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Tools and Technology

A Self-Adjusting Expandable GPS Collar for Male Elk

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ABSTRACT It is a challenge to use collars on male cervids because their neck size can increase substantially during the rut and also because of growth as the animal matures. We describe how to build a self-adjusting expandable collar for yearling or adult male Rocky Mountain elk (*Cervus elaphus*) to which very high frequency transmitters and global positioning system (GPS) units can be attached. We evaluated performance and durability of 35 expandable collars placed on male elk from 2009 through 2011 within the Starkey Experimental Forest and Range enclosure, Northeast Oregon, USA. Twenty-four (69%) collars remained on elk throughout our sampling period for GPS fixes from March or April to 1 November each year. Eight (23%) collars broke before 1 November and 3 (9%) collars were removed when males were harvested by hunters. Six of 8 collars that broke before 1 November came off during the rut. Mean date these collars broke was 19 September (SE = 7.1 days, 95% CI = 1 Sept. to 7 Oct.). Excluding 1 collar still being worn by a male elk and those collars either recovered when males were harvested by hunters (3) or removed from adult males on the winter feed ground (7), mean number of days collars stayed on was 279 (SE = 25.5, 95% CI = 225.8–331.3 days). No deaths or injuries were attributed to the collars. Because these collars can break, especially during the rut, we recommend sample sizes of males be increased $\geq$25% to compensate for collars that may come off during that period. Collars are not recommended for multi-year studies of male elk without substantial modifications to our design and further testing.

KEY WORDS *Cervus elaphus*, expandable collar, GPS, male elk, Oregon, radiotelemetry, telemetry.

Using telemetry collars on male cervids has always been problematic. Changes in neck size caused by growth or swelling during the rut can result in collars that are too tight: restricting airflow, circulation, and swallowing (Keister et al. 1988, Holzenbein 1992). Poorly fitting collars can also result in abrasions, lesions, and necrosis (Krausman et al. 2004). Fixed-length collars that are adjusted loosely with tape or padding added may still result in head-slipping or foot entrapment in the belting (Bon and Cugnasse 1992, Holzenbein 1992). As Bleich et al. (2007) point out, researchers are bound by ethical, legal, political, and pragmatic considerations to minimize pain and discomfort to radiocollared research animals. This has resulted in many different approaches to developing an expandable collar design, primarily to accommodate growth in neonates and young animals (Hamilton 1962, Beale 1966, Kolz and Johnson 1980, Steigers and Flinders 1980, Strathearn et al. 1984, Keister et al. 1988). Most current designs have problems with complexity and/or durability (Smith et al. 1998). In addition, the advent of global positioning system (GPS) technology has greatly increased the use of collars fitted with GPS receivers. Standard GPS collars use an antenna mounted on top of the collar with a coaxial cable connection to the electronics mounted at the bottom. This precludes GPS units from being mounted on current expandable collar designs. For adult male cervids, combat during the rut also requires an extremely durable design.

As part of an ongoing study initiated in 2008 to determine responses of Rocky Mountain elk (*Cervus elaphus*) and mule deer (*Odocoileus hemionus*) to hunters that use all-terrain-vehicles during hunting seasons, we had a need to intensively evaluate habitat use and movements of adult male elk before, during, and after 3 big game hunts each year. The period of interest for these hunts runs from mid-August to 1 November.

Our objective was to develop a reliable and durable self-adjusting expandable collar for male elk that would serve as a platform for a GPS unit, as well as a very high frequency (VHF) transmitter. We also desired a collar that would survive the rut and remain on males from March or April, when they were deployed, to 1 November each year without causing injury, stress, or mortality.

STUDY AREA

We evaluated collar performance at the Starkey Experimental Forest and Range (Starkey), located on the Wallowa–Whitman National Forest, 35 km southwest of La Grande,

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Union County, Oregon, USA. Vegetation was a mosaic of coniferous forests and open areas containing shrublands and grasslands. Forest stands were dominated by ponderosa pine (*Pinus ponderosa*), with grand fir (*Abies grandis*), and Douglas fir (*Pseudotsuga menziesii*) occurring on northern aspects. Elevation ranged from 1,120 m to 1,500 m.

Starkey was enclosed with a 2.4-m-tall woven-wire fence. Male elk were collared in March or April each year before being released from the winter feed ground to the 7,770-ha Main Study Area. The Main Study Area was open to elk and deer (*Odocoileus* spp.) hunting each year. Rowland et al. (1997) provides a more detailed description of Starkey.

METHODS

We modified the self-adjusting expandable collar developed by Keister et al. (1988), which was originally built for young pronghorn (*Antilocapra americana*). This basic collar design has also been used successfully by the Oregon Department of Fish and Wildlife in studies that deploy VHF transmitters on neonate elk (Rearden 2005, Rearden et al. 2011). We based our new collar design around a self-contained GPS unit (Quantum 4000 Enhanced Ext Memory LSH20 SIRFlll) produced by Telemetry Solutions (Concord, CA). Research on male elk at Starkey is in accordance with approved animal welfare protocols (Sikes et al. 2011) under the supervision of an established Institutional Animal Care and Use Committee (Wisdom et al. 1993).

Collar Design

We formed the collar from Kydex (Port Plastics, Portland, OR) thermoplastic sheeting, an acrylic–polyvinyl chloride alloy, available in 1.22 m × 2.44 m × 3.18 mm sheets from a variety of plastics distributors. We tried slightly thicker material to increase durability (3.96 mm, 4.75 mm) but were unable to get the collar to expand reliably. The Kydex material was cut into strips 92.5 cm long and 7 cm wide, with 2 tabs or "ears" at each end that measured 2.5 cm × 2.5 cm (Fig. 1). Once cut out, we heated the blank in an oven to 125°C for 3 min, wrapped it around a wooden form, and allowed it to cool, thus forming a "coiled spring" (Keister et al. 1988). The resulting collar had an expansion range of 60–90 cm in circumference, reliably expanding and contracting as pressure was increased or decreased. We based the expansion range on neck measurements taken during spring elk-handling at the Starkey enclosure (B. L. Dick, unpublished data) and from hunter-killed elk in Colorado (D. J. Freddy, Colorado Division of Wildlife, unpublished data).

After forming the collar, we mounted a GPS unit on top and a VHF transmitter on the bottom. The GPS unit weighed approximately 235 g, had a footprint 38 mm wide and 95 mm long (including mounting flanges) and was 60 mm tall. The base was curved to fit our collar shape, and grooved to mount over the VHF antenna. The GPS unit was mounted on top of the collar to provide full access to the sky for its internal antenna. The GPS unit had remote download capabilities as well as store-on-board capacity. We mounted a Model 400 VHF transmitter with a 4-hr motion-activated mortality sensor (Telonics, Inc., Mesa, AZ) on the bottom of the collar. We added approximately 100 g of 6.25-mm-sheet lead between the collar and VHF transmitter to counter the weight of the GPS unit and maintain vertical orientation of the collar. We mounted the GPS and VHF units using steel or aluminum pop-rivets, and formed Kydex tabs into retainers using a heat gun. The VHF antenna was held in place using a combination of glued-on Kydex tabs and Gorilla brand tape (Gorilla Glue Company, Cincinnati, OH). We fitted the terminal end of the VHF antenna with 14-gauge crimped electrical fitting to help retain the antenna. Total weight of the collar with the GPS unit and VHF transmitter was 860 g (Fig. 2).

Kydex collars were designed to fit both yearling and older male elk. In deploying these collars, we found they easily slipped over the heads of yearling males that had shed their antlers (or had them cut off), fit snugly when retracted, and provided ample room for expansion. On 2-year-old males,

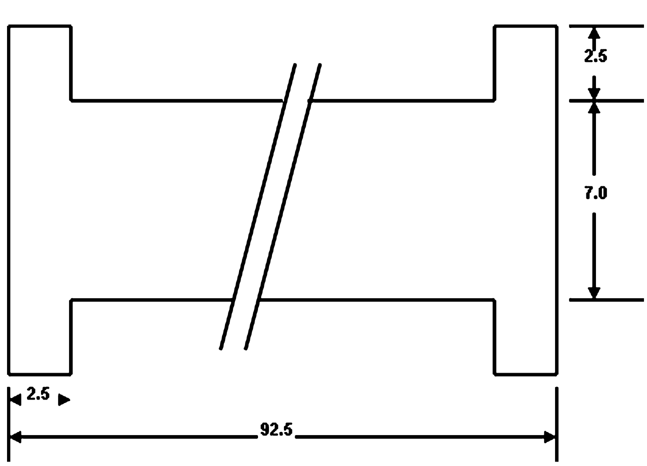

Figure 1. Dimensions (cm) of expandable self-adjusting collar deployed on yearling and older male elk from 2009 through 2011 within the Starkey Experimental Forest and Range enclosure, Northeast Oregon, USA.

Figure 2. Self-adjusting expandable collar with very high frequency transmitter and global positioning system unit attached. Maximum circumference (left) was 90 cm, and minimum circumference (right) was 60 cm.

however, the 90-cm maximum expansion barely fit over the head of the elk, and only if the antlers were freshly shed. Sawn-off antler bases or new antler growth prevented the collar from clearing the maximum dimension of the skull (angular process of the mandible to the top of the pedicel) on older males. To improve our collaring options in 2011, we converted half our finished collars to 2-piece collars and deployed them on 2- and 3-year-old males. We cut the finished collar just above the VHF transmitter opposite the antenna and then overlapped and reattached the Kydex using 2 standard belt-collar stud–plate–nut closures (Fig. 3). This reduced the maximum collar expansion by <2 cm. We believed it was not necessary to compensate for this loss in circumference by adding to the initial length of Kydex material because, based on male elk neck circumference measurements, our Kydex collars could still easily expand enough and safely be used on mature male elk. Detailed instructions, including photos, on how to make these collars are available as on-line supplementary material.

Collar Evaluation

We fitted 8, 11, and 16 male elk with expandable collars mounted with GPS units and VHF transmitters in March or April 2009, 2010, and 2011, respectively. During the 3 years, we collared 25 yearlings, 9 2-year-old males, and 1 3-year-old male. In 2011, we fitted all seven 2-year-old males and one 1-year-old male with 2-piece collars (Table 1). The above ages are those of male elk when they entered the study in March or April. Moreover, ages of elk increased by 1 year when the new biological year began on 1 June.

We programmed GPS units to obtain locations every 15 min during three 20-day sampling periods, except in 2010 when locations were obtained during two 20-day sampling periods. The latest sampling date for obtaining GPS location data ended 1 November. We chose these sampling dates to obtain GPS fixes in order to evaluate how elk and mule deer responded to hunters that used all-terrain-vehicles during 3 autumn hunting seasons.

Figure 3. Two-piece expandable Kydex collar, which shows the attachment with 2 standard belt-collar stud–plate–nut closures. This design allowed us to fit collars on mature male elk.

Table 1. Number of Kydex collars deployed on elk by year, age of males,[a] and collar design at the Starkey Experimental Forest and Range, Northeast Oregon, USA.

	1-piece collar			2-piece collar		
Male age	**1 year**	**2 year**	**3 year**	**1 year**	**2 year**	**3 year**
Year						
2009	7 (0)[b]	1 (1)				
2010	10 (3)	1 (0)				
2011	7 (0)		1 (0)	1 (0)	7 (4)	

[a] Age of males when fitted with a collar.
[b] No. in parenthesis is no. of collars that broke by 1 Nov.

We monitored collars regularly for mortality signals so that retention times could be determined. In 2009 and 2010, we monitored male elk collars <1 time/month before the rut in late August and 1–4 times/month subsequently. Our monitoring was increased in 2011 when collars were monitored 2–8 times/month starting in May, which was within 3 weeks of collaring and releasing male elk from the winter feed ground. We normally recovered broken collars within a week of receiving a mortality signal from the VHF transmitters. Although we removed 1 collar from a male elk on 7 December 2009 and removed 6 collars from 16 to 21 December 2010 when elk were recaptured on the winter feed ground, collared males did not always frequent the winter feed ground. Thus, we continued to monitor collars for breakage each year after our main sampling period for GPS locations ended. The length of time collars remained on male elk was defined as the number of days from the date males were fitted with collars to the mid-point between when VHF transmitters were heard in mortality mode and the previous date when the pulse rate on transmitters was normal.

Statistical Analysis

We used a 2-sample t-test (Zar 1998) with data pooled by year and collar type to determine whether retention times of Kydex collars on male elk collared as 1 year olds were different from older males (collared as 2- or 3-year olds). We considered results significant if $P \leq 0.05$. Because sample sizes were inadequate, we were unable to make statistical comparisons between retention times of Kydex collars among years, collar types, and specific ages of male elk. Likewise, because of small sample sizes, we were unable to use statistics to determine whether GPS unit malfunction was related to collar design or collar failure.

RESULTS

In 2009, our estimates of break-off dates were >30 days from the actual date on which collars broke for 4 of the 24 collars that we deployed on male elk; therefore, we excluded these 4 collars when estimating mean break-off dates. Our mean estimate of when the other 20 collars broke was 5.9 days (SE = 0.72, 95% CI = 4.3–7.4 days) from the time collars broke. Twenty-four (69%) of 35 collars deployed from 2009 to 2011 remained on male elk each year from March or April until at least 1 November (Fig. 4). Of the 11 collars not retained by male elk by 1 November each year, the Kydex on

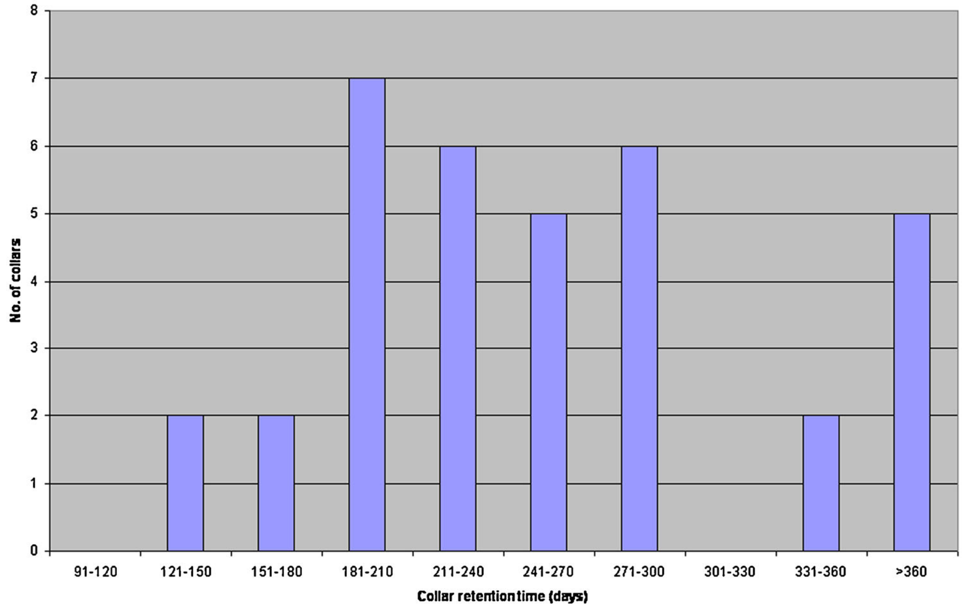

Figure 4. Kydex collar retention times of 35 male elk radiocollared from 2008 to 2011 on the Starkey Experimental Forest and Range, Northeast Oregon, USA.

8 (23%) of these collars broke while 3 (9%) collars were recovered when males were harvested by hunters. Of these 8 collars that broke, 6 appeared to have broken during the rut. Mean date when these 6 collars broke was 19 September (SE = 7.1 days, 95% CI = 1 Sept. to 7 Oct.) with a mean collar life of 184.7 days (SE = 8.89, 95% CI = 164.6–204.8 days). Excluding collar retention times from 3 male elk harvested by hunters, 7 elk recaptured for collar removal on the winter feed ground, and 1 collar still worn by a male, mean number of days collars stayed on elk was 279 ($n = 24$, SE = 25.5, 95% CI = 225.8–331.3 days). Collars stayed on older males (collared as 2- or 3-year olds) the same amount of time as on younger males (collared as 1 year olds; $t = 1.150$; df = 22; $P = 0.263$). In 2011, however, 6 of 8 collars deployed on males collared as 2- or 3-year-old broke by 6 December. None of the 2-piece collars broke where the Kydex was bolted together. No deaths or injuries could be attributed to the Kydex collars, and we did not witness any unusual wear of neck hair, lesions, or other evidence the collars rubbed or fit poorly on necks of the 3 male elk harvested by hunters or of 7 elk recaptured for collar removal on the winter feed ground.

Based on performance of GPS units recovered, it appeared our collar design satisfactorily maintained units in an upright position. The combined mean percentage of successful location attempts (fix rate) of 22 GPS units that did not malfunction in 2010 and 2011 was 87.0% (SE = 2.66, 95% CI = 81.5–92.6%). There appeared to be no relationship between GPS unit malfunction and collar design or collar failure. Of the 4 GPS units that malfunctioned in 2010 and 2011, all were on 1-piece collars; 3 of which were found broken and the other one was removed from a male on the winter feed ground. The retention time of one Kydex collar and fix rate of the GPS unit from this same collar still worn by a male collared in 2011 was not included in these analyses.

DISCUSSION

We successfully designed a collar that met our criteria for durability, expandability, and safety. Collars were susceptible, however, to breakage during the rut, most likely during combat among older males. The weakest part of the collar was adjacent to where the GPS unit attaches to the Kydex material. