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Shedding excess: small tape patches as a lower-impact transmitter attachment method for snakes

Tyler C. Christensen[1,*] and Jason A. Fantuzzi[2]

Radiotelemetry revolutionised wildlife research in the past half century by making it possible to reliably track individual animals through space and time (Kenward, 2000). For snakes, which are usually cryptic and difficult to detect, radiotelemetry data have been the basis for many conservation-pertinent discoveries related to their ecology and behaviour (e.g., mortality, inter and intraspecific interactions, home range, habitat selection, and responses to disturbance; Ujvari and Korsos, 2000; Carfagno and Weatherhead, 2008; Wolfe et al., 2018). For radiotelemetry to be effective, animals must carry a transmitter throughout a period of interest without detrimental effects on behaviour or fitness. Surgical implantation has been the most common method of securing transmitters to snakes because external attachments typically rely on the presence of prominently regionalised bodies or external structures (e.g., limbs, fins, feathers, fur, etc.; Reinert and Cundall, 1982; Silvy et al., 2005; Riley et al., 2017; Zdenek et al., 2021). However, snakes possess simple, limbless bodies and regularly shed their skins, limiting or precluding many common external transmitter attachment methods.

Despite these difficulties, researchers often opt to use external transmitter attachment (e.g., tape, glue, subdermal sutures, rattle attachments) instead of implantation. This can be due to the relatively high costs of surgeries, ethical concerns over invasive procedures for short-duration studies, the small body size of target snake species, or other factors (Zdenek et al., 2021). Studies involving external transmitter attachment on snakes vary considerably in their study species and environments, as well as the attachment materials, placement position, size, and mass of the transmitter packages. Such methodological details influence the efficacy and safety of external attachments: in our earlier systematic review, we found that adverse effects of external transmitter attachments on snake behaviour or health were reported in more than one third of studies (Christensen and Fantuzzi, 2024). Entrapment of the transmitter antenna or the transmitter package itself was one of the most reported issues and was the sole cause of transmitter-related snake deaths. Bulky attachments (e.g., securing the transmitter using full body wraps of duct tape) were often found to affect snake movement by catching on soil, vegetation, or other structures in the snakes' environment (Imlay, 2009; Lonsdale, 2022; Blais et al., 2023). Glue attachments had the shortest durations and were associated with a higher probability of nonlethal injury, such as removal of skin and scales, bleeding, and scarring, relative to other attachment methods. Attaching transmitters via subdermal sutures is increasingly used but improves attachment duration only slightly over tape-only attachments, lasting just 3 days longer on average (Christensen and Fantuzzi, 2024).

Based on our review, we concluded that common adverse effects could likely be partially mitigated by: (1) adopting conservative limits on the transmitter-to-snake mass ratio; (2) shortening transmitter antennas; (3) placing transmitters on a narrow part of the body; (4) using tape attachments rather than more injurious methods; and (5) minimising the amount of attachment material to reduce bulk and impacts on snake manoeuvrability. These measures could reduce adverse outcomes and make external transmitters safer and less burdensome for snakes under study. Here, we evaluated the safety and efficacy of a minimalist tape patch method for attaching small transmitters to two species of North American vipers.

[1] Rutgers University Department of Ecology, Evolution, and Natural Resources, 14 College Farm Rd, New Brunswick, New Jersey 08901, USA.
[2] EcolSciences, Inc. 75 Fleetwood Drive, Suite 250, Rockaway, New Jersey 07866, USA.
[*] Corresponding author. E-mail: t.christensen@rutgers.edu

