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Hunter 2007, Long et al. 2010).

ABSTRACT

Radiotelemetry provides fine-scale temporal and spatial information about an individual's movements and habitat use; however, its use for monitoring amphibians has been restricted by transmitter mass and lack of suitable attachment techniques. We describe a novel waistband for attaching external radiotransmitters to anurans and evaluate the percentages of resulting abrasions, lacerations, and shed transmitters. We used radiotelemetry to monitor movements and habitat use of wood frogs (*Lithobates sylvaticus*) in 2006 and 2011–2013 in Maine, USA; American toads (*Anaxyrus americanus*) in 2012 in North Carolina, USA; and, wood frogs, southern leopard frogs (*L. sphenocephalus*), and green frogs (*L. clamitans*)in 2012 in South Carolina, USA. We monitored 172 anurans for 1–365 days (56.4 ± 59.4) in a single year and 1–691 days (60.5 ± 94.1) across years. Our waistband resulted in an injury percentage comparable to 7 alternative anuran waistband attachment techniques; however, 12.5% fewer anurans shed their waistband when attached with our technique. Waistband retention facilitates longer monitoring periods and, thus, provides a greater quantity of data per radiotagged individual.

KEYWORDS: amphibian, belt, frog, tag, telemetry, toad, tracking.

Radiotelemetry provides fine-scale temporal and spatial information about an animal's movements and habitat use; however, this may be with costs (e.g., behavior, health) to the animal (Richards et al. 1994, Madison et al. 2010). Improvements in radiotransmitter technology and attachment techniques enable longer tracking periods with presumably reduced influence on behavior, improving the quality and quantity of data gathered per radiotagged individual. Preferred transmitter attachment techniques 1) minimize physical, physiological, and behavioral effects; 2) are lightweight; 3) are quick and easy to implement; and 4) incorporate a failure mechanism that degrades with time or breaks with resistance (Bartelt and Peterson 2000). Transmitter mass and the lack of suitable attachment techniques have restricted the use of radiotelemetry for anurans (Richards et al. 1994, Rathbun and Murphey 1996, Muths 2003).

Internally implanted (e.g., gastrically, surgically) and externally attached transmitters (e.g., armbands, waistbands) have injury and study design trade-offs when used on anurans (Bartelt and Peterson 2000, Bull 2000, Muths 2003, McAllister et al. 2004). Internally implanted transmitters eliminate external abrasion (Long et al. 2010), but the necessary surgeries are invasive procedures with their own set of risks, and long-term studies require repeated surgeries to replace transmitters. Surgery requires anesthesia, incisions into the ceolomic cavity, and relatively long handling and recovery times. And, at least for caudates, the efficacy of surgical sutures in amphibians may be reduced with repeated surgeries; sutures are more prone to failing when placed in scar tissue (K. Hoffmann, University of Maine, personal communication). Surgery is not required for external transmitters, which are quickly attached with arm and waistbands constructed of various materials (see Bull 2000, Goldberg et al. 2002); however, anurans have thin skin, which can be easily injured (e.g., abrasion), and occupy habitats with potential snags (e.g., vegetation, downed woody debris) that may entangle waistbands and antennae. Although internal transmitters reduce entanglement risks, they are outfitted with helical antennae that have shorter detection distances than those of external transmitters outfitted with whip antennae (Madison 1997, Bartelt and Peterson 2000, Faccio 2003). Shorter detection distances may prevent researchers from relocating animals and, thus, these animals may never be relieved of their transmitters. Internal and external transmitters that exceed 5–10% of an anuran's mass may affect its health, physiology, and behavior (Richards et al. 1994, Goldberg et al. 2002, Blomquist and Hunter 2007, Long et al. 2010). For example, excessively heavy transmitters may promote abrasion, increase an individual's energy expenditure, and restrict foraging ability. Although more expensive and shorter lived, light-weight transmitters may lessen these effects (Madison et al. 2010).

