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Review of radio transmitter attachment methods for West Indian rock iguanas (genus *Cyclura*)

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Abstract
Methods for attaching radio transmitters to rock iguanas (genus *Cyclura*) are described and compared based on signal range, longevity of attachment, and potential disturbance to animal behavior or health. Case studies are described for all instances of internal implantation, ingestion, and external attachment of transmitters for which data are available. Signal range did not differ dramatically between attachment methods, but did differ between transmitter models and habitats in which iguanas were tracked. Only transmitters with coiled antennas showed a dramatic reduction in signal range. Longevity of transmitter attachment varied greatly among attachment methods, and was greatest for implantation, least for ingestion, and intermediate for external methods. Internal placement of transmitters via ingestion or implantation was advantageous in having no external apparatus to snag on vegetation or rocks. However, ingestion yielded less than one week of data, and implantation required costly, potentially stressful surgery. External attachment methods, including suturing of transmitters, mounting with adhesive, and harnesses or collars with breakaway mechanisms, entailed low cost and low risk, but were less reliable for long-term attachment. Harnesses or belts that lacked breakaway mechanisms entailed higher risk, because iguanas may suffer injury or death if not monitored frequently and recaptured for removal of attachment devices. In many studies, iguanas successfully mated, nested, and appeared to behave normally with transmitters attached by various methods. However, further research is needed to determine how different attachment methods affect the health, behavior, and survivorship of iguanas, particularly in smaller species and juveniles, which are more susceptible to predation.

Key words
Caribbean, endangered species, lizard, radio telemetry, radio tracking.

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Introduction

Radio telemetry is an important tool for investigating behavioral ecology and aiding in conservation monitoring. The genus *Cyclura* (Sauria: Iguanidae sensu Frost and Etheridge, 1989; but see discussion of taxonomy in Hollingsworth, 2004) is a group of large, herbivorous lizards restricted to islands in the Greater Antilles and the Bahamas. Six of the nine species of these rock iguanas are considered endangered, and the remaining three are vulnerable (IUCN, 2007). Past and current threats include habitat destruction and degradation (Alberts, 2000), predation by and competition with introduced animals (Iverson, 1978; Mitchell, 1999), hunting by humans (Carey, 1975; Knapp et al., 1999; references in Vogel et al., 1996), and illegal capture for the pet trade (Alberts and Grant, 1999). Radio telemetry can help researchers to monitor the extent and impact of these threats, while collecting information about animal behavior, movement, and habitat use to aid in management and conservation. Intensive research on *Cyclura* has only been conducted over the past three decades. Much about the natural history of these unique and long-lived lizards (up to 50 years, Iverson et al., 2004) remains unknown.

There are several valuable reviews that examine radio telemetry techniques and their tradeoffs, including cost, accuracy, reliability, and effects on study subjects (Amlaner and Macdonald, 1980; Kenward, 1987; Kenward, 2000; Manly et al., 2002; Mech, 1983; Millspaugh and Marzluff, 2001; White and Garrott, 1990). However, particular challenges face rock iguana researchers. While often sedentary, iguanas may have large home ranges (up to 38 ha, Goodman et al., 2005), necessitating a large signal range for effective telemetry. Rock iguanas occupy xeric limestone habitats that often include dense shrubs and jagged rock outcroppings (Alberts, 2000). These make the external attachment of transmitters problematic, because many iguanas retreat for the night, or during the heat of day, into narrow crevices or sinkholes of rocky substrates (Alberts, 2000). These habits increase the potential for externally mounted transmitters to detach or cause the accidental entrapment of study animals. While death of animals due to transmitter attachment is never considered acceptable, it is particularly important to minimize this risk when studying threatened or endangered species. Extra caution is necessary when working with juvenile iguanas, which are smaller and therefore more vulnerable than adults to both natural and introduced predators (Carey, 1975; Christian, 1986; Levering and Perry, 2003; Vogel et al., 1996). Finally, investigators should strive to minimize any disturbance of behavior that may affect study results.

We review and evaluate radio transmitter attachment methods that have been used with rock iguanas. Most of this information was gathered from field notes up to two decades old; therefore varying levels of detail are available for each study. Where information on methods used or impacts on animals are not described, it is because these details are unavailable. For internal implantation, ingestion, and external attachment methods, we describe: (1) methodological details if not published previously, (2) longevity of attachment, (3) signal range, and (4) potential costs in terms of disturbance to behavior and threats to health and survival.

Internal implantation of transmitters

Radio transmitters have been implanted internally in a variety of animals, including amphibians (reviewed in Richards et al., 1994), snakes (Beaupre, 1995; Charland and Gregory, 1990), and some lizards (Beck and Lowe, 1991; Ellisquinn and Simon, 1991; Guarino, 2002; Kingsbury, 1994; Klingenbock et al., 2000; Schauble and Grigg, 1998). In 1993, F.J. Burton used internally implanted transmitters in three adult male hybrid iguanas (*Cyclura lewisi* × *Cyclura nubila caymanensis*, age 3 years, approximately 1.2 kg; unpublished data). Transmitters with coiled antennas were encased in sterile bone wax and sutured internally to the abdominal body wall (see table 1 for model and size specifications of all transmitters). Surgeries were performed by a veterinarian on Grand Cayman, and iguanas were monitored for several days before release. Iguanas were tracked in the dry shrubland and forest of the Salina Reserve in eastern Grand Cayman. The typical range of transmitter signal was 100 m, although range increased up to approximately 200 m in less densely vegetated areas. Transmitters were not removed at the end of the study. No disturbance to the behavior or health of iguanas was observed during two months of intensive monitoring followed by a year of sporadic monitoring. One iguana carrying a transmitter was killed by a dog six months after implantation. Subsequent necropsy revealed that the transmitter had bonded to the body wall with connective tissue, which showed no pathological signs.

