Evaluation of subcutaneous implants for monitoring American black bear cub survival

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Abstract: Implanting radiotransmitters in wild animals to monitor physiological processes and survival rates is an accepted practice, but the degree of success for subcutaneous implants rarely has been reported, making it difficult to improve the practice of and equipment for subcutaneously implanting transmitters. We implanted radiotransmitters subcutaneously in 42 (21M:21F) wild American black bear (*Ursus americanus*) cubs from 2 study areas in Virginia during 1996–1999. We monitored the cubs from the date of implantation until the implants fell out, the cubs died, the transmitters failed or became undetectable, or until the cubs denned as yearlings the following den season. We removed 3 animals from our analysis because we judged that their fates were unrelated to the implants. Over 64% (25 of 39) of implants fell out or were rejected prematurely (2–198 days), 23% (9 of 39) presumably failed for unknown reasons, 5% (2 of 39, part of the previous 9) failed and were worn to the following den season, and 1 of 39 bears died less than 1 month after implant surgery. Only 10% (4 of 39) of implanted black bear cubs wore working transmitters to the following den season. We estimated an overall implant survival estimate of 6.5% for the implants. Our success was very limited using subcutaneous implants, but this can be improved through improvements in the surgical procedures, further miniaturization of transmitters and batteries, impermeable transmitter packages, and better understanding interactions among family members following implant surgery.

Key words: American black bear, cub, implant, Program MARK, subcutaneous, surgery, survival, telemetry, *Ursus americanus*, Virginia

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Wildlife scientists have been challenged by the difficulty of obtaining unbiased survival data for bear cubs. Some believe that American black bear cubs are most vulnerable during the first 5 months of life (Erickson 1959, LeCount 1987, Elowe and Dodge 1989) because they are still naïve to their surroundings and largely dependent upon their mothers. However, extensive monitoring of cubs beyond the age of 5 months is rare due to the problems associated with keeping rapidly growing cubs equipped with radiotransmitters. Therefore, we know little about the importance of mortality factors beyond 5 months of age and throughout a cub's first year of life.

Radiotransmitters have been implanted in the peritoneal cavities of a variety of wildlife species, including grizzly bears (*U. arctos*; Philo et al. 1981), beavers (*Castor canadensis*; Guynn et al. 1987), river otters (*Lontra canadensis*; Melquist and Hornocker 1979), sea otters (*Enhydra lutris*; Williams and Siniff 1983), white-footed mice (*Peromyscus leucopus*; Smith and Whitney 1977), mallards (*Anas platyrhynchos*; Korschgen et al. 1996), deer mice (*P. maniculatus*; Reynolds 1992), prairie voles (*Microtus ochrogaster*; Reynolds 1992), montane voles (*M. montanus*; Koehler et al. 1987), Ord's kangaroo rats (*Dipodomys ordii*; Koehler et al. 1987), Townsend's ground squirrels (*Spermophilus townsendii*; Koehler et al. 1987), and yellow-bellied marmots (*Marmota flaviventris*; Van Vuren 1989). A few other researchers have reported the use of subcutaneous implants in black bears

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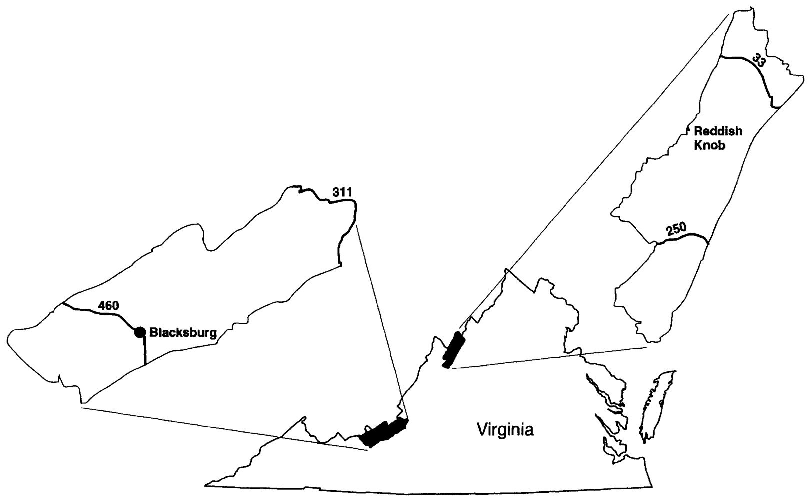

Fig. 1. Northern and southern study areas of the Cooperative Alleghany Bear Study, Virginia, for a study of subcutaneous implants on black bear cubs, 1996–1999.