We used radiotransmitters to monitor 4 anuran species in different landscapes in the eastern United States: wood frog (*Lithobates sylvaticus*) in Maine (2006, 2011–2013); American toad (*Anaxyrus americanus*) in North Carolina (2012); and wood frog, southern leopard frog (*L. sphenocephalus*), and green frog (*L. clamitans*) in South Carolina (2012). We describe the waistband and variations used to attach radiotransmitters externally to these species. To evaluate the effectiveness of our waistband, we compared our injury and shed waistband percentages with those previously reported for alternative anuran waistband attachment techniques.

STUDY AREA

The southern Maine study was conducted in 4 wetland complexes in relatively populated areas of York and Cumberland counties (Baldwin et al. 2006). Three complexes were composed of mid-successional oak (*Quercus spp*.) and pine species (*Pinus spp*.). The fourth was dominated by mature eastern hemlock (*Tsuga canadensis*), yellow birch (*Betula alleghaniensis*), and red oak (*Q. rubra*). The northern Maine study was conducted in the 17,800-ha Nahmakanta Public Reserved Land, located within the Quebec–New England Boundary Mountains ecoregion in Piscataquis County. The study area was largely coniferous, with stands of spruce species (*Picea spp*.), balsam fir (*Abies balsamea*), and northern white–cedar (*Thuja occidentalis*) mixed with red maple (*Acer rubrum*), aspen (*Populus spp*.), and birch species (*Betula spp*.). The North Carolina study was conducted in the 5,841-ha Green River Game Land, a mixed-use recreation area located within the southern Appalachian Mountains in Polk County (Pitt et al. 2013). The study area primarily consisted of oak–hickory (*Carya spp*.) forest, with understory shrubs including mountain laurel (*Kalmia latifolia*), rhododendron (*Rhododendron maximum*), and blueberry (*Vaccinium spp*.). The South Carolina study was conducted in the 7,082-ha mixed-use Clemson Experimental Forest, located within the Piedmont ecoregion in Pickens County. The area was dominated by oak species, yellow poplar (*Liriodendron tulipifera*), sweet gum (*Liquidambar styraciflua*), and red maple.

MATERIALS AND METHODS

We monitored 4 anuran species with radiotelemetry during 16 April 2003–05 May 2013 and complied with guidelines established by the University of Maine and Clemson University's Institutional Animal Care and Use Committees (Table 1; Protocol nos.: A2009–04–08, A2012–03–06, AUP2011–035, and AUP2011-061). We relocated radio-tagged individuals 1–7 times/week and replaced transmitters prior to battery failure. At a minimum, we inspected each individual when replacing transmitters and recorded the absence or presence of injury (no visible injury, skin discoloration, abrasion, laceration). We defined "abrasion" as the wearing or rubbing away of the epidermis by friction, and "laceration" as the tearing of epithelial tissue. We did not consider skin discoloration an injury. Unless we observed evidence of predation (e.g., bite marks), we assumed all recovered transmitters resulted from shed waistbands.

We attached transmitters to anurans with waistbands made from 1 mm-diameter stretch bead cord (Stretch Magic, Pepperell Braiding Company, Pepperell, MA). We threaded the cord through the transmitter attachment hole, tied a square knot to produce the desired waistband diameter, and closely trimmed the cord ends. Next, we restrained the anuran's rear legs inside a wetted piece of rubber tubing, stretched the waistband over the tubing, and positioned it around the anuran's pelvic girdle. A well-fitted waistband provided a 0.25–0.5 cm gap between the sacral hump and waistband when the transmitter was pulled away from the anuran's body (Fig. 1).

We first used this transmitter attachment technique in southern Maine (Baldwin et al. 2006), and incorporated modifications in the 3 subsequent studies (Table 1). In northern Maine we used smaller transmitters and a smaller diameter stretch bead cord. We secured the square knot with Krazy Glue (Krazy Glue, Columbus, OH) and encapsulated it in 1 cm of 1.1906 mm-diameter heat-shrink tubing, threaded on the cord prior to knotting. We slid the tubing over the knot, heated it with a lighter until it tightly encased the knot, and occasionally used tweezers warmed with a lighter to compress the tube ends around the cord. The heat-shrink tubing helped to further secure the knot, as well as protect the anurans from the abrasive glue and trimmed cord ends (Fig. 1). Also, we restrained each anuran with our left hand, rather than wetted rubber tubing, and used our right hand to slip the waistband over the individual's extended rear legs and into position. A well-fitted waistband slid snuggly over the thickest portion of the anuran's legs. We employed the heat-shrink tubing modification during initial transmitter attachment events in North and South Carolina; however, we quickly abandoned its use because it became rigid and caused abrasion. Alternatively, we left approximately 2.5 cm lengths of cord on both sides of the unglued knot to avoid abrasive points near the anuran's body (Fig. 1).

We calculated abrasion, laceration, and shed waistband percentages across our 4 studies to compare with those previously reported for alternative anuran waistband attachment techniques (Table 2). We also calculated transmitter/ body mass ratios for each study because increased transmitter weight, relative to body size, may promote waistband-related injuries (Tables 1, 3). Alternative technique papers were identified by performing a literature search using Web of Science and Google Scholar, and by reviewing the references cited in anuran radiotelemetry studies. We included only those technique papers that reported injury or shed waistband data, and we tabulated how each study reported injuries (Table 3). We combined our abrasion and laceration results into a single "injury" category and compared our overall occurrence of injury with that of the alternative waistband studies. All injury and shed waistband percentages were standardized by the number of anurans monitored during the respective study. Therefore, the percentages we report do not correspond with those reported by McAllister et al. (2004), who based their percentages on the number of transmitters attached, rather than the number of frogs monitored. Additionally, Burow et al. (2012) reported a shed waistband percentage (approx. 50%) that incorporated only 2009–2010 data, whereas we incorporated 2009–2011 data.

RESULTS

We monitored 172 anurans of 4 species for 1–365 days (56.4 ± 59.4) in a single year and 1–691 days (60.5 ± 94.1) across years, and outfitted each with 1–9 transmitters. Forty-three (25.0%) radiotagged anurans shed their waistbands, 128 (74.4%) were uninjured, 23 (13.4%) were abraded, and 21 (12.2%) were lacerated (Table 2). In northern Maine, we found one frog with its antennae entangled in woody debris, and we attributed its death to desiccation. We documented the smallest abrasion and laceration percentages in northern Maine in 2011, which corresponded with use of the lightest transmitter and smallest transmitter/body mass ratio. In North and South Carolina, we noted reduced incidents of abrasion and laceration after discontinuing the use of heat-shrink tubing and leaving cord ends untrimmed. Nearly all abrasions and lacerations observed in Maine occurred dorsally, aside the sacral hump, whereas those observed in North and South Carolina occurred ventrally. Generally, abrasions and lacerations developed asynchronously rather than during distinct periods (e.g., early spring, first transmitter attachment event).

We identified 7 alternative anuran waistband technique publications that reported injury or shed waistband data for 280 anurans monitored for 11.5–104 days and outfitted with 1–5 transmitters (Rathbun and Murphey 1996, Bartelt and Peterson 2000, Bull 2000, Goldberg et al. 2002, Muths 2003, McAllister et al. 2004, Burow et al. 2012). All but 3 publications reported mean monitoring periods <60 days. The alternative techniques employed different waistband designs and materials (Table 3). These waistbands were attached to 8 anuran species in the midwestern and western United States and represented ≤8.6% of the average anuran mass; however, not all studies reported transmitter/body mass ratios. Across the 7 studies, 20.3% (48/237) of radiotagged anurans were injured and 37.5% (105/280) shed their waistbands. Injuries, however, were reported differently in each study (Table 3). Three studies reported skin sores, 2 reported abrasions, and 1 reported lacerations. We observed 5.3% more injuries and 12.5% fewer shed waistbands than were observed during the alternative waistband studies.

DISCUSSION

The waistband we developed to externally attach radio-transmitters to anurans is functionally similar to previously described techniques, however, our technique differs in important ways. Our waistband is constructed from few, lightweight materials, has minimal potential abrasion points, is relatively quick and easy to attach, and can be used on different species and in different environments. Unlike waistbands constructed from aluminum beaded chains and glass seed beads, ours do not have potential pinch points that could promote or exacerbate injuries. Also, our waistband does not incorporate metal materials, which may corrode after 2 months and facilitate waistband shedding (Bartelt and Peterson 2000). Finally, the surface of our waistband is smooth and does not have edges or texture (e.g., ribbon, thread). Our technique would be improved with the incorporation of a failure mechanism that releases individuals with time or resistance (Bartelt and Peterson 2000). For example, cotton thread, which degrades with time, could be used to join the cord ends, provided the thread does not come in contact with the animal. Thread type and weight should be evaluated because abrasion, laceration, and transmitter loss potential may vary with different threads.

Our waistband is effective for attaching radiotransmitters to anurans because it resulted in smaller shed waistband percentages than previously reported for alternative waistbands. We attribute our slightly greater injury percentage to our longer monitoring periods and the greater number of transmitters we attached to individuals. To our knowledge, the northern Maine study was the first to monitor radiotagged anurans outfitted with external transmitters across multiple breeding seasons (Madison et al. 2010). Although we documented relatively few abrasions and lacerations in southern Maine, Long et al. (2010) reported that 33 of 84 radiotagged wood frogs and boreal toads (*Anaxyrus boreas boreas*) were injured using the same waistband design as was used in southern Maine (Baldwin et al. 2006). Waistband-related injuries potentially can be reduced by incorporating heat-shrink tubing or by leaving cord ends untrimmed; however, heat-shrink tubing may not be appropriate for all anurans and climates. For example, prolonged, high temperatures may cause the tubing to become brittle, which may facilitate injury or waistband shedding. Although not observed during our studies, deterioration of stretch bead cord in eastern Missouri, USA, resulted in 9 broken waistbands (Rittenhouse et al. 2009). None of 42 (Rittenhouse and Semlitsch 2007) and 1 of 117 (Rittenhouse et al. 2009) wood frogs monitored in eastern Missouri shed their waistbands, which were the same as the waistbands used in southern Maine (Baldwin et al. 2006). Trade-offs between transmitter retention and injury may exist, with better retention providing more movement and habitat-use data per individual.

Minimizing injury is an important consideration for Animal Care and Use Committees. For this reason, we emphasize that more than half of the 44 anurans injured during our studies received only abrasions. No matter the technique used, the welfare of anurans outfitted with external radiotransmitters can be improved. First, injury and energetic costs may be reduced with lighter transmitters. It is generally recommended that an anuran carry <5–10% of its body mass (Richards et al. 1994, Goldberg et al. 2002, Long et al. 2010); however, we know of no systematic study to evaluate the effects of transmitter/body mass ratios on anuran injury or fitness. Second, properly fitting waistbands may reduce injury and entanglement risks, thereby facilitating extended monitoring periods. Third, frequent, visual transmitter inspections (performed in a manner that minimizes animal behavioral effects) allow for the assessment and correction of waistband fit, which may be affected by seasonal changes in anuran weight. Larger anurans, such as those monitored in North and South Carolina, can carry heavier, longer lived transmitters for longer periods, allowing for waistband constriction and injury attributed to extended periods of growth if waistband fit is not regularly evaluated and adjusted. Finally, transmitter attachment techniques that consider climate (e.g., high temperatures), habitat features (e.g., potential snags), and species' life histories (e.g., movement propensity) may reduce entanglement and injury risks.

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FIGURES

Table 1. Species, sex, and average mass and standard deviation (SD) of 172 anurans monitored during 4 telemetry studies conducted during 2003–2013 in the United States. Because we used 10 variants of 2 transmitter (Trans.) models in North and South Carolina, we provide the minimum and maximum battery (Batt.) life and transmitter mass values. Waistband modification indicates a major departure from the technique first used in the southern Maine study.

Location	Species	N (F/M)	$\bar{x}$ mass (g)	SD of $\bar{x}$mass	Trans. model	Batt. life	Trans. mass (g)[a]	% body mass	Cord	Modification
Southern ME	Wood frog	43[b] (16/25)	8.1	3.3	HolohilBD-2A[c]	21 days	0.6	≤8.6	1 mm, clear	
Northern ME	Wood frog	71[d] (42/29)	10.7	3.1	ATS R1614,R1625[e]	45, 67 days	0.3,0.5	≤5.1	0.7 mm, clear	Heat-shrink tubing
NC	American toad	26 (12/14)	44.5	18	Holohil BD-2,PD-2	9 weeks–3 months	1.4–2.5	≤7.4	1 mm, black	Untrimmed cord ends[f]
SC	Green frog	6 (3/3)	24.1	4.1	Holohil BD-2, PD-2	28 days–3 months	0.8–2.5	≤9.3	1 mm, black	Untrimmed cord ends[f]
SC	S. leopard frog	11 (7/4)	38.2	16	Holohil BD-2, PD-2	56 days–6 months	1.2–3.8	≤8.6	1 mm, black	Untrimmed cord ends[f]
SC	Wood frog	15 (8/7)	24.7	9.9	Holohil BD-2	21 days–14 weeks	0.6–1.8	≤7.5	1 mm, black	Untrimmed cord ends[f]

[a] Transmitter mass is the mass of the transmitter alone and does not include waistband mass.
[b] Two subadults were unable to be sexed.
[c] Holohil Systems Ltd., Carp, ON, Canada.
[d] Thirty-one frogs monitored in 2011, 29 in 2012, and 11 in both yr.
[e] Advanced Telemetry Systems, Isanti, MN, USA.
[f] Heat-shrink tubing initially used, but abandoned. No glue was applied to the knots.

Figure 1. Adult wood frog outfitted with a waistband-mounted radiotransmitter used to monitor movements and habitat use during 2011–2013 in northern Maine, USA. Lower left insert: knotted cord with trimmed ends encased in heat-shrink tubing. Upper right insert: knotted cord with untrimmed ends.

Table 2. Shed waistband and injury counts (unparenthesized) and percentages (parenthesized) for 172 anurans monitored during 4 anuran telemetry studies conducted in the United States during 2003–2013. The range, average, and standard deviation (SD) of days monitored are provided for each species and study.

Location	Year	Species	Days monitored	$\bar{x}$ days	SD of $\bar{x}$ days	Shed waistband	No injury	Discolor.	Abrasion	Laceration	Total injury[a]
Southern ME	2003	Wood frog	1–83	25.6	20.0	9 (20.9)	11 (25.6)	14 (32.6)	6 (14.0)	1 (2.3)	7 (16.3)
Northern ME	2011	Wood frog	1–159[b]	47.3	37.7	6 (14.3)	24 (57.1)	3 (7.1)	7 (16.7)	–[c]	7 (16.7)
Northern ME	2012	Wood frog	1–172[b]	47.1	46.5	14 (35.0)	15 (37.5)	3 (7.5)	8 (20.0)	1 (2.5)	9 (22.5)
NC	2012	American toad	4–124	50.8	41.3	10 (38.5)	18 (69.2)	–	1 (3.8)	7 (26.9)	8 (30.8)
SC	2012	Green frog	11–84	51.2	25.0	1 (16.7)	3 (50.0)	–	–	3 (50.0)	3 (50.0)
SC	2012	S. leopard frog	1–108	52.4	29.9	1 (9.1)	7 (63.6)	–	–	4 (36.4)	4 (36.4)
SC	2012	Wood frog	4–141	48.4	37.9	2 (13.3)	9 (60.0)	–	1 (6.7)	5 (33.3)	6 (40.0)

[a] Total injury includes both abrasions and lacerations.
[b] Eleven individuals were monitored in multiple years for 234–691 days (355.5 ± 110.7).
[c] Dash (–) indicates deficient data.

Table 3. Waistband injury counts (unparenthesized) and percentages (parenthesized) for 248 anurans monitored during 7 anuran telemetry studies conducted in the United States during 1992–2011. All studies used Holohil transmitters (Holohil Systems Ltd., Carp, ON, Canada; Trans.). Injury and shed waistband metrics are standardized by the number of anurans monitored during the respective study.

Study	Species	$\bar{x}$mass (g)	Location, years	Trans.model, mass (g)	% body mass (g)	Waistband materials	Reported injuries	Injury (%)	Shed waistbands (%)
Bartelt and Peterson (2000)	Western toad	48.5	ID, 1993–1995	BD-2GT, 1.85	4.2	Polyethylene tubing, flyline eyelet	Sores: mild excoriations to open wounds	7/38 (18.4)	16/38 (42.1)[a]
Bull (2000)	Columbia spotted frog	–[b]	OR, 1998	BD-2, 1.85	2–8	Satin ribbon, carpet thread, glue	Abrasions: subcutaneous (slight) or muscular (deep)	17/51 (33.3)[c]	13/51 (25.5)[d]
Burow et al. (2012)	N. leopard frog, Am. toad	38.3, 34.6e	IA, 2009–2011	BD-2, 1.85	4.7, 5.2[e]	PVC tubing, copper wire	Abrasions: mild to serious	10/34 (29.4)[f]	23/66 (34.8)[g]
Goldberg et al. (2002)	Barking frog	25–45	AZ, 1996–2000	BD-2T, 2G, 1.2–1.55	<5	Aluminum beaded chain; silicon tubing	Sores: bleeding and deep ulcerations	4/5 (80.0)	1/5 (20.0)
McAllister et al. (2004)	OR spotted frog	–	WA, 1997–1999	BD-2, 2G, 1.0–1.8	–	Nylon ribbon, cotton thread	Lacerations	4/62 (6.5)	32/62 (51.6)
Muths (2003)	Wood frog	11.6	–, 2002	BD-2A, 0.61	<8.6	Glass seed beads, craft elastic	–	–[h]	6/11 (54.6)
Rathbun and Murphey (1996)	CA red-legged frog	–	CA, 1992–1995	BD-2G, 1.8	–	Aluminum beaded chain	Sores: small (1–2 mm diam.)	6/47 (12.8)	14/47 (29.8)[i]

[a] Includes 9 waistbands shed within 2 weeks and 7 shed near the end of the season.
[b] Dash (–) indicates deficient data.
[c] Includes 50% of 21 frogs successfully tracked in Apr–May ($N = 11$) and 37% of 17 frogs successfully tracked in Aug–Sep ($N = 6$).
[d] Includes 11 frogs transmitted in Apr–May and 2 frogs transmitted in Aug–Sep.
[e] Northern leopard frog and American toad, respectively.
[f] Injury counts and percentages based on 2009–2010 data; injuries incurred in 2011 were not reported.
[g] Shed waistband percentages based on 2009–2011 data; 9 frogs (2011) excluded because no fates reported (still being tracked).
[h] On account of deficient data, we did not include this study in the overall injury percentage calculation.
[i] Includes 4 waistbands shed early in study and 10 frogs later identified by Passive Integrated Transponder tags.

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