Experimental intra-coelomic implantation of transmitters was studied by A.C. Alberts in three adult female captive Cuban iguanas, *Cyclura nubila nubila* (age 7.5 years, 2.50-2.56 kg) at the San Diego Zoo in 2001-2004 (unpublished data). Transmitters with flexible, stainless steel antennas were modified with slight protrusions on either end, so units could be secured internally by suture. Transmitters were constructed with three different antenna configurations: 20 cm whip antenna coiled around transmitter with entire unit encased in biologically compatible helix rubber; 20 cm antenna extending from rubber-encased transmitter; and trimmed 10 cm antenna extending from rubber-encased transmitter (table 1).

Surgical implantations were performed by veterinarians at the San Diego Zoo hospital. During surgery, the transmitter was placed within the coelomic cavity, approximately two-thirds down the length of the body and posterior to the most caudal kidney, and the antenna was inserted into the body cavity. Transmitters were secured on each end with a single suture through the intercostal muscles. Lizards were moved to a warm chamber (27°C) for 48 hours of observation and recovery and then returned to their normal housing.

To test signal range, iguanas were transported in cloth bags to nearby coastal sage scrub habitat with shrub vegetation <2 m high and no trees, canyons, or valleys. Signal range was positively associated with free antenna length. Signals from transmitters with coiled, 10 cm free, and 20 cm free antennas had ranges of 36, 372 and 641 m, respectively. Transmitters were not removed from the lizards after the batteries expired, in order to mimic field situations and evaluate potential long-term health complications. Four years after implantation, none of the females

Table 1.
Details of radio transmitters used in studies of rock iguanas, genus *Cyclura*. Length, width and depth are shown for box-shaped transmitters, and length and diameter are given for cylinders. Entries are listed in their order of appearance in the text.

Investigators and dates of study (publication)	Species	Manufacturer and model	Dimensions (mm)	Mass (g)	Antenna type	Battery life (mo)	Maximum range (m)
Burton, 1993	*C. lewisi* × *C. caymanensis*	Wildlife Materials Inc. (Carbondale, Illinois), SOTB2380	34 × 15 × 8	5.5	Coiled	Unknown	200
Alberts, 2001	*C. nubila*	Holohil Systems, Ltd. (Carp, Ontario), SI-2H coiled antenna	38 × 12	16.6	Coiled, 20 cm	12	36
Alberts, 2001	*C. nubila*	Holohil Systems, SI-2 free antenna	38 × 12	9.3	Flexible, 20 cm	12	641
Alberts, 2001	*C. nubila*	Holohil Systems, SI-2 free antenna	38 × 12	9.3	Flexible, 10 cm	12	372
Bradley and Gerber, 2003-4	*C. pinguis*	Holohil Systems, AI-2T	38 × 15	16	Flexible, 24 cm	24	1350*
Bradley and Gerber, 2003-4	*C. pinguis*	Holohil Systems, SI-2	33 × 11	9	Flexible, 20 cm	12	470*
Goodyear and Lazell, 1992 (1994)	*C. pinguis*	L.L. Electronics (Manomet, Illinois), one-stage	20 × 40	–	Looped	–	–
Christian et al. (1986)	*C. nubila*	Mini-mitter (Sunriver, Oregon), model L	–	–	–	–	–
Burton, 1995	*C. lewisi*	Wildlife Materials, model unknown	12 × 7 × 6	0.7	Flexible, 9 cm	–	50
Burton, 2001	*C. lewisi*	Wildlife Materials, model LPB2350	–	15	Flexible	–	–
Knapp, 2002	*C. cychlura*	Wildlife Materials, SOM 2190	28 × 14 × 8	4.3	Flexible	–	400
Burton, 1992	*C. lewisi*	Wildlife Materials, LPB 2350	65 × 18 × 15	15	Flexible, 19 cm	–	500
Goodman, 2002 (2005)	*C. lewisi*	Holohil Systems, AI-2	45 × 15	35-40	Flexible, 23 cm	6	350
Knapp and Owens, 2003 (2005a)	*C. cychlura*	Holohil Systems, AI-F	–	19	Flexible	10	600
Knapp and Owens, 2003 (2005a)	*C. cychlura*	Advanced Telemetry Systems (Isanti, Minnesota), F2050	–	14	Flexible	8	600

Table 1.
(Continued).