(Jessup and Koch 1984), grizzly bears (Philo et al. 1981), sea otters (Williams and Siniff 1983), and mourning doves (*Zenaida macroura*; Schulz et al. 1998). With these devices, researchers have gathered data on animal movements, assessed home range size, and monitored physiological processes, primarily in the adults of these species. The definition of implant success, however, has varied among authors.

Intraperitoneal implants have been used successfully to monitor both wild and domestic animals, but black bear cubs are not good candidates for intraperitoneal implants due to their small size at birth. Intraperitoneal implants small enough for a bear cub do not have enough power to transmit a signal with adequate range. These weak signals worsen as the animal grows and gains weight. Researchers using abdominal implants in adult black bears have reported reduced signal detection and differences in detection probabilities between the sexes (Koehler et al. 2001).

The widespread notion that subcutaneous implants are prone to infection and are often rejected is not supported in the literature. Jessup and Koch (1984) had mixed success with subcutaneous implants in adult black bears, with results including implant rejection, implant failure, and complete success, but their sample size was small ($n = 10$). There is no information on the success of attempts to use subcutaneous implants to monitor black bear cub survival. We evaluate the effectiveness of subcutaneous implants in black bear cubs as a tool to monitor survival during their first year of life. We also explore the potential impact of adult female and sibling bears on the retention rates of subcutaneous implants.

Study area

We used the northern and southern study areas of the Cooperative Alleghany Bear Study (Fig. 1). The 840-km^2 northern study area on the George Washington and Jefferson National Forests was centered in Augusta and Rockingham counties. It contained portions of the Deerfield and Dry River Ranger Districts in the Ridge and Valley Province of the Appalachian Mountain chain. The northern study area was bordered by Long Run Road (Forest Service Route 72) to the north, West Virginia to the west, Virginia Route 42 to the south, and the Shenandoah Valley to the east (Godfrey 1996, Higgins 1997).

Annual temperatures averaged 10.3°C in 1996, 10.9°C in 1997, and 12.7°C in 1998 and ranged between –25°C and 33°C (National Oceanic and Atmospheric Administration 1996, 1997, 1998). Annual rainfall averages 86 cm with an average of 71 cm of snowfall. Climatological data for 1999 were unavailable. Elevations ranged from 488 m along the base of Little North Mountain to 1,360 m at the top of Elliott Knob (Kozak 1970).

The 1,544-km^2 southern study area included parts of Giles, Craig, and Montgomery counties in southwest Virginia (Fig. 1). This study area encompassed parts of the Blacksburg and Newcastle Ranger Districts within the Ridge and Valley Province of the Southern Appalachian Mountain chain (U.S. Department of Agriculture 1965). The southern study area was bordered by West Virginia to the west, Bland County to the south, Virginia Route 624 to the east and Virginia Route 311 to the north (Ryan 1997). Elevations ranged from a low of 492 m in the Craig Creek Drainage to 1,378 m in the Mountain Lake region.

Annual temperatures averaged 8.3°C and 6.9°C for the 1997 and 1998 seasons, respectively, and ranged between –23.8°C and 29.2°C. Annual precipitation ranged between 119 cm and 153 cm. Information for 1996 and 1999 was unavailable.

Methods

Field techniques

We trapped and radiocollared adult black bears during summer, 1994–98, using spring-activated Aldrich foot snares and culvert traps. We immobilized bears with a 2:1 mixture of ketamine hydrochloride (Ketaset, Fort Dodge Animal Health, Fort Dodge, Iowa, USA; here and throughout, mention of trade names does not imply endorsement by the U.S. Government) and xylazine hydrochloride (Rompun, Bayer Corporation, Shawnee Mission, Kansas, USA) at a dosage of 4.4 mg/kg of ketamine and 2.2 mg/kg of xylazine (1 cc/45 kg). We weighed immobilized bears to the nearest kg, marked them with a uniquely numbered ear tag, and tattooed them with a corresponding number on their upper lip. We also pulled a premolar for aging purposes (Willey 1974). We placed radiotransmitter collars on selected adult females (Telonics, Inc., Mesa, Arizona, USA; Lotek Engineering, Ontario, Canada) and monitored them until they denned, when we located their dens and listened for cub vocalizations to confirm the presence of cubs.

In March, we entered the dens of female bears with newborn cubs. We immobilized the adult female, and counted, measured, and weighed the cubs. We selected cubs that appeared healthy and weighed at least 1.80 kg to receive subcutaneous implants (AVM Instrument Company, Ltd., Livermore, California, USA; Advanced Telemetry Systems Inc., Isanti, Minnesota, USA). This *a priori* weight criteria was based on the size cub we felt would most easily accommodate the implants we were using. Flat implants weighed, on average, 25.2 g (SE = 0.53, n = 15) and measured 63.1 mm (SE = 0.76, n = 16) × 26.2 mm (SE = 0.23, n = 16) × 11.0 mm (SE = 0.20, n = 16). The 0.9-mm diameter Teflon-covered antenna averaged 132.4 mm (SE = 0.73, n = 13) in length. Round implants weighed, on average, 17.28 g (SE = 0.06, n = 2) and measured 17.5 mm (SE = 0.50, n = 2) in diameter × 49 mm (SE = 1.50, n = 2) long with an antenna length of 129.5 mm (SE = 0.50, n = 2). Antennas were equipped with a bead of inert material attached to the end to help prevent irritation. The transmitters were coated in Scotchcast electrical resin #5 (3M Distributors, St. Paul, Minnesota, USA). All implants were sterilized in ethylene oxide gas and sealed in plastic until surgery. Each implant was equipped with a motion-sensitive mortality sensor with a 4-hour delay.

Each cub selected to receive an implant was immobilized with a 5:1 mixture of ketamine hydrochloride and xylazine hydrochloride at a dosage rate of 1.8 mg/kg of ketamine and 0.4 mg/kg of xylazine (1 cc/45 kg). Once the cub lost consciousness, it was placed in sternal recumbency for surgery. We noted the frequency of breaths for each cub, but did not monitor heart rate or body temperature. We placed a rolled towel under the cub's neck to maintain flexion.

We shaved about 8 cm^2 of fur between the base of the neck and the base of the shoulder blades, and 21 cm caudal, we shaved a second area (3 cm^2) near the base of the tail. These areas were scrubbed with povidone iodine and wiped with isopropyl alcohol and allowed to air dry. We draped the cub, cut fenestrations in the drape large enough to expose the proposed incision areas, and secured the drape by clamping it to the cub's fur with Allis-tissue forceps (Jorgenson Laboratories, Inc., Loveland, CO, USA).

In 1996, longitudinal incisions were made between the shoulder blades of the cubs to accommodate the subcutaneous implant. All 1996 surgeries were performed in the northern study area only.

During the 1997 den season, we continued to use the longitudinal incision between the shoulder blades in the northern study area, but in the southern study area we changed to a lateral incision between the base of the neck and the scapular region, effectively creating a pocket. We also surgically implanted transmitters in 2 wild cubs captured after the den season in July 1997 and released them at their capture site following complete recovery from the surgical anesthesia.

During 1997 and 1998, we implanted transmitters in cubs born to captive females at Virginia Tech's Center for Ursid Research as part of an ongoing reproduction and nutrition study and monitored their behavioral responses to the implants until their release from captivity in mid-May or early June. We observed cubs between the ages of 55 and 109 days to determine what, if any, effect the adult female and any siblings had on implant retention rates. We observed the cubs from a distance and therefore were unable to discern individuals.

During the 1998 den season, we changed the suture type from a simple interrupted skin suture to a simple continuous subcuticular pattern in both study areas. Additionally, we performed surgeries in the northern study area using only the lateral incision technique first used on the southern study area cubs in 1997.

Table 1. Number of wild black bear cubs with subcutaneous radio transmitter implants and fate of the transmitters, George Washington and Jefferson National Forests, Virginia, during 1996–99.

Year	Implanted (M:F)	Rejected	Malfunctioned	Retained
1996	2 (2:0)	1	1	0
1997	13[a] (6:7)	8	4	0
1998	13 (8:5)	7	2	4
1999	11 (3:8)	9	2	0

[a]One cub died of unknown causes.

In 1999, we tested a cylindrical transmitter in addition to the flat model. We continued to use the 1997 modified lateral incision technique and the continuous subcuticular pattern of suturing first begun in 1998.

During all surgeries, we made a 5-cm longitudinal incision through the hide from the base of the neck to the scapular region and a second 1-cm incision 21 cm below the first incision. Using hemostats, in the first incision we separated the hide from the muscle and fascial tissue and created a pocket to hold the transmitter. We used alligator forceps to tunnel between the caudal incision and the upper incision. We held the tip of the antenna with the forceps that tunneled between the upper and lower incisions and carefully inserted the transmitter into the pocket, drawing the antenna down through the tunnel toward the base of the tail until the transmitter was completely seated in the pocket. We closed both incisions. We initially used simple interrupted skin sutures of 2-0 PDS II (Polydioxanone) on a cutting needle (Ethicon, Inc., Somerville, New Jersey, USA), and in 1998 and 1999 changed to a 3-0 coated vicryl (Polyglactin 910) suture on a cutting needle (Ethicon, Inc., Somerville, New Jersey, USA) in a simple continuous subcuticular pattern.

Implanted cubs received LA200 (oxytetracycline, Pfizer, distributed by Animal Health, New York, New York, USA) at a dosage rate of 800 mg/kg (4 cc/45 kg) intramuscularly to help combat infection. Each cub then was administered Yobine (yohimbine hydrochloride, Lloyd Laboratories, Shenandoah, Iowa, USA) at 10 mg/kg (2 cc/45 kg) or Antagonil (yohimbine hydrochloride, Wildlife Laboratories, Incorporated, Fort Collins, Colorado, USA) at 10 mg/kg (1 cc/45 kg) intramuscularly to reverse the xylazine hydrochloride. Licensed veterinarians performed all surgeries in field situations using sterile gloves and equipment that had been steam autoclaved in commercial wraps and kept in Ziploc bags until surgery.

We monitored the signals of all implanted wild cubs daily for 48 hours following implantation and daily or every second day until the cub reached 5 months of age, after which they were checked 2–3 times weekly. Mortality signals were investigated immediately and the transmitters and carcasses were recovered quickly whenever possible. All of our procedures were approved by the Virginia Tech Animal Care Committee (ACC#98-069-F&W).

Analysis

We defined implant surgery failure rate as the number of cubs whose implants failed (fell out, were rejected, or were pulled out, potentially by the cub, the sow, or a sibling cub) in less than a year, divided by the number of transmitters implanted.

We used Spearman's rank correlation to determine if cub age, cub weight, total length, or chest girth, influenced the length of time (days) implanted transmitters were retained. Cub ages were estimated using a regression equation developed by Godfrey (1996) using known-age cubs. We used the Wilcoxon rank-sum test as well as the Multiple Response Permutation Procedure (MRPP), both distribution-free tests, to compare the length of time male and female black bear cubs retained their transmitters (Mielke et al. 1981, Mielke and Berry 1994). All tests were considered significant at $\alpha = 0.1$.

We used the known-fate procedure of Program MARK (White and Burnham 1999) to estimate "survival" of the 39 implants unaffected by our research activities. For this analysis, survival was defined as a retained and operating transmitter in a living cub. We removed 3 animals with implants whose "death" we did not feel was directly related to the use of implants, but rather to the overall influence of our research. Prior to treating data from all years as a single sample, we tested for between-year differences in implant survival using Kruskal-Wallis. We generated survival results for 12, 24, 36, and 44 weeks (the last data points in our study).

Results

We implanted radiotransmitters subcutaneously in 40 wild black bear cubs (21M:19F) during the 1996–99 den seasons (Appendix), 10 captive cubs (6M:4F) in 1997 and 1998, and 2 (0M:2F) wild cubs captured during trapping efforts in July 1997.

1996–97 implants

Nine of 18 transmitters implanted in wild cubs during the first 2 years of study were rejected within 5 months of surgery; 7 of these were rejected within 2 months. Rejection does not necessarily imply infection; some of these transmitters fell out, were pulled out, were rejected by the body, or were groomed out by the adult female. The fates of the remaining 9 cubs were as follows: 2 died within 6 days of surgery; 2 died within a month following abandonment by their mother; and 5 experienced transmitter failures 2–10 months post surgery (Table 1; Appendix).

The 2 cubs that died within 6 days of surgery were examined to determine cause of death. The first was examined by the veterinary surgeon that performed the procedure, and no evidence of infection was detected. The suture line was remarkably well healed, and the body already had begun to seal off the implant. The second cub was taken to Virginia Tech's College of Veterinary Medicine and evaluated by a veterinary pathologist. The cause of death was attributed to starvation and malnutrition consistent with abandonment. Thus, this cub was removed from our analysis. In addition, the 2 cubs that died following abandonment by their mother were removed from our analysis because we felt our presence at the den site and not the implant surgery led to their deaths.

Two of the 5 cubs whose transmitters failed prematurely wore their transmitters until the next den season, when the transmitters were detected under the skin of the then-yearlings. The other 3 failed after 2 months ($n = 1$) and 6 months ($n = 2$).

1998 implants

Four of 6 implant surgeries performed on the northern study area during the 1998 den season were rejected after 18–77 days; the remaining 2 transmitters failed or became undetectable after 60–109 days. Four of 7 implanted cubs in the southern study area retained their transmitters until the 1999 den season, and the other 3 were rejected 1–6 months after surgery.

1999 implants

All but 2 of the 11 transmitters implanted during the 1999 season fell out and were recovered before the end of June. The remaining 2 transmitters, both cylindrical models, could no longer be detected by mid-September 1999.

Correlates of implant success

We documented an overall implant surgery failure rate of 59.5% ($n = 42$) for all cubs not in captivity. The rate was 64% ($n = 39$) when we removed the 3 cubs whose deaths were not directly related to the surgery. Transmitter retention rates varied widely and differed between the sexes (Fig. 2). The mean retention time for all wild cubs was 101.4 days (SE = 17.2, $n = 39$). Male cubs ($\bar{x} = 148.3$, SE = 29.0, $n = 19$) retained their transmitters longer ($\chi^2 = 4.271$, 1 df, $P = 0.038$) than female cubs ($\bar{x} = 56.8$, SE = 13.7, $n = 20$).

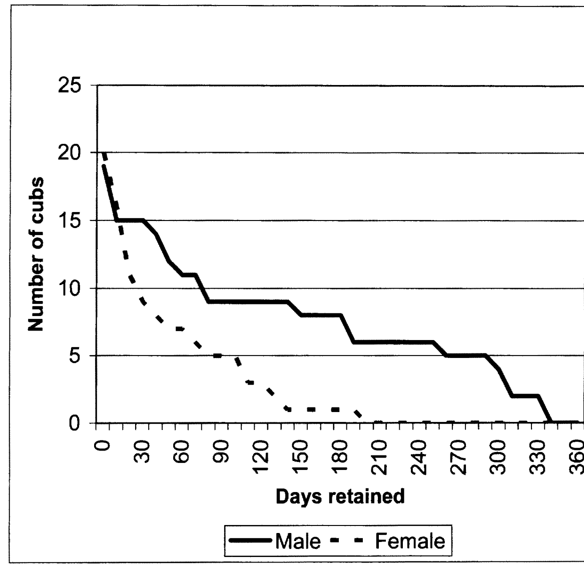

Fig. 2. Retention of transmitters implanted subcutaneously in black bear cubs on the George Washington and Jefferson National Forests, Virginia, 1996–1999, (*n* = 39; 20M:19F).

Cub weight was positively correlated with retention time ($r_s = 0.401$, $P = 0.014$), but neither cub age ($r_s = -0.210$, $P = 0.201$), chest girth ($r_s = 0.004$, $P = 0.982$), or total length ($r_s = -0.083$, $P = 0.616$) were significantly correlated with retention time. Males retained their transmitters longer than females ($\Delta = -3.99$, $P = 0.008$).

We detected no differences among annual implant survival rates ($H = 7.04$, 3 df, $P = 0.071$), so we combined all 4 years in the Program MARK analysis. Survival rates at 12, 24, 36, and 44 weeks were 36.0% (SE = 8%), 17.7% (SE = 6%), 8.7% (SE = 4%), and 6.5% (SE = 3%), respectively.

Captive cubs

Within 10 days of the captive cubs' surgeries, 2 cubs in a litter of 4 showed signs of infection and rejection, including drainage and an opening of the incision. Within 3 weeks, these 2 transmitters came out and the 2 other littermates' incisions were beginning to appear infected. At least 6 of the 10 implants festered to the point of rejection within one month of implantation. Periodically, we made attempts to intervene, to clean the incision or re-suture, but were largely unsuccessful in keeping the implants in.

Table 2. Average age, weight, total length, and chest girth of wild male and female black bear cubs that received subcutaneous radiotransmitter implants in the George Washington and Jefferson National Forests, Virginia, 1996–99.

	Males (*n*)	Females (*n*)
Age (days)	66 (19)	73 (20)
Weight (kg)	2.4 (19)	2.2 (18)
Length (mm)	484 (19)	508 (20)
Chest girth (mm)	265 (18)	254 (17)

Discussion

We documented a 64.1% implant surgery failure rate and calculated a 44-week implant survival rate of 6.5% using Program MARK. Even evaluated at 3 months, the 36% implant survival we documented was inferior to the expandable collars we used (Vashon et. al 2003).

We can not explain all the circumstances under which implants came out of bear cubs, but we confirmed that at least 12 of 25 cubs that rejected their implants survived (K.N. Echols unpublished data). We cannot substantiate speculation regarding the role of maternal intervention, sibling involvement, irritation from the transmitter or antenna, and infection in the rejection of implants, nor can we determine which of these factors might have been the most influential.

We found a relationship between cub weight and the implant retention period, but cannot explain the lack of detectable relationships between other factors that are often correlated with weight, such as cub age and some morphological measurements. All these factors may be influenced by differences in litter size and adult female age and condition that result in different cub growth rates, which may obscure such relationships. The larger average weight of male cubs ($\bar{x} = 2.40$, SE $= 0.080$, $n = 19$) versus female cubs ($\bar{x} = 2.21$, SE $= 0.082$, $n = 18$; Table 2) appears to explain the relationship between cub weight and retention time; however, cubs often appeared more capable of reacting to their own incisions with increased age and size, and on several occasions, implanted cubs were seen reaching behind their backs to scratch at the incision and suturing. Overall, we found that the larger the cub, the less intrusive the surgery and therefore the greater chance of acceptance. However, the 2 female cubs implanted during the summer of 1997 that were larger than all other cubs at the time of implant surgery retained their implants only a very short time. This leads us to speculate there might be a threshold weight past which the implant surgery is no longer as successful, or possibly a behavioral component that plays a role after reaching a certain age.

Schober and Wagner (1988) suggested that the greatest problem with most transmitters rested with the size, shape, elasticity, and flexibility of the radiotelemetry unit. They indicated that transmitter rejection might be reduced or eliminated if the implant is well suited in size and shape for its location inside the animal. Schulz et al. (1998) discovered a reduction in incision dehiscence when they moved the transmitter away from under the sutures.

We encountered a substantial number of transmitter failures. We lost contact with 9 of 39 implanted cubs during the 4 years of implant surgeries. We do not know the circumstances behind all of these failures, but suspect a combination of premature failure of the transmitters due to broken antennas compromising the transmitter's integrity, destruction by the bear wearing them, or destruction by natural events such as predation. We recovered one of the failed transmitters at a 1997 den site and determined the transmitter had a faulty battery. Female 446, whose transmitter failed on 10 July 1998, was trapped on 20 July 1999 and her subcutaneous implant was detected under the skin at the site of implantation.

The condition of several of the recovered dropped transmitters suggests that there may be a failure in the integrity of the transmitter packages. The antennas of at least 5 recovered transmitters had broken off. We do not know if the bears retained the antennas or if the antennas worked their way free of the body prior to the loss of the implant itself. In each case, the antennas broke at the point of attachment to the transmitter, and in a few cases, it appeared that this break could have allowed body fluid to enter the transmitter. Schober and Wagner (1988) found that if the antennas broke away from the transmitter package, subcutaneous infections could arise from these irritations that would eventually result in the expulsion of the entire transmitter.

We observed that at a relatively young age (~7–10 weeks), cubs in captivity become mobile and playful. Their sharp claws could have caused some of the infection and some of the suture failures. Adult females may influence the retention of these transmitters through grooming the cubs or cleaning wounds. Although these observations provided some ideas to help explain the transmitter loss we experienced with wild cubs, we acknowledge some important differences. Captive-born cubs may be more prone to pay attention to their implant due to confinement, and confined cubs may interact more with each other than wild cubs. We found the wounds of wild cubs healed more quickly. In cases where the rejected implant was recovered and the cub was examined at a later date, there was no evidence of long-term harm. There appears to be little risk of life-threatening infections that can result from intraperitoneal implant surgeries (VanVuren 1989, Reynolds 1992), such as peritonitis or organ blockage from free-floating implants.

Because wildlife telemetry studies are generally conducted on animals in their natural habitats, post-surgical examinations are at best limited and often impossible to conduct except in cases of mortality (Schober and Wagner 1988). The fate of 6 of 10 black bears implanted by Jessup and Koch (1984) remains unknown, and the circumstance of the rejection of 3 transmitters implanted by them is unclear due to an inability to conduct a hands-on post-surgical evaluation. Schulz et al. (1998) found the use of subcutaneous implants to be preferable to intraperitoneal implants in captive mourning doves following examination of post-treatment blood chemistry analyses. Such findings suggest that what may at first appear to be successful implantations may have undetected, potentially deleterious effects.

The definition of success by authors of implant papers varied substantially. In mallards, Korschgen et al. (1996) reported all but 1 mallard exhibited some reaction to their intraperitoneal implant ranging from mild to severe, but noted that no behavioral or physiological effects were detected. Philo et al. (1981) used both intraperitoneal ($n = 3$) and subcutaneous ($n = 1$) implants in grizzly bears and found the subcutaneous implant festered initially before healing completely, 1 of the intraperitoneal implants healed without complication, 1 resulted in a large scar from the sutures being ripped out, and the third outcome was unknown. These authors used a subcutaneous implant because of previous but unpublished success by J. Siperek (as cited in Philo et al. 1981) with black bears. Melquist and Hornocker (1979) reported 3 of the 11 river otters they implanted with intraperitoneal implants died, likely as a result of their surgical procedures, but the remaining 8 otters survived without incident. In their conclusions, however, they emphasized the need to use the technique most suitable for the animal being studied because collars, subcutaneous implants, and intraperitoneal implants each have advantages and disadvantages.

Management implications

The use of subcutaneous implants to monitor black bear cub survival is currently not the most effective means to obtain black bear cub survival data during the first year of life. Subcutaneous implants do not obtain consistently longer-term survival data than the expandable radio-collars we designed for black bear cubs (Vashon et al. 2003). Although subcutaneous implants did not perform as well as we had hoped, we are not inclined to rule out their future use. Advances in technology (miniaturization, more powerful batteries) may solve some of the problems we encountered. However, until then, and until such factors as maternal and sibling intervention can be quantified and measures taken to prevent this and other interventions, we can not recommend subcutaneous implants for black bear cubs. Although they can provide some of the same valuable data, the problems we encountered plus the added expense and coordination of a veterinarian lead us to conclude that subcutaneous implants should not yet be the method of choice.

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Appendix

Ultimate outcome of implant surgery and number of days subcutaneous radiotransmitter functioned in 42 wild black bear cubs in the George Washington and Jefferson National Forests, Virginia, 1996–99.

Study area	Bear ID	Sex	Age[a] (days)	Implant date	Days worn	Results and comments
North	N229	M	65	24 Mar 96	38	Transmitter failed post den emergence
	N232	M	71	28 Mar 96	8	Transmitter recovered in den: transmitter rejected or cub consumed?
	N311	F	63	4 Mar 97	29	Died from abandonment, exposure, or starvation; removed from analysis
	N312	F	63	4 Mar 97	2	Cub died of unknown causes in den
	N313	M	63	4 Mar 97	29	Died from abandonment, exposure, starvation; removed from analysis

Appendix Table Continued.

Study area	Bear ID	Sex	Age[a] (days)	Implant date	Days worn	Results and comments
	N317	M	67	10 Mar 97	6	Cub died from starvation; removed from analysis
	N318	F	67	10 Mar 97	84	Transmitter rejected, recovered in sow's home range: cub survived
	N324	F	68	13 Mar 97	14	Transmitter rejected, recovered in den: cub survived
	N325	F	68	13 Mar 97	14	Transmitter rejected, recovered in den: cub survived
	N326	F	70	13 Mar 97	137	Transmitter rejected, recovered in sow's home range: cub survived
	N333	M	62	17 Mar 97	2	Transmitter rejected, recovered in den: cub survived
	N334	M	62	17 Mar 97	2	Transmitter rejected, recovered in sow's home range
	N431	M	82	16 Mar 98	77	Transmitter rejected, recovered in sow's home range
	N432	M	82	16 Mar 98	48	Transmitter rejected, recovered in sow's home range: cub survived
	N433	F	82	16 Mar 98	18	Transmitter rejected, recovered in sow's home range: cub survived
	N444	F	72	25 Mar 98	28	Transmitter rejected, recovered in den: cub survived
	N445	M	72	25 Mar 98	60	Transmitter failed post den emergence
	N446	F	72	25 Mar 98	109	Transmitter failed post den emergence but remained subcutaneous: cub survived
	N561	F	64	15 Mar 99	28	Transmitter rejected, recovered in den: cub survived
	N563	F	64	15 Mar 99	48	Transmitter rejected, recovered in den
	N564	F	54	16 Mar 99	179	Transmitter failed: cub survived
	N565	F	54	16 Mar 99	75	Transmitter rejected, recovered in sow's home range: cub survived
	N566	M	54	16 Mar 99	175	Transmitter failed: cub survived
	N568	F	51	16 Mar 99	13	Transmitter rejected, recovered in den
South	S117	M	59	28 Mar 97	340	Transmitter failed but worn until denning, reimplanted 1998: cub survived
	S118	M	59	28 Mar 97	340	Transmitter failed but worn until denning, reimplanted 1998: cub survived
	S125	M	60	21 Mar 97	189	Transmitter failed
	S126	M	60	21 Mar 97	189	Transmitter failed
	S128	F	~153	3 Jul 97	5	Transmitter rejected: cub survived
	S129	F	~153	3 Jul 97	11	Transmitter rejected: cub survived
	S165	M	66	23 Mar 98	296	Transmitter worn until denning 1999
	S166	F	66	23 Mar 98	124	Transmitter rejected
	S167	M	75	23 Mar 98	304	Transmitter worn until denning 1999
	S168	M	75	23 Mar 98	304	Transmitter worn until denning
	S169	M	75	23 Mar 98	142	Transmitter rejected
	S170	M	58	30 Mar 98	254	Transmitter worn until denning
	S171	F	58	30 Mar 98	198	Transmitter rejected, recovered in sow's home range
	S195	M	60	18 Mar 99	41	Transmitter rejected, recovered in den
	S196	F	60	18 Mar 99	31	Transmitter rejected, recovered in den
	S198	F	66	25 Mar 99	9	Transmitter rejected, recovered in sow's home range
	S199	F	66	25 Mar 99	9	Transmitter rejected, recovered in sow's home range
	S200	M	66	25 Mar 99	9	Transmitter rejected, recovered in sow's home range

[a]Cub ages from the regression equation developed by Godfrey (1996).