Materials and Methods

We used a tape-only method (the "tape patch" method), to attach transmitters to Eastern Copperheads, *Agkistrodon contortrix* (Linnaeus, 1766), and Timber Rattlesnakes, *Crotalus horridus* Linnaeus, 1758, at two different sites in New Jersey, USA. Copperheads were studied in rocky, mountainous terrain in the New York-New Jersey Highlands of northern New Jersey, while rattlesnakes were studied in the pine barrens of southern New Jersey's coastal plain. We used external transmitters on individuals unsuitable for surgical implantation, such as subadults, gravid females, or snakes captured too late in the summer to allow sufficient healing time before winter. Transmitters weighed 1.2 g (Model R1655, Advanced Telemetry Systems, Isanti, Minnesota, USA). For the tape patch we cut an obround (i.e., "pill-shaped") patch of flexible, high-adhesive orthopaedic tape (Leukotape®, BSN Medical, South Africa) approx. 4.5 cm x 3.0 cm (approx. 2 cm wider and longer than the transmitter body; Fig. 1A). A 1.25-cm slit cut longitudinally from the centre of a rounded side became the posterior exit for the transmitter antenna. The combined mass of the tape and transmitter was 1.5 g. We limited transmitter mass to 2 % of snake body mass, and we released snakes weighing < 75 g. We shortened antennas to 10 cm to lower the chance of entanglement

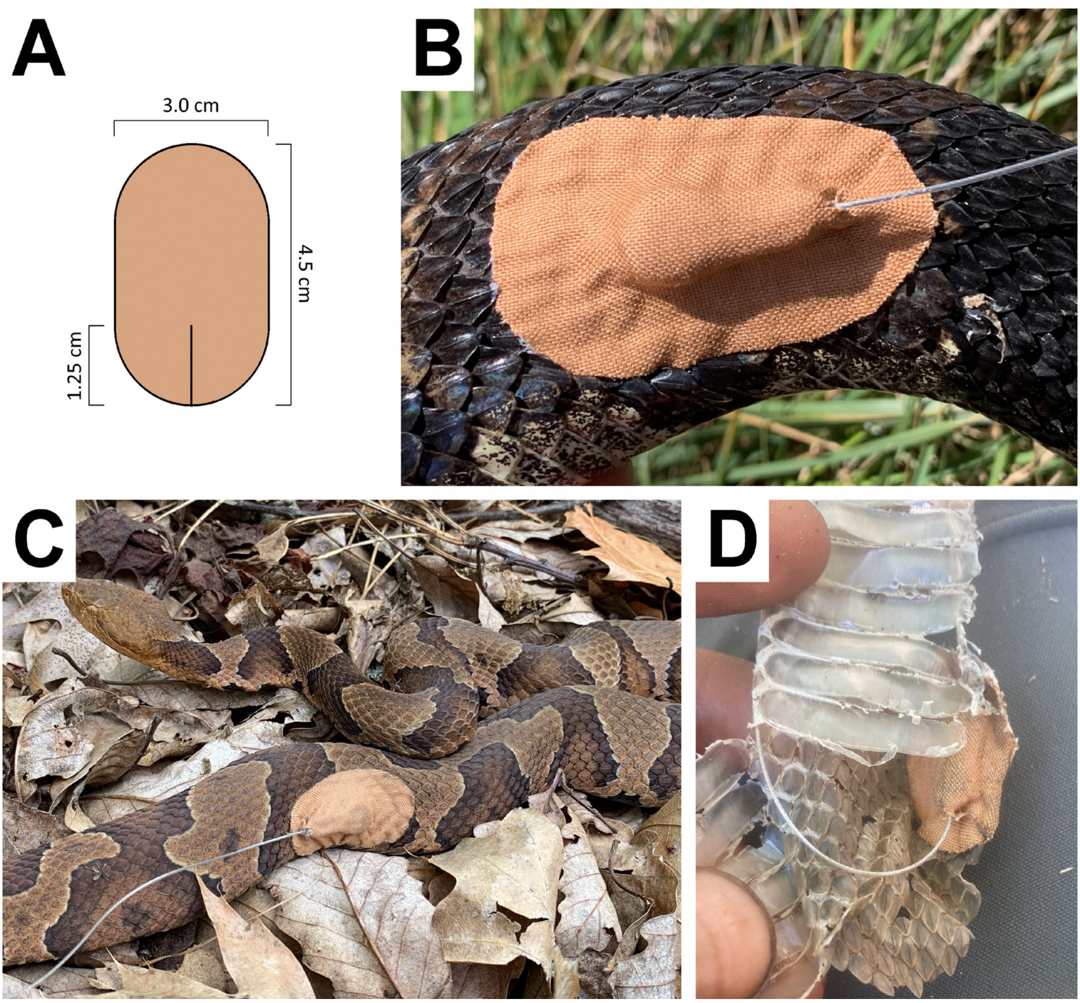

Figure 1. Tape-patch method of external transmitter attachment: (A) schematic showing the shape and dimensions of the tape patch; (B) attachment on a post-parturient female Timber Rattlesnake (*Crotalus horridus*); (C) attachment on a gravid female Eastern Copperhead (*Agkistrodon contortrix*); (D) shed transmitter from a female copperhead. Photos by Tyler Christensen.

in vegetation or rock. However, this may have impacted transmission strength by placing antennas at non-resonant lengths (Kenward, 2000).

We prepared the tape patch and attached the tape to the transmitter first, and then attached the tape-transmitter package to the snake. One researcher manually restrained the snake's anterior body in a tube while another applied the transmitter. We attached transmitters to the snakes' posterior at approximately 70–80% of the snout-vent length (SVL), and dorsolaterally so the bottom edge of the tape was at least 1–2 scale rows above the ventral scales (Fig. 1B, C). In these two wide-bodied viper species, positioning transmitters at 70–80% SVL ensured the combined width of the posterior and transmitter remained narrower than the widest part of the body, reducing the risk of entrapment in rocks or vegetation. The transmitter antenna was oriented posteriorly. We secured the tape from front to back, taking care to avoid creating wrinkles that could catch on vegetation or substrate. At the back, we crossed the "tails" of the tape beneath the base of the antenna. During application we spread the snake's scales slightly to minimise any resistance from the tape to the skin bending and stretching. Afterwards, we used a metal probe to gently press the entire surface of the tape to maximise adhesion to the scales. On cooler days the tape's adhesive was less effective, and we found it beneficial to gently compress the transmitter to the snake with a warm hand after attachment to better activate the adhesive. In addition, we implanted each snake with a uniquely-coded passive integrated transponder (PIT) tag (Avid Identification Systems, Norco, California, USA) for long-term individual identification. We released snakes at their points of capture and tracked them every 48–72 hours during the active season (i.e., prior to winter brumation) and approximately once monthly during winter. Upon each visit, we visually assessed the transmitter attachments whenever the snakes were visible. Because we had no way of determining how long snakes retained their transmitters while stationary underground, we conservatively considered transmitters to be attached only until the last date the snake was seen with the transmitter or tracked to a new location.

Results and Discussion

From 2017–2023, we used the tape patch method to attach transmitters to 17 Eastern Copperheads (*Agkistrodon contortrix*) and, in 2023, to 2 Timber Rattlesnakes (*Crotalus horridus*). External transmitters allowed us to track individuals that we would not have implanted, such as subadults that were too small for implantable transmitters, gravid females, or snakes captured late in the active season.

Mean attachment duration for transmitters attached with tape patches was 32.5 d (Table 1). External attachments had three outcomes: 1), snakes retained transmitters through fall ingress, and transmitters died over winter (n = 10); 2), snakes shed their transmitters (n = 8); 3), the transmitter began to detach, was reapplied, and was later shed (n = 1). We tracked snakes for a cumulative 618 days. During that time, we witnessed snakes moving, gestating, birthing, mating, and foraging normally. We saw no evidence of transmitter attachments becoming entrapped in rock, vegetation, or soil, despite snakes routinely traveling through those obstacles. The snakes appeared to have no difficulty shedding normally, with transmitters remaining attached to the shed skin. We did not observe any evidence of injuries around the attachment site such as abrasions, bleeding, scarring, or scale malformation (e.g., Figueroa, 2006; Wylie et al., 2011; Riley et al., 2017). Using PIT tags, we were able to identify several snakes up to seven years later that previously had external transmitters and observed no evidence of skin injuries or any other effects from the former attachments.

Table 1. Performance of external transmitter attachments on Eastern Copperheads (*Agkistrodon contortrix*) and Timber Rattlesnakes (*Crotalus horridus*) using the tape patch method. TSR = transmitter to snake mass ratio (expressed as a percentage of snake mass). SVL = snout-vent length. Values reported are the mean ± SD (range).

Species	SVL (cm)	Mass (g)	TSR (%)*	Attachment duration (d)
Agkistrodon contortrix	61.1 ± 6.5 (53.3, 70.0)	255.8 ± 87.4 (102.7, 378.1)	0.7 ± 0.3 (0.4, 1.5)	31.1 ± 15.7 (12, 61)
Crotalus horridus	80.9 ± 4.8 (77.5, 84.3)	545.0 ± 63.6 (500.0, 590.0)	0.3 ± 0.03 (0.3, 0.3)	45 ± 19 (31, 58)

The attachment duration of our tape patches ($\bar{x}$ = 32.5 ± 16.7 d) slightly exceeded the average for full-body tape wrapping methods of other studies ($\bar{x}$ = 28.2 ± 22.7 d; Christensen and Fantuzzi, 2024). While attachment durations were similar, full-body wraps can be bulkier (but see Wylie et al., 2011), often use less-flexible materials (e.g., duct tape; Tozetti and Martins, 2007; Smith et al., 2017), and the leading edge must pass over the substrate when the snake moves, sometimes resulting in the transmitter package getting caught in sand, soil, and vegetation (Imlay, 2009; Riley et al., 2017; Lonsdale, 2022; Blais et al., 2023). Mean transmitter attachment duration with tape patches was also longer than that reported for glue-only (16.3 ± 4.8 d) and avoided the relatively high risk of skin injuries associated with glue (Christensen and Fantuzzi, 2024). The tape patch attachments averaged only 2.5 d shorter than subdermal sutures (35.0 ± 11.2 d), and because it is less invasive, risks such as infection or injury are probably lower.

We chose *a priori* to limit the transmitter package mass to a maximum of 2 % snake mass. Tape patches added only 0.3 g, and the combined 1.5-g transmitter and tape patch weighed up to 1.5 % of snake body mass in copperheads and 0.3 % in rattlesnakes. In contrast, the average transmitter mass in prior studies – typically excluding the additional mass of attachment materials – was 2.7 ± 0.6 % snake mass, with some cases as high as 12 % (Christensen and Fantuzzi, 2024). Based on that review and the results of the present study, we believe that imposing conservative limits on minimum snake body size, maximum transmitter mass, quantity and weight of attachment materials, and transmitter-to-snake mass ratios is likely to reduce the probability of adverse effects.

We found our comparatively minimalist tape-based patch method to be safe, effective, and preferable to alternatives, but emphasise that species- and environment-specific constraints preclude the notion of a single best approach. For example, transmitter placement at 70–80% SVL may reduce entrapment risk in wide-bodied snakes like vipers, but even a small transmitter may still be an entrapment hazard in narrow-bodied species. Likewise, shortening transmitter antennas with the intent to reduce entrapment risk comes at a cost of reduced transmission strength, which may not be practical for all species. In our study, shortening antennas did not impact tracking copperheads, which occupied relatively small home ranges (Christensen et al., 2025). However, it made relocating the relatively wide-ranging rattlesnakes (Reinert and Zappalorti, 1988) much more challenging. Differences in body size, vagility, skin texture, shed frequency, habitat, and other traits will also likely influence the efficacy and safety of various techniques. Researchers must continue to incorporate their knowledge and anticipate system-specific trade-offs before deciding whether and how to attach transmitters to snakes.

We devised our patch method to address the most commonly reported causes of adverse effects from external transmitters by: (1) imposing a conservative 2% maximum transmitter-to-snake mass ratio; (2) shortening transmitter antenna length; (3) placing transmitters on a narrow part of the body; (4) relying on tape rather than more injurious materials and methods; and (5) using the lightest and least amount of material possible to minimise package bulk and impacts to snake manoeuvrability. Although we anticipate that our method will not be equally suitable for all species or all environments, we encourage snake researchers to explore similar design modifications to mitigate the high rates of negative impacts from transmitter attachments that have been reported in the herpetological literature.

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