Investigators and dates of study (publication)	Species	Manufacturer and model	Dimensions (mm)	Mass (g)	Antenna type	Battery life (mo)	Maximum range (m)
Mitchell, 1988-90	*C. pinguis*	L.L. Electronics, two-stage	50 × 15	–	Flexible	–	–
Mitchell, 1999-2000	*C. carinata*	L.L. Electronics, model unknown	10 × 10	–	Looped, see text	3	–
Pérez-Buitrago, 1998-2000 (Pérez-Buitrago and Sabat, 2007; Pérez-Buitrago et al., 2007)	*C. cornuta*	L.L. Electronics, LF-1-357-RS-T	–	6	Flexible	4	700
Pérez-Buitrago, 1998-2000 (references above)	*C. cornuta*	Holohil Systems, RI-2D	34 × 19 × 15	15	Flexible	18-30	700
Knapp and Owens, 2003-4 (2005b)	*C. cychlura*	Holohil Systems, BD-2	17 × 8.5 × 5.5	1.9	Flexible, 20 cm	3	1200
Knapp and Owens, 2003-4 (2005b)	*C. cychlura*	Holohil Systems, PD-2	23 × 12 × 5.5	2.7	Flexible, 20 cm	3	1200
Goodman, 2002 (2005)	*C. lewisi*	Holohil Systems, AI-2	45 × 15	35-40	Flexible, 23 cm	6	>200
Thornton and Hayes (Thorton, 2000)	*C. rileyi*	Wildlife Materials, SOPB2190	–	5	Flexible	8	–
Fry and Hayes (Fry, 2001)	*C. rileyi*	Wildlife Materials, SOPB2190	–	5	Flexible	8	–
Iverson, 2002	*C. cychlura*	LGL Limited (Sidney, British Columbia), LF-1-STL-357-RS	30 × 15 × 10	25	Internal, looped	–	>150

*Maximum signal range in this study was obtained with the use of a 25 ft high tower with four three-element yagi antennae.

had shown any complications, and all females laid eggs without incident each year from 2001 to 2004. One female died in 2004, but this appeared to be unrelated to her implanted transmitter. Upon necropsy, the transmitter was in place within the body cavity, showing no evidence of encapsulation, inflammation, or infection.

In 2003, K.A. Bradley and G.P. Gerber used implanted transmitters to track 12 male and 12 female headstarted *Cyclura pinguis* (age 4-6 years, 0.75-2.05 kg) upon release to the wild in Anegada, British Virgin Islands (unpublished data). Depending upon animal size, a Holohil Systems model AI-2T or model SI-2T transmitter was implanted surgically into the coelomic cavity in the posterior abdomen. Both transmitter models were temperature sensitive, encased in a hermetically sealed brass cylinder and coated with multiple layers of a biologically inert butyl rubber. Each transmitter case had two small grooves to facilitate suturing to the abdominal wall during implantation and a stainless steel, Teflon-coated antenna reinforced at the base with silicone tubing. The whip antenna was coiled to fit through the surgical incision, and then allowed to loosely uncoil in the body cavity. Implantation surgeries were performed in a provisional hospital in Anegada by veterinary doctors and technicians. Iguanas were given subcutaneous fluids (dextrose and sodium chloride) immediately afterward, and allowed to recover for 2-10 days before release.

Signal range was up to 400 m for the SI-2T model and 1200 m for the AI-2T model when using a handheld, three-element Yagi antenna. A 7.6 m high tower with four three-element antennas allowed signals from SI-2T model transmitters to be detected at 470 m and from AI-2T model transmitters at 1350 m.

The behavior and health of most iguanas did not appear to be affected during 12 months of periodic observation following implantation and release. One iguana was found dead two days after release (10 days after surgery) with a ruptured coelomic cavity and was partially eviscerated. Subsequent necropsy indicated a primary rupture adjacent and parallel to one side of the suture line, which remained completely intact, and a similar, smaller rupture on the other side of the suture line. The transmitter remained securely attached to the body wall, which showed no signs of irritation or cause of rupture. Of the 24 animals released in 2003, 20 were alive and healthy one year after release, at which time transmitter batteries began to fail. In addition to the animal that died two days after release, two animals died for unknown reasons (possibly predation, as only the transmitters were recovered) two and six months after release. An additional animal found in poor health six months after release was taken into captivity, where it died several days later. Subsequent necropsy revealed that the animal died from causes unrelated to the implanted transmitter, which remained intact and surrounded by a thin, almost transparent membrane. No signs of granuloma formation or inflammation were present.

In 2004, Bradley and Gerber released another 12 male and 12 female headstarted iguanas (age 3-5 years; 0.55-1.60 kg) with implanted transmitters on Anegada. One of these animals died from unknown causes approximately two months after release (again, only the transmitter was found). The desiccated carcass of a second animal that died of undetermined causes was found approximately four months post-release. The other 22 animals were alive and healthy when observed in 2007.

The above cases indicate that the majority of transmitter implantations do not result in alterations of behavior or serious health risks to iguanas. Only one of over 50 documented implantations is suspected of potentially contributing to the death of an iguana. No obvious alterations to the behavior of iguanas were noticed by researchers after the initial recovery period. With the exception of possible rare health complications, internal transmitters, lacking the potential to catch on retreats or be bitten and pulled during social interactions, may alter the behavior of iguanas less than externally-attached transmitters.

For internally implanted transmitters, signal range depends on the model used and the free antenna length. However, implantation itself does not seem to limit signal range when compared with other methods described below. Disadvantages of using internal implantation of transmitters in *Cyclura* include greater financial cost (due to the necessity of surgery being performed by qualified veterinarians), an apparently small risk of death due to surgery, and potential long-term effects of leaving implanted transmitters in these long-lived lizards.

Ingestion of transmitters

Goodyear and Lazell (1994) fed radio transmitters in chicken skins to adult *C. pinguis* (SVL > 40 cm, one male and three females) on Guana Island in the British Virgin Islands. Transmitters typically remained inside iguanas for 4-7 days before being passed in feces. No negative implications for the behavior or health of iguanas were noted during the study period. Although the length of observation following use of transmitters was unspecified, negative health impacts after transmitters have successfully passed through the body are not expected. Christian et al. (1986) fed temperature-sensitive transmitters in bananas to four adult male *C. nubila nubila*. Again, no ill effects were reported. Unfortunately, data on signal range for these studies are unavailable.

The primary benefits of feeding transmitters to iguanas include absence of handling and potential disturbance to the animals. However, a major drawback is the short period that transmitters remain inside iguanas to provide data. Also, supplemental feeding by researchers may alter the subsequent behavior of iguanas (Stamps and Tanaka, 1981), making them more prone to visit humans or human-occupied habitats (Iverson et al., 2004). The use of this tracking method with gravid females might be limited by either an unwillingness to eat prior to oviposition or potential unforeseen health complications due to retention of transmitters in the gastrointestinal tract during stressful periods such as gravidity and nesting.

External attachment of transmitters

Attachment of transmitters with duct tape

In 1995, F.J. Burton used duct tape to secure transmitters to two juvenile *C. lewisi* (age 1 year, 0.19 and 0.20 kg, sexes unknown) in the Queen Elizabeth II Botanic Park (QEIIBP) in Grand Cayman (unpublished data). Transmitters were placed against the side of the dorsal crest on the tail base, with duct tape wrapped around tail at several points (where the unit sat, and distally along the tail). The duct tape began unraveling within 2 days, became torn and frayed, and deteriorated rapidly. The first transmitter detached in 10-14 days, whereas the other remained attached after three weeks. In 2001 Burton used the same technique on two males and two females (age 4-6 years; 28.6-41.0 cm SVL) in the same site. Transmitters detached after 3-13 days. Maximum signal range was not determined. No disturbances of behavior or threats to the health or safety of iguanas were observed during close monitoring throughout attachment. Iguanas were infrequently observed to bite the duct tape. Although the intent of iguanas did not appear to be consumption, accidental ingestion of small amounts of tape is possible.

C.R. Knapp used duct tape to secure transmitters to six adult *C. c. cychlura* on Andros Island, Bahamas (1.36-8.98 kg, 30.1-53.5 cm SVL) in 2002 (unpublished data). Transmitters were attached to the tail base in the manner as that used by Burton (above). Longevity of attachment ranged from 7-60 days. The primary cause of transmitter detachment was fraying of duct tape on the ventral side due to tail dragging on rugged limestone substrate. During the short time of attachment, iguanas did not exhibit any attention toward the tape or transmitter. Radio telemetry signals were detected up to 400 m away in open flat terrain but were reduced to 150 m in closed forest.

Attaching transmitters to iguanas with duct tape is a low-cost, low-risk method. However, similar to feeding transmitters to iguanas, this method allows only a limited duration of data collection. As with all other methods except ingestion, use of duct tape requires capturing and handling, which induces stress and may make iguanas more wary of humans. Permanent loss of costly transmitters might be more common when duct tape or other external attachments are used, as iguanas may lose transmitters in burrow or cavity retreats where they may be difficult to retrieve. With ingested transmitters this problem is less likely, because iguanas defecate outside of retreats.

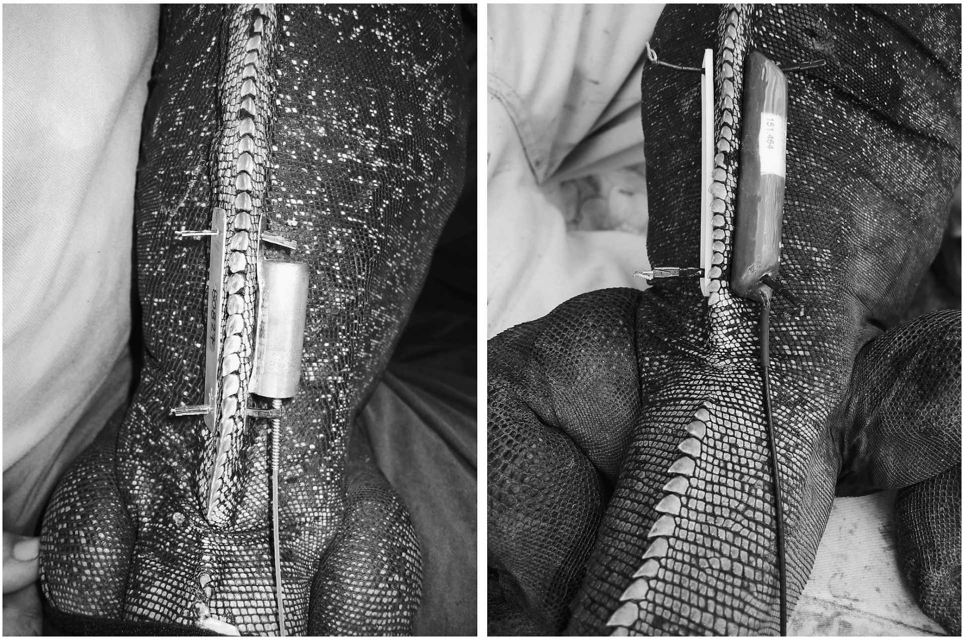
Suture of transmitters to dorsal crests

Suturing radio transmitters to animals has not been reported with lizards other than iguanas. The method has, however, been used with other vertebrates (snakes, Ciofi and Chelazzi, 1991; fish, Erkinaro et al., 1999). The first use of this method with iguanas was that of F.J. Burton in 1992 (unpublished data). Transmitters were sewn onto the dorsal crests of two adult *Cyclura lewisi* (one male and one female, >5 kg, ages unknown) that were subsequently tracked in the Salina Reserve on Grand Cayman. Transmitters were bonded to a 13×66 mm rectangular flat base containing a hole at each corner. These units were sutured just below the dorsal crest (posterior dorsum on one iguana, anterior dorsum on the other) by threading nylon-coated, stainless steel wires through each of the lower (more ventral) holes in the transmitter, and then through a hypodermic needle passing through the skin of the dorsal crest beneath the crest scales. After removal of the needle, each wire was looped over the dorsal crest between spines, and threaded through the upper (more dorsal) hole in the transmitter. The wire ends were pulled moderately tight and secured with leader sleeves (crimping tubes). This arrangement required only two wire sutures to pass through the crest flap.

In dense shrubland and forest, the average signal range was approximately 200 m. Signal range increased to at least 500 m through elevation of the antenna (e.g., by climbing a tree). The female iguana retained her transmitter for six months until nesting season, at which time it was apparently torn off either by a conspecific or during nest-digging. The male iguana retained his transmitter for a minimum of two months, after which the animal was lost. At the last sighting of this iguana, the transmitter was still firmly attached. There were no indications of injury or disturbance to behavior.

R.M. Goodman sutured radio transmitters to adult *C. lewisi* in Grand Cayman in 2002, using modifications of the previous method. Five male adults (36-49 cm SVL, 2.2-5.1 kg) were tracked in QEIIBP in Grand Cayman for 16-48 days. After resolving an initial problem (incomplete clamping down with pliers on the crimping beads; see details in Goodman, 2005), all transmitters remained attached for the time periods above. The maximum signal range was 350 m, which included tracts of densely vegetated forest, shrubland, and swamp. Neither the health nor the behavior of iguanas, which were located hourly, was substantially impacted by transmitters. One male was observed mating successfully within fifteen minutes of transmitter attachment. However, transmitters did catch on vegetation or rock surfaces in a few instances. In all cases, iguanas responded by pushing forward until the transmitter came free of the obstruction. No transmitter detachment or injury to iguanas resulted from these movements. However, these instances do demonstrate a potential risk in external mounting via suture, as this could result in an iguana becoming stuck in a retreat or tearing through the dorsal crest tissue to release the transmitter. This risk can be minimized by mounting transmitters on the posterior, narrower portion of the body and by packaging transmitters in a shape that minimizes snagging. In the above study, holes in the crest were small and healed cleanly after transmitter removal.

Knapp and Owens (2005b) sutured transmitters to adult *C. c. cychlura* on Andros Island in 2003. Two types of transmitters were used for ten males and eight females (36.1-55.0 cm SVL, 1.13-7.25 kg): Holohil model A1-F (fig. 1a) and Advanced Telemetry Systems (ATS) model F2050 (fig. 1b). The latter came with backing tabs that were made of PVC and curved to allow attachment of transmitters to smaller



(a) (b)

Figure 1. Radio transmitters attached to adult *Cyclura c. cychlura* by suturing through the dorsal crest and securing with a backing plate. (a) This model uses a metal backing plate and may catch easily on vegetation or retreats due to the sharp angle between the cylinder and flat base. (b) This model uses a PVC backing plate and has a shape less prone to catching. Photographs: Charles Knapp. (Color originals — see http://www.ahailey.f9.co.uk/appliedherpetology/cariherp.htm)

animals and a closer fit of the transmitter for iguanas of all sizes. The transmitters were sutured as described in Goodman (2005) with some modifications. No foam was used on the backing plate or tabs. Wires were secured with crimped leader sleeves on both sides of the transmitter. To prevent slipping, excess wire was allowed to protrude and was either heated so that the ends would melt and bulge, or the excess was tied in a knot and then heated to melt the plastic together.

For both models, maximum signal distances ranged from 600 m in open, flat terrain to 300 m in closed forest. Transmitters often detached partially after slipping at one of the two suture points, usually in the anterior. The anterior end may have experienced more pull pressure as animals entered narrow limestone retreats. The anterior tabs of the Holohil transmitters were pulled back in two instances, indicating that iguanas had caught transmitters against substrate or vegetation. Transmitters remained attached for 25-180 days (mean = 85.3, SD = 54.9 days), sometimes with only one suture point secured. In this case, transmitters were able to rotate around the remaining suture point and thus presumably experience less stress as animals entered small retreats. Transmitter attachment failed at the suture points either by having one of the crimping tubes slip (most commonly), or by being pulled through the dorsal crest (twice). On two occasions, previous loss of backing plates necessitated that transmitters be attached using only 4-mm glass beads as a backing medium instead of a plate. These transmitters remained attached for 63 and 48 days. Knapp suggests future use of disk-shaped transmitters with only one suture point, as this arrangement allows rotation around the suture point (as noted in the above study) and therefore may minimize premature detachment.

Holes in the dorsal crest from sutures healed within days of transmitter removal. All adult iguanas were monitored 3-4 times per week for up to five months, during which no disturbance to health or behavior was noticed. Adult females successfully excavated nests with externally attached transmitters.

Externally suturing transmitters to iguanas appears to be a reliable method for attachment. Choosing a transmitter shape that minimizes snagging is important. It appears that minimal risk to health and safety of iguanas is posed by transmitters occasionally catching on vegetation and retreats. To keep transmitters attached securely, crimping tubes need to be firmly clamped, and protruding excess wire should be heated to create bulges that help secure crimping tubes. Longevity of attachment for suturing is lower than for implantation, but greater than for ingestion or gluing or taping of transmitters to iguanas. Behavioral effects of suturing transmitters to iguanas appear minimal, as evidenced by successful mating and nesting of transmittered individuals. Another advantage of suturing is that transmitters can be attached by researchers in situ and without anesthesia.

Transmitter collars, belts and harnesses

Only one researcher to date has used waist belts to attach radio transmitters in adult *Cyclura*. From 1988 to 1990, Mitchell (1999) used converted dog collars holding transmitters to track nine adult *C. pinguis* on Anegada Island (2 females: 43-48 cm SVL, 2.16-2.72 kg; 7 males: 43-56 cm SVL, 3.86-5.67 kg). After trials of collars with free antennas proved problematic, antennae were wrapped and sewn to the inside of the collars. Mitchell used neck collars to attach transmitters to *C. c. carinata* in the Turks and Caicos from 1999-2000 (Mitchell, pers. comm.). Custom collars were approximately 1 cm wide and 1 cm in depth where the transmitter sat. The antenna was a brass loop about 3 mm wide and 1 mm high that encircled the collar and closed with a screw attachment. Collars were tightened so that they neither interfered with eating nor slipped off the head. Iguanas showed no injury or abrasion resulting from collars when they were removed after three months. However, some individuals lost weight during this period; this may have been due to radio collars or other circumstances. Data on longevity of attachment for waist belts and collars were unavailable.

Pérez-Buitrago (Pérez-Buitrago and Sabat, 2007; Pérez-Buitrago et al., 2007; pers. comm.) used collars on adult and hatchling *C. cornuta stejnegeri* on Mona Island, Puerto Rico. Hatchlings (mean SVL = 11.45 cm, SD = 0.39 cm, mean mass = 78 g, SD = 3 g) were fitted with radio collars from 1998 to 2000, and over 32 adults were fitted with collars from 2003 to 2004 (fig. 2). Both models had

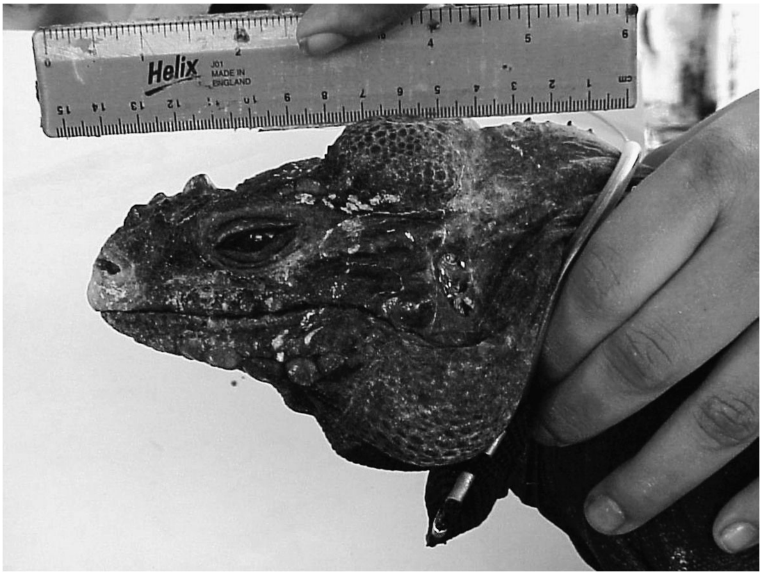


Figure 2. A radio-collar secures a transmitter to an adult *Cyclura cornuta stejnegeri.* Photograph: Nestor Pérez-Buitrago. (Color original — see http://www.ahailey.f9.co.uk/appliedherpetology/cariherp.htm)

a breakaway mechanism. Collars on adults were modified by wrapping transmitter units with cloth to secure them more tightly. Collars remained on hatchlings from 6 days to over 3 months, when all but one were removed. Collars on adults remained attached for two weeks to 15 months.

The signal range for both types of collars was 100-600 m depending on the habitat and thickness of vegetation. Pérez-Buitrago did not observe any obvious disturbance to the behavior or decline in health of iguanas during radio tracking. No physical irritation in the neck region was observed for any iguanas. Only one collared iguana died during the study, and this appeared unrelated to the radio collar. One hatchling wore a collar for seven months before recapture, and showed no signs of injury or reduced growth. However, keeping collars on juveniles for long periods is not recommended because of the possibility that collars will become dangerously tight before pressure is sufficient to break the collar. Because some iguanas may not be recaptured at the end of a study or they may emigrate from the study area, it is essential that collars or belts have breakaway mechanisms to prevent injury or death.

Several types of backpacks and harnesses have been used to secure radio transmitters to lizards (Burrow et al., 2001; Fisher and Muth, 1995; Grant and Alberts, 2001; Guarino, 2002; Reaney and Whiting, 2003; Richmond, 1998; Traeholt, 1995; Ussher, 1999). Lewis (2002) used pectoral harnesses to carry epoxy-coated transmitters on head-started adult *C. collei* released in the Hellshire Hills of Jamaica in 2001. Each transmitter fit into a harness pocket and rested to one side of the dorsal

(a) (b)

Figure 3. Pectoral vests secure radio transmitters to adult rock iguanas. (a) A successful model of vest used on *Cyclura collei* was made of stretch Cordura and produced by the Nike Corporation. Photograph: Rick Hudson. (b) A simpler and less successful model was used on *Cyclura c. cychlura*. Photograph: Charles Knapp. (Color originals — see http://www.ahailey.f9.co.uk/appliedherpetology/cariherp.htm)

crest (fig. 3a). The pectoral harnesses were supplied by the Nike Corporation's All Condition Gear Footwear Design Department and made of a stretch Cordura material that was both durable and elastic. Harnesses were secured to the animals by an elastic string passing through the anterior harness edge and encircling the chest. Lewis noted (pers. comm.) that over-tightening of the strings must be avoided as this caused temporary injury to one iguana.

The harnesses used to hold the transmitters worked well, but were not without difficulties. Harnesses often fell off of animals in a few days if the elastic strings were either not tied, or were not tied sufficiently tight. Iguanas were radio tracked an average of 5.6 times per month for six months. If a transmitter or harness became damaged, the animal was captured, re-fitted, and released. Harnesses were difficult to remove from the animals and at times had to be destroyed to facilitate removal. Because these harnesses do not break away, they should only be used if both special care is taken when securing them, and iguanas are monitored routinely until harness removal. If iguanas emigrate from the study area and cannot be located by the researcher, harnesses may remain attached indefinitely and pose risks to safety. These concerns are critical for juvenile iguanas that experience rapid growth and might become injured or suffocated by unremoved harnesses. Even properly fitting vests that encircle the chest with fabric may affect behavior, particularly thermoregulation.

C.R. Knapp had less success using pectoral harnesses on ten male and four female adult *C. c. cychlura* (361-550 mm SVL, 1.13-7.25 kg) on Andros Island in 2002 (unpublished data). Harnesses were modified from descriptions in Ussher (1999). Transmitters were sewn into a square pouch made from cross-stitched material. Then two one-centimeter slits were cut on the anterior and posterior sides of the pouch. Polyester straps (1 cm wide) were inserted through the anterior slits and crisscrossed at the chest. Straps were then next inserted through the posterior slits, tightened, and tied into a knot (fig. 3b). Straps were tightened as much as possible without causing irritation to the animal. Signal distances ranged from 150 m in closed, forest conditions to 400 m in open, flat terrain. Harnesses detached quickly, within 30 seconds to 7 days, due to the flexible strap catching on substrate or vegetation. No impacts on the behavior of iguanas were noted.

Pectoral harnesses are a promising technique for external attachment of transmitters. However, different methods of harness construction vary widely in longevity of attachment and need to be tested prior to field use. Data are needed to assess the effects of pectoral vest attachment on behavior and health of iguanas before widespread use can be recommended.

Knapp and Owens (2005a) used an alternative technique of harnessing transmitters to hatchling *C. c. cychlura* (31-57 g, 8.4-10.6 cm SVL) on Andros Island in 2003-2004. Transmitters with whip antennas were attached using a simple pelvic harness of monofilament line that encircled the body just anterior and posterior to the hindlimb insertion points. The maximum signal distance of 1200 m in open, flat terrain was reduced to 200 m in closed, forest conditions. The pelvic harnesses appeared to have no obvious effect on behavior or movement, as all hatchlings ran, jumped, swam, and climbed trees without apparent difficulty. There was a tendency for the posterior monofilament line to snag on surfaces. Therefore, ten of 41 transmitters in 2003 and all 36 transmitters in 2004 were attached using only the anterior loop of line, which was secured more loosely. This method allowed transmitters to move, rotate, and even flip over, reducing drag pressure and preventing abrasions to the inguinal region. Knapp and Owens suggested encasing the monofilament line in small diameter Tygon tubing to prevent the harness from injuring the inguinal region.

Pelvic harnesses used by Knapp and Owens were easy to construct in the field and remained attached up to eight weeks. Utility of this method in adults and for longer periods of time should be investigated. However, this technique is only recommended if lizards can be reliably recaptured for removal of harnesses. It should be noted that these authors did not compare rates of predation on hatchlings with and without transmitters. Indeed, such a study would be difficult to execute. Particularly for hatchlings, any decrease in locomotion capacities could entail a critical reduction in survivorship (Miles, 2004).

Adhesive-mounted transmitters

Various methods have been used to mount transmitters externally on lizards using adhesives (Cuadrado, 1998; Green et al., 1991; Griffiths and Christian, 1996; Sabo, 2003). Goodman (2005) used cyanoacrylate gel for transmitter attachment with *C. lewisi* in QEIIBP on Grand Cayman in 2002. Transmitters were encased in liquid plastic to create smooth units that were attached to the posterior dorsum along the side of the crest. Transmitters were repeatedly attached to seven females and one male (27-38 cm SVL, 0.9-2.7 kg). Of 17 transmitter attachments, eight fell off within two weeks, four were removed within one month for use on other iguanas, and four were removed after 30 days. One transmitter remained attached for 45 days. No severe adverse effects of gluing transmitters to iguanas were noted during hourly tracking, although skin sometimes showed a darker patch through the next shedding where the transmitter had been attached. Transmitter signals were detectable up to at least 200 m, although the maximum range was not tested.

B. Thornton and W.B. Hayes attached transmitters with silicone cement to 18 adult female *C. rileyi nuchalis* (16.8-23.8 cm SVL, 0.19-0.47 kg) on several cays in the Bahamas (Thornton, 2000). Transmitters were affixed to the right dorsal surface of the pelvic girdle, just superior to the hind limb; the wire antenna trailed along the tail. To assure proper curing of the cement (which produced negligible heat), iguanas were kept in captivity for 3 hrs or overnight. S. Fry and Hayes also used silicone cement to attach transmitters to *C. rileyi cristata* in the Bahamas (Fry, 2001). Transmitters were glued to the posterior hip of five adult males (21.8-27.0 cm SVL, 0.49-0.72 kg) and five subadult females (15.5-18.4 cm SVL, 0.15-0.24 g). Each iguana was held for one hour minimum while the cement cured and then kept in a cloth bag overnight before being released at the capture site. Maximum signal ranges were not calculated in these two studies. For both, transmitters typically fell off iguanas in less than one month (Hayes, pers. comm.). Many transmitters detached with ecdysis. Some were removed at the end of the study by prying off the transmitter and peeling off the silicone.

Animals did not appear to be disturbed or injured by adhesion of transmitters. Gravid females, captured and fitted with external transmitters 1-24 days before oviposition, all nested successfully. Iguanas were monitored daily for up to six weeks following transmitter attachment and sporadically thereafter. If silicone was not removed entirely, skin showed irritation and did not shed properly. This suggests a need for long-term study of the effects of transmitter attachment with silicone (Hayes, pers. comm.).

J.B. Iverson used both silicone and duct tape to attach transmitters to *C. cychlura inornata* on Leaf Cay in the Allen Cays, Bahamas in 2002 (unpublished data). Transmitters were placed on 15 adult females (approx. 25-35 cm SVL, 0.75-2.00 kg) by applying a ball of clear silicone bathtub sealer (1.5 cm diameter) to the crest at the tail base and imbedding the transmitter in the silicone. Duct tape wrapped around the transmitter and tail added further security of attachment and allowed release of iguanas before the silicone had entirely set. Maximum signal range was not tested, but reached at least 150 m in dense vegetation. One month after attachment, seven of 15 transmitters remained attached. Several of the eight transmitters that detached had been dragged into crab burrows, where crabs had chewed on the wax coating. Transmitters that remained on females at the end of the study were removed by gently peeling off the tape and silicone. Females did not show any adverse reactions to attachment.

Gluing transmitters to iguanas is a very low cost, low risk attachment method useful for short-term data collection (typically one to four weeks). Like other external attachment methods, transmitters that detach can readily be reattached or used on different animals. Animals need to be captured for transmitter attachment. While this imposes stress, handling time can be minimized by using fast drying adhesives or duct tape during the setting of adhesives. Future studies utilizing adhesives to attach transmitters should investigate potential skin irritation and possible impediments to shedding.

Conclusions

Tradeoffs are involved in each of the transmitter attachment methods described. Signal range did not differ dramatically between most methods, but did differ across habitats and among transmitter models, especially in relation to free antenna length. Weaker signal strength was documented for transmitters with coiled antennas regardless of the attachment method. Because of the need for coiled antennas, feeding transmitters to iguanas is the only method necessitating a limited signal range. For all other attachment methods, free whip antennas should be used. An additional consideration is the trade-off between signal strength and battery life. Different researchers using the same model of transmitter may have signal strengths set differently, and thus experience large differences in signal range and battery life.

Longevity of transmitter attachment varied greatly among methods. Ingested transmitters resulted in the shortest period of data collection (less than one week). External attachment using duct tape and adhesives secured transmitters for slightly longer periods, typically one week to one month. Other external methods including collars, belts, vests, and suturing resulted in highly variable lengths of data collection periods (from one to several months, even within a single method). Implantation of transmitters allowed the longest period of data collection and was limited only by the transmitter battery life.

Based on longevity and range, implantation of transmitters appears to be the most successful method for securing transmitters. Additionally, this method benefits from a lack of external apparatus that may affect the behavior of animals, particularly when moving through dense vegetation. However, implantation requires surgery that is invasive, costly, and poses potential health risks. Also, some researchers may only want to collect data for a few weeks or a few months, in which case external attachment methods would be more cost effective.

We can only speculate on the potential costs of different methods in terms of disturbance to behavior and threats to the health and survival of animals. In most cases, researchers noticed no obvious responses of iguanas to transmitters. In several studies, iguanas successfully mated, nested, and moved about with transmitters attached by various means. However, particularly with respect to behavior, there has been little quantitative investigation of the effects of transmitter attachment or implantation. Therefore, studies should be conducted to compare foraging, courtship, and locomotion in iguanas with and without transmitters. Particularly in the case of smaller iguanas, or iguanas in predator-rich environments, researchers should determine whether different methods of transmitter attachment affect vulnerability to predation. Little is known of the biology of hatchling *Cyclura*. Therefore, the cost of any method of radio transmitter attachment must be weighed against the potential benefits of gaining information critical to conservation and management of species in this genus.

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