). The vaginal implants were designed to be expelled at parturition (a temperature-sensitive trigger increased the pulse rate from 40 to 80 beats per min) and allowed us to determine exact birthdates for neonates captured from specific does. Implants were monitored one to three times weekly until 15 May and then three times daily until all implants were expelled (typically by mid-June). The techniques used to locate neonates, including the implant's design and the doe monitoring protocol, were described by Carstensen et al. (2003).

During springs 2001 and 2002, we captured neonates of radio-collared pregnant does by monitoring vaginal implant transmitters, as well as by using behavior of does not fitted with implants, to locate probable fawning sites. Our goal was to capture neonates as soon as possible following parturition. When a neonate was located, it was approached cautiously and gently restrained. We assumed each captured fawn had a probable sibling; however, failure to locate a sibling could have resulted from an inability to find it, prior predation/scavenging, or the captured fawn actually being a single. All captured fawns were fitted immediately with a cloth head cover, placed in a pillowcase, and weighed with a spring scale to the nearest 0.2 kg. No immobilizing chemicals were used. Blood samples were obtained by venipuncture of the jugular vein. New hoof growth and total hoof size were measured on the right front and hind hooves (Haugen and Speake, 1958; Sams et al., 1996). Ages (in days) of neonates captured from nonimplanted does were estimated using new hoof growth (Sams et al., 1996). We estimated birth masses by assuming a mean daily mass gain of 0.2 kg since birth (Verme and Ullrey, 1984; Rawson et al., 1992). Chest girth and hind-leg length were also determined (2002 only). Rectal temperatures were recorded but not consistently throughout the study. Last, neonates were ear tagged and fitted with an expandable radiocollar (Model M2110, Advanced Telemetry Systems). Typically, handling time was 8–10 min.

Hematologic analyses included hemoglobin, packed cell volume (PCV), red blood-cell (RBC) count, white blood-cell (WBC) count, MCH, MCV, and MCHC and were conducted within 48 hr of sampling at the MNDNR research laboratory in Grand Rapids, Minnesota, USA. Values of hemoglobin, MCH, and MCHC from lipemic blood samples were deleted prior to statistical analyses (Sams et al., 1995). Serum triglycerides, cholesterol, urea nitrogen, creatinine, total protein, calcium, phosphorus, and creatine kinase (CK) were analyzed using a CobasMira autoanalyzer (Roche Diagnostic Systems, Montclair, New Jersey, USA). Serum concentrations of triidothyronine (T_3), thyroxine (T_4), and cortisol were analyzed by radioimmunoassay (Diagnostic Products Corporation, Los Angeles, California, USA). Sodium and potassium concentrations were measured by flame photometry.

Statistical analysis

All fawns used in this analysis were determined to be ≤7 days of age at capture; however, neonates of known age (i.e., doe was implanted with a vaginal transmitter) were analyzed separately from those in which age had to be estimated. We were unable to pool known and estimated-age neonates into one group because the mean age at capture of the latter group was significantly older ($F_{1,57}$=31.2, n=59, P=0.01); these age discrepancies could have confounded our analyses of blood and morphologic parameters. Two-way analysis of variance was used to determine potential effects of sex, capture year, and sex-by-year interaction on all morphologic and blood characteristics of known and estimated-age neonates. Simple linear regression was used to evaluate the relation of morphologic characteristics to neonatal age (in days) and body mass at capture. Dams of known-age neonates were categorized into two age classes, ≤5 and >5 yr old, based on age-specific survival rates and a hazard model that estimated an increasing trend in the probability of death in does >5 yr old (DelGuidice et al., 2002). Two-way analysis of variance was used to assess the influence of dam age, capture year, and dam age-by-year interaction on morphologic and blood parameters of known-age neonates. Differences were considered significant at P≤0.05.

RESULTS

A total of 59 neonates were captured during springs 2001 (28) and 2002 (31). Exact age was determined for 43 neonates (21 in 2001 and 22 in 2002) of 38 does that survived to the spring fawning season with functional vaginal implant transmitters (Carstensen and DelGiudice, 2002; Carstensen et al., 2003). Age was estimated for the remaining 16 fawns. New hoof growth did not differ significantly between right-front and hind hooves; therefore, we estimated age using the right-front hoof to

TABLE 1. Morphologic characteristics of known-age, free-ranging white-tailed deer neonates captured during springs 2001 (nine males, 13 females) and 2002 (12 males, nine females), north central Minnesota.[a]

Characteristic[b]	2001				2002			
	n	Mean	SE	Range	*n*	Mean	SE	Range
Age at capture (days)[c]	22	0.3	0.1	0.0–1.0	21	1.6	0.4	0.0–7.0
Capture date (Julian day)	22	151	1.8	137–170	21	151	1.6	140–166
Birth date (Julian day)	22	150	1.8	136–170	21	149	1.8	136–166
Capture mass (kg)	22	2.9	0.2	1.5–5.0	21	3.2	0.2	1.4–5.7
Birth mass (kg)[d]	22	2.8	0.2	1.5–4.8	21	2.9	0.2	1.0–4.3
RH hoof length (mm)	22	22.1	0.7	16.0–27.0	21	22.0	0.8	16.0–28.0
RF hoof length (mm)	22	21.5	0.6	16.0–27.0	21	21.2	0.7	14.0–29.0
RH new hoof growth (mm)[c]	22	1.9	0.2	0.0–4.0	21	3.5	0.3	2.0–7.0
RF new hoof growth (mm)[c]	22	1.7	0.2	0.0–3.5	21	3.1	0.2	1.0–5.0
Rectal temperature (C)[c]	6	37.1	0.3	36.6–37.7	20	38.0	0.5	34.5–39.7
Hind-leg length (cm)[e]	0				21	25.4	0.4	21.0–30.0
Chest girth (cm)[e]	0				21	32.2	0.7	24.2–39.0

[a] Spring 2001 followed a severe winter (winter severity index [WSI]=153), whereas spring 2002 followed a historically mild winter (WSI=45). See Materials and Methods for calculation of WSI.
[b] RH = right hind; RF = right front.
[c] Means were significantly different at $P \leq 0.05$.
[d] Birth weight was estimated by assuming a mean daily mass gain of 0.2 kg since birth (Verme and Ullrey, 1984; Rawson et al., 1992).
[e] Hind-leg length and chest girth were not measured for fawns captured during spring 2001.

be consistent with past studies (Haugen and Speake, 1958; Sams et al., 1996). All neonates were determined to be ≤7 days old at the time of their capture (Table 1).

For known-age fawns, there was a year-by-sex interaction effect ($P=0.01$) on birthdate, being later for females and earlier for males during spring 2001 compared with 2002. Mean 2001 birthdates were 2 June (SE=2.5 days, $n=13$, range=142–170 Julian days) for females and 26 May (SE=2.0, $n=9$, range=136–155) for males versus 2002 birthdates of 25 May (SE=2.0, $n=9$, range=138–152) for females and 31 May (SE=2.5, $n=12$, range=136–166) for males. Consistent with the above interaction was a significant ($P=0.03$) year-by-sex interaction for total hoof length (right front). In 2001, total hoof length was 22.3 mm (SE=0.9, $n=13$, range=16–27) and 20.3 mm (SE=0.8, $n=9$, range=16–25) for females and males, and in 2002, it was 19.9 mm (SE=1.0, $n=9$, range=14–25) and 22.1 mm (SE=1.0, $n=12$, range=18–29), respectively. Mean age at capture differed ($P<0.01$) between years; neonates were slightly younger during 2001 (Table 1). Consequently, new hoof growth was less in 2001 versus 2002 for these fawns (Table 1). There was no effect of year on birthdate or birth mass of neonates, but rectal temperatures were slightly lower during spring 2001 (Table 1). Body mass at capture was linearly related ($P<0.01$) to hind-leg length, chest girth, and new hoof growth (Fig. 1). There was no linear relation between total hoof length and mass at capture or between birth mass and birthdate for known-age neonates. Age (in days) was not correlated with any morphologic characteristic for known-age neonates.

For neonates of estimated age (≤7 days old), there was a significant ($P=0.04$) year-by-sex interaction for estimated birthdate only. Mean 2001 birthdates were 18 May (SE=1.3 days, $n=5$, range=136–143 Julian day) and 28 May (SE=0.0, $n=1$) for females and males, and mean 2002 birthdates were 27 May (SE=3.2, $n=4$, ranges=138–153) and 24 May (SE=1.7, $n=6$, ranges=138–149), respectively. Mean hoof length differed between years (Table 2).

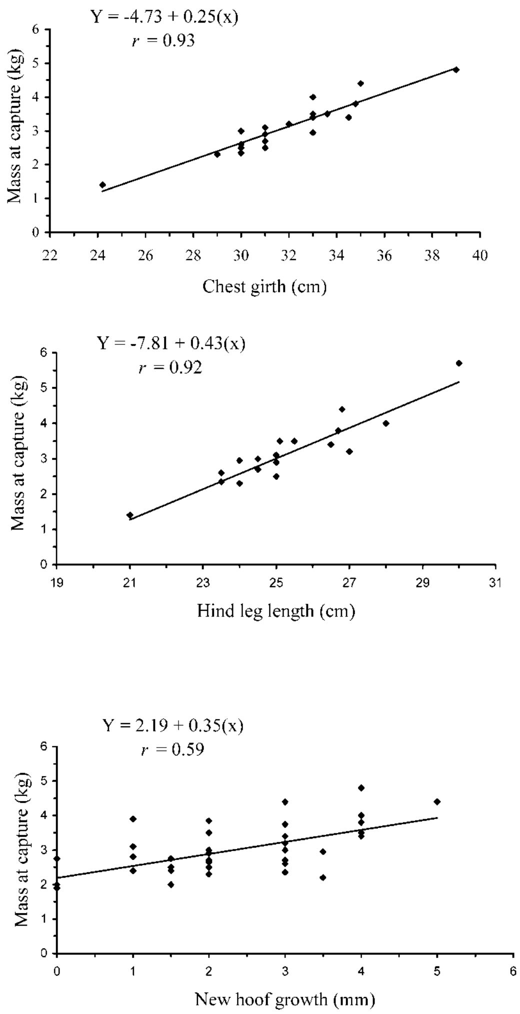

FIGURE 1. Relationship between body mass at capture and chest girth (n=20, spring 2002), hind-leg length (n=20, spring 2002), and new hoof growth (right front, n=39, springs 2001 and 2002), for known-age, free-ranging white-tailed deer neonates, north central Minnesota.

There were no significant sex effects on birth or morphologic characteristics of neonates of known or estimated age.

There were no year-by-sex interaction effects on any blood characteristics of known-age neonates (Table 3). There were significant sex effects for RBC (P=0.04) counts, serum cholesterol (P=0.01), and cortisol (P=0.01). Mean RBC count (8.3±0.3 versus 7.4±0.2 10^6 μl) was higher, and cholesterol (34.6±3.4 versus 46.7±3.5 mg/dl) and cortisol (7.6±0.8 versus 11.4±1.3 μg/dl) concentrations were lower in females than in males. Mean corpuscular volume was the only blood characteristic that differed (P<0.01) between years, with higher values occurring in 2001 (Table 3).

Mean values for hematologic and serum constituents of neonates of estimated age are presented by capture year in Table 4. There was a year-by-sex effect (P=0.04) on serum triglyceride; mean concentrations were 38.8 (SE=11.5, n=4, range=10–65) and 167.0 mg/dl (SE=0.0, n=1) for female and male neonates in spring 2001 and 55.5 (SE=31.6, n=4, range=7–145) and 55.7 mg/dl (SE=16.3, n=6, range=9–117) in 2002. The only year effect (P=0.03) was for RBC counts with lower values in 2001 (Table 4). There were no sex effects on blood constituents.

There were no significant interactions of dam age and year on morphologic or blood characteristics of known-age neonates; however, mean birthdate (P=0.01) was later for dams ≤5 (n=18) than for dams >5 (n=22) years old (2 June, SE=2.2 days vs. 26 May, SE=1.3 days). Mean new hoof growth was less (P=0.01) in neonates captured from dams ≤5 yr old compared with dams >5 yr old (1.8, SE=0.3 and 3.0, SE=0.2 mm). The only main effect of dam age on blood constituents of neonates was a higher (P=0.02) mean triglyceride concentration (54.4, SE=7.4 mg/dl) for fawns of dams ≤5 yr old than for fawns of dams >5 yr old (29.2, SE=8.3 mg/dl).

DISCUSSION

Vaginal implant transmitters and an intensive monitoring schedule allowed us to determine location and time of parturition within 8 hr (Carstensen et al., 2003). This afforded our study a distinct advantage over others examining characteristics of free-ranging neonates; we could determine birthdates and birth masses with certainty, rather than relying on estimation. Mean parturition dates for known-age fawns were not affected by severity of win-

TABLE 2. Morphologic characteristics of free-ranging, white-tailed deer neonates of estimated age (known 7 days old), captured during springs 2001 (one male, five females) and 2002 (six males, four females), north central Minnesota.[a]

Characteristic[b]	2001				2002			
	n	Mean	SE	Range	*n*	Mean	SE	Range
Age at capture (days)[c]	6	2.7	1.1	0.0–6.0	10	4.6	0.7	0.0–6.0
Capture date (Julian day)[d]	6	143	2.3	136–150	10	150	1.4	144–157
Birth date (Julian day)[e]	6	140	2.0	136–148	10	145	1.6	138–153
Capture mass (kg)	6	3.5	0.1	3.2–4.0	10	4.0	0.2	3.1–4.6
Birth mass (kg)[f]	6	3.0	0.3	2.0–3.6	10	3.1	0.2	2.1–3.8
RH hoof length (mm)[d]	6	22.2	0.7	19.5–24.0	10	24.5	0.6	21.0–27.0
RF hoof length (mm)	6	21.4	1.0	18.0–24.0	10	23.2	0.6	19.5–26.0
RH new hoof growth (mm)	6	3.3	0.7	1.0–5.0	10	3.9	0.2	3.0–5.0
RF new hoof growth (mm)	6	2.7	0.6	1.0–4.0	10	3.6	0.2	2.0–4.0
Rectal temperature (C)[g]	0				8	39.4	0.6	38.1–40.7
Hind-leg length (cm)[g]	0				10	26.1	0.4	23.9–26.2
Chest girth (cm)[g]	0				10	33.4	0.6	31.1–36.0

[a] Spring 2001 followed a severe winter (winter severity index [WSI]=153), whereas spring 2002 followed a historically mild winter (WSI=45). See Materials and Methods for calculation of WSI.
[b] RH = right hind; RF = right front.
[c] Age at capture was estimated using new hoof growth of the right hind foot (Sams et al., 1996).
[d] Means were significantly different at $P \leq 0.05$.
[e] Birth date was calculated by subtracting the estimated age at capture from the capture date.
[f] Birth weight was estimated by assuming a mean daily mass gain of 0.2 kg since birth (Verme and Ullrey, 1984; Rawson et al., 1992).
[g] Rectal temperatures, hind-leg length, and chest girth were not measured for fawns captured during spring 2001.

ter in this study, although females tended to be born later than males in 2001 and earlier in 2002. Studies of captive does nutritionally restricted in late winter-early spring (e.g., 26% loss in body mass [Verme, 1962]), an experimental treatment intended to mimic the impact of severe weather conditions, reported prolonged gestational periods by 4–6 days (Verme, 1962, 1965; Langenau and Lerg, 1976). Unknown conception dates and gestational periods for the does of our free-ranging neonates preclude us from formulating any conclusions about the later parturition dates of the females in 2001.

It is noteworthy that winter severity had no apparent effect on mean birth masses of the known-age neonates or those of estimated age. However, there was no difference in body condition (i.e., fat reserves) of does during January–March of 2001 (7.8±0.2%, n=24) and 2002 (6.9±0.2, n=15) (Carstensen Powell, 2004). Mean birth masses of our neonates of known (2.9 kg) and estimated age (3.1 kg) were similar to those of free-ranging neonates reported by some studies (2.8–3.2 kg, Verme, 1977; 2.9 kg, Nelson and Woolfe, 1985) but were slightly lower compared with others (3.5 kg, Kunkel and Mech, 1994). Our range of birth masses (1.0–4.8 kg for all neonates) was much larger than the range observed by Nelson and Woolfe (2.5–3.3 kg, 1985), but similar to that reported by Kunkel and Mech (2.0–4.8 kg, 1994). In comparison with birth masses documented in captive studies, our range is again similar (0.9–4.6 kg, Verme, 1963; 1.4–4.1 kg, Langenau and Lerg, 1976). However, Verme (1962) reported that mean birth mass of neonates of captive does decreased relative to the nutritional plane of their doe, such that does on a high nutritional plane (good winter diet, good spring diet) produced fawns averaging 3.5 kg at birth, and fawns born to does on moderate or poor nutritional planes (poor winter diet, good spring diet and poor winter diet, poor spring diet) averaged 2.6 and 1.9 kg, respectively. Our two smallest neonates (1.0 kg in 2001 and

TABLE 3. Blood characteristics of known-age, free-ranging white-tailed deer neonates captured during springs 2001 (nine males, 13 females) and 2002 (12 males, nine females), north central Minnesota.[a]

Characteristic[b]	2001				2002			
	n	Mean	SE	Range	*n*	Mean	SE	Range
Hemoglobin (g/dl)	22	8.5	0.3	6.1–11.4	18	7.9	0.2	5.9–8.9
PCV (%)	22	29.8	1.2	21.0–42.0	20	27.6	1.0	19.0–34.0
Red blood cells (10^6/μl)	22	7.8	0.3	5.6–10.7	20	7.8	0.2	6.0–9.2
MCH (pg)[c]	22	10.9	0.2	8.0–13.0	18	9.8	0.2	8.0–11.0
MCV (fl)[c]	22	38.2	0.5	32.0–43.0	20	35.2	0.8	29.0–41.0
MCHC (g/dl)	22	28.5	0.4	26.0–33.0	18	27.7	0.5	24.0–33.0
White blood cells (10^3/μl)	22	3.1	0.3	1.0–6.2	20	2.6	0.2	1.1–4.3
Triglycerides (mg/dl)	22	36.5	6.6	5.0–133.0	20	42.5	9.3	6.0–186.0
Cholesterol (mg/dl)	22	41.1	3.4	19.0–80.0	20	40.1	4.0	16.0–80.0
Triidothyronine (ng/dl)	22	270	24.0	107–475	20	286	14.7	137–430
Thyroxine (μg/dl)	22	17.0	1.7	4.4–38.5	20	14.2	1.5	3.4–29.4
Cortisol (μg/dl)	22	10.3	1.3	1.6–29.0	20	8.5	0.9	2.3–16.9
Urea nitrogen (mg/dl)	22	21.4	1.4	14.0–41.0	20	20.8	1.5	9.0–40.0
Creatinine (mg/dl)	22	1.1	0.1	0.4–1.7	20	1.0	0.1	0.0–1.6
Total protein (g/dl)	22	4.9	0.2	3.2–6.3	20	4.8	0.2	3.3–7.3
Sodium (mEq/l)	22	145	0.7	140–155	20	145	0.6	139–150
Potassium (mEq/l)	22	5.1	0.1	3.9–6.4	20	4.9	0.1	4.3–6.2
Calcium (mg/dl)	22	10.9	0.2	7.7–12.1	20	11.1	0.2	9.7–14.4
Phosphorus (mg/dl)	22	10.4	0.3	8.1–13.0	20	10.5	0.4	7.4–14.3
CK (IU/l)	22	284	88.3	64–2055	20	281	43.2	83–782

[a] Spring 2001 followed a severe winter (winter severity index [WSI]=153), whereas spring 2002 followed an historically mild winter (WSI=45). See Materials and Methods for calculation of WSI.

[b] PCV = packed cell volume; MCH = mean corpuscular hemoglobin; MCV = mean corpuscular volume; MCHC = mean corpuscular hemoglobin concentration; and CK = creatine kinase.

[c] Means were significantly different at $P\leq0.05$.

1.5 kg in 2002) died within 48 hr after birth and were similar in mass to captive neonates that were stillborn or succumbed to nutritive failure—a term applied to newborns born moribund, too small to nurse from a standing dam, or not permitted to nurse by their dam (Verme, 1962, 1963). Historic weather and population trends may help explain the absence of an apparent effect of winter severity (2000–01) on doe condition and subsequent reproductive characteristics in spring 2001. The severe winter of 2000–01 was preceded by an historically unprecedented, three consecutive mild winters (WSIs of 57, 46, and 45 for 1997–98, 1998–99, and 1999–2000, respectively). Does entering winter 2000–01 may well have been in exceptional condition. Further, recent work has shown that increasing snow depth has a strong negative impact on the winter survival of does in Minnesota, whereas cold ambient temperatures exhibited little apparent effect (Nelson and Mech, 1986b; DelGiudice et al., 2002). But the elevated WSI of severe winter 2000–01 was attributable almost as much to cold ambient temperatures as to moderately deep snow cover, which it appears did not compromise the nutritional condition of the surviving does sufficiently to manifest itself in altered birth, morphologic, or biochemical characteristics of their offspring.

Whereas Verme (1963) showed that skeletal development of captive fawns (i.e., hind-hoof length, body length) was adversely affected by low nutritional plane of the does, we failed to detect a difference in skeletal development (i.e., hind-hoof length, new hoof growth) relative to winter severity. Again, this indicates that the severity of winter conditions during 2000–01 did not have a serious enough effect on

TABLE 4. Blood characteristics of free-ranging, white-tailed deer neonates of estimated age (known 7 days), captured during springs 2001 (one male, five females) and 2002 (six males, four females), north central Minnesota.[a]

Characteristic[b]	2001				2002			
	n	Mean	SE	Range	*n*	Mean	SE	Range
Hemoglobin (g/dl)	4	6.8	0.5	5.8–8.0	4	7.2	0.3	6.5–7.9
PCV (%)	5	22.2	1.7	17.0–27.0	9	25.2	0.8	22.0–30.0
Red blood cells (10^6/μl)[c]	5	6.4	0.3	5.3–6.9	9	7.7	0.3	6.8–9.4
MCH (pg)	4	11.0	0.4	10.0–12.0	4	10.0	0.4	9.0–11.0
MCV (fl)	5	34.8	1.5	32.0–40.0	9	32.8	0.8	30.0–38.0
MCHC (g/dl)	4	31.5	1.0	30.0–34.0	4	29.2	0.5	28.0–30.0
White blood cells (10^3/μl)	5	3.1	0.6	2.1–5.6	9	2.9	0.3	1.7–4.0
Triglycerides (mg/dl)	5	64.4	27.2	10.0–167.0	10	55.6	14.9	7.0–145.0
Cholesterol (mg/dl)	5	58.8	3.5	49.0–67.0	10	54.7	6.3	21.0–81.0
Triidothyronine (ng/dl)	5	275	35.8	181–370	10	221	24.0	72–305
Thyroxine (μg/dl)	5	8.6	1.4	5.2–12.4	10	11.3	1.5	6.0–23.2
Cortisol (μg/dl)	5	6.8	0.6	4.7–7.9	10	6.2	0.8	1.8–11.3
Urea nitrogen (mg/dl)	5	18.6	1.5	16.0–24.0	10	18.2	2.2	11.0–37.0
Creatinine (mg/dl)	5	0.6	0.1	0.2–0.7	10	0.6	0.1	0.1–1.0
Total protein (g/dl)	5	5.8	0.2	5.2–6.1	10	5.0	0.3	3.8–7.0
Sodium (mEq/l)	5	143	2.5	137–151	10	148	1.1	143–155
Potassium (mEq/l)	5	5.8	0.7	4.6–8.6	10	5.2	0.2	4.4–6.3
Calcium (mg/dl)	5	11.0	0.6	9.8–13.0	10	11.1	0.4	9.7–13.6
Phosphorus (mg/dl)	5	11.1	0.9	9.2–14.3	10	11.7	0.5	9.5–14.0
CK (IU/l)	5	287	174.0	58–974	10	231	62.0	63–721

[a] Spring 2001 followed a severe winter (winter severity index [WSI]=153), whereas spring 2002 followed an historically mild winter (WSI=45). See Materials and Methods for calculation of WSI.

[b] PCV = packed cell volume; MCH = mean corpuscular hemoglobin; MCV = mean corpuscular volume; MCHC = mean corpuscular hemoglobin concentration; and CK = creatine kinase.

[c] Means were significantly different at $P \leq 0.05$.

the nutritional condition of dams to adversely influence fetal development. Adams (2003) reported that marrow fat deposition and skeletal growth (i.e., hind-hoof length) of free-ranging caribou (*Rangifer tarandus*) calves were inversely related to winter severity. In that study, severe winters were characterized by late winter (February–May) snowfall, which Adams and Dale (1998) had shown to be highly correlated with condition of adult females. Differences in hoof length (neonates of estimated age only) and new hoof growth (known-age neonates only) in our study may be attributed to subtle differences in age at capture as well as the wide range of values we detected for new hoof growth. Robinette et al. (1973) noted that hind-hoof length of captive mule deer (*Odocoileus hemionus*) neonates was highly correlated to their age (r=0.96); whereas, Nelson and Woolfe (1985) reported a weaker relation (r=0.66) in free-ranging, farmland white-tailed deer neonates. Known-age fawns that we captured at <1 day old (n=21) appeared to have less new hoof growth (1.9 mm) than captive mule deer neonates of similar age (2.5 mm, Robinette et al., 1973). Sams et al. (1996) noted a mean 2.4 mm of new hoof growth for captive 1-day-old fawns, which was similar to our 1-day-old fawns (2.5 mm, n=15). However, we observed greater variation of new hoof growth at birth (range=0–4 mm) and by 1 day of age (range=1–5 mm), compared with values for their 1-day-old fawns (1.0–3.5 mm, Sams et al., 1996). New hoof growth has also been highly correlated with captive fawn age (r=0.98, Robinette et al., 1973; r=0.86, Sams et al., 1996). We noted no such correlation for our known-age neonates, which may reflect the influences of more variable environmental conditions and, perhaps, of greater genetic variation in free-ranging neonates compared with captive individuals.

We were unable to compare values of chest girth and hind-leg length between years, but both characteristics were correlated with mass at capture (r=0.92 and r=0.93, respectively) in spring 2002. Similarly, studies in captivity have reported high correlations between chest girth and body mass (r=0.97, Russel et al., 1976). Whereas new hoof growth for known-age, free-ranging neonates was only weakly related to capture mass (r=0.55) and no morphologic characteristics were correlated with age (in days), previous studies of captive fawns have concluded that new hoof growth, hind-hoof length, chest girth, and body mass were reliable predictors of age (Robinette et al., 1973; Russel et al., 1976; Sams et al., 1996).

To the best of our knowledge, only one previous study has documented rectal temperatures of free-ranging white-tailed neonates (White and Cook, 1974). These authors reported a mean rectal temperature of 39.9 C for fawns in south Texas (n=50) that was uninfluenced by sex or age. Mean rectal temperatures of our known-age fawns tended to be lower and differed between years. These annual differences were likely attributable to uneven sample size between years (n=6 and n=20 in springs 2001 and 2002, respectively), age at capture of the neonates, or stress levels during handling (DelGiudice et al., 2001).

Dam age had an apparent effect on parturition dates as neonates born to younger dams (≤5 yr old) had a mean birthdate 1 wk later than those born to older dams. This difference in parturition dates is likely due to older, dominant does beginning estrous cycles and being bred earlier in the rut than younger and, perhaps, more subordinate does (Verme and Ullrey, 1984).

Blood profiles have value for assessing the nutritional, disease, and reproductive status of captive and free-ranging deer as well as for contributing to our understanding of ecological relations when scrutinized in combination with environmental data (Kitchen and Pritchard, 1962; Seal and Erickson, 1969; White and Cook, 1974; Seal et al., 1978, 1981; Warren et al., 1982; Waid and Warren, 1984; DelGiudice et al., 1987, 1990c). Most of this work has involved fawns ≥0.5 yr old and adults (≥1.0 yr old). The blood data collected from 57 northern, free-ranging white-tailed deer neonates (≤7 days old) in our 2-yr study contributes to an area of research where reference data and information have been almost nonexistent for captive (Tumbleson et al., 1970; Rawson et al., 1992; Sams et al., 1995) and free-ranging deer (White and Cook, 1974; Kunkel and Mech, 1994). Documenting reference values for known-age neonates is of particular importance to enhancing our understanding of their rapid physiologic development, concomitant changes in mean values of their blood constituents, and the natural variability that appears to be associated with those values.

Hemoglobin concentrations, RBC counts, MCHC, and WBC counts of our free-ranging neonates (birth to 7 days old) occurred within the range of variability of these characteristics in captive fawns of comparable age and being fed an optimum diet (Tumbleson et al., 1970; Rawson et al., 1992; Sams et al., 1995). Rawson et al. (1992) documented positive relations between age of captive neonates up to 50–90 days postpartum and RBC counts, PCV, hemoglobin, and MCHC, and concluded that these temporal hematologic changes maximized the ability of the fawns' blood to carry oxygen as oxygen requirements increased with increasing body mass and mass-specific resting metabolic rate. The lower RBC counts of 2001 neonates of estimated age compared with 2002 neonates of this cohort may be ascribed in part to their younger mean age at capture (2.7 versus 4.6 days old). Red blood cell and hemoglobin concentrations in the free-ranging neonates were about 50–75% of those reported for captive and free-ranging, adult white-tailed deer in Minnesota (DelGiudice et al., 1990b, c, 1992).

White blood cell counts were particularly variable (overall range=1.0–6.2 10^3/μl), which may be attributed to a variety of causes, including early physiologic development (Benjamin, 1981). Causes of a mild leukopenia may include infections (viral or bacterial), transient retention of leukocytes in a variety of endogenous reservoirs, shock, or nutritional deficiencies, whereas a leukocytosis may be associated with physical exertion, excitement or fear, digestion (particularly in neonates), or certain local or generalized infections. It's reasonable that one or more of these causes could have influenced the WBC counts of the newborn fawns captured and handled in our study. Differential WBC counts would be necessary to making a more conclusive determination. Interestingly, the mean (and range) WBC concentrations of these neonates also are comparable with reports for captive and free-ranging adult deer (DelGiudice et al., 1990b, c, 1992).

The range of PCV and MCV in free-ranging neonates also were notably more variable than has been reported for captive neonates of similar age (Rawson et al., 1992). This is partially explained by our greater sample size compared with the captive study. Nonetheless, PCV values of our free-ranging neonates not only ranged higher than in the captive neonates but also were greater in the known-age compared with the estimated-age neonates, which tended to be older at capture in our study. This is consistent with the larger, immature RBCs (i.e., greater MCV) evident in the known-age neonates compared with the neonates of estimated age. Mean corpuscular volume was inversely related to age of captive fawns 2–50 days old (Rawson et al., 1992). Higher PCV values in some of the free-ranging, known-age neonates may be partially attributable to differences in hydration status (i.e., mild dehydration) as well as greater excitement levels associated with the capture and handling compared with the captive neonates (Benjamin, 1981; Rawson et al., 1992). The larger MCVs of 2001 versus 2002 known-age fawns also are likely explained by the younger mean age at capture in 2001. The relatively stable MCH values of our free-ranging neonates were similar to those of captive neonates (Tumbleson et al., 1970; Rawson et al., 1992; Sams et al., 1995).

As might be expected, some of the more homeostatically regulated serum characteristics, total protein, potassium, sodium, calcium, and phosphorus, exhibited smaller ranges of values compared with other constituents (e.g., T_3, T_4, urea nitrogen, cortisol, triglycerides, cholesterol, CK) that tend to be more sensitive to recent diet, physical exertion, or stress (Kirkpatrick et al., 1975; Seal et al., 1981; Warren et al., 1982; DelGiudice et al., 1990b, c). Overall, serum triglyceride (5–186 mg/dl) and CK (64–2,055 IU) ranged most widely. Maximum concentrations of triglycerides, cholesterol, and urea nitrogen were likely postprandial effects of recent feeding or nursing and associated thyroid activity (Kirkpatrick et al., 1975; Benjamin, 1981; Card et al., 1985; DelGiudice et al., 1987, 1990c). Compared with the milk of lactating domestic cows, the milk of the white-tailed doe contains twice as much fat and protein (Robbins, 1993). Serum T_3 and T_4 concentrations of deer are affected by energy intake (Seal et al., 1972; Bahnak et al., 1981; DelGiudice et al., 1987, 1990c). Serum cortisol may be elevated by reductions in energy intake as well as by physical exertion and stress (Thurley and McNatty, 1973; Franzmann et al., 1975; Seal et al., 1981; DelGiudice et al., 1990a, b, c), which probably accounts for the variability and range of values we observed. The response of neonates to our approach, capture, and handling varied from no movement or apparent resistance (i.e., stress) to flight and physical exertion during the subsequent brief handling. Because serum cortisol is sensitive to stimuli and responds rapidly (Seal et al., 1981), serum concentrations were probably influenced by handling as well as by the alternating bouts of nursing and nutritional deprivation they are subjected to by their does. The limited endogenous energy reserves associated with the neonates' immature development affords them only a minimal physiologic buffer, which may certainly be challenged by the varied attentiveness of its doe (Verme, 1962, 1977; Langenau and Lerg, 1976).

Although serum calcium and phosphorous concentrations in the free-ranging neonates exhibited no influence of year (i.e., winter severity) or sex, interestingly, they were significantly ($P \leq 0.05$) greater than concentrations reported for captive and free-ranging adult deer in Minnesota (Seal et al., 1978; DelGiudice et al., 1990c, 1992). Indeed, mean calcium and phosphorous concentrations of free-ranging neonates were up to 31% and 172% greater than concentrations in free-ranging does (DelGiudice et al., 1992). Numerous physiologic processes, particularly maximum bone mineralization in growing neonates, are associated with increased requirements of calcium and phosphorous (Robbins, 1993). Further, calcium and phosphorous are major mineral components of the does' milk; thus, periodic nursing bouts throughout the day would affect blood concentrations of these minerals in the neonate (Jacobson and McGilliard, 1984).

Our examination of birth, morphologic, and blood characteristics of free-ranging neonates has shown that our understanding of many of the relations documented initially in studies of captive animals may not apply or be extrapolated directly to natural settings, where the individual and combined influences of natural diets, activity, and energy budgets, and environmental conditions can be highly variable. Despite the improved samples of neonates examined, facilitated by recent refinements of vaginal implant transmitters, we observed little effect of previous-winter severity on birth, morphologic, or blood characteristics. This was consistent with the absence of a difference in body condition of does during winters 2000–01 and 2001–02 (Carstensen Powell, 2004). This and the range of values documented for most of the characteristics are biologically meaningful and suggest that caution should be exercised when applying physiologic models derived from captive situations to free-ranging populations. Clearly, further study of free-ranging populations is needed to allow us a greater understanding of the effects of winter severity on deer reproduction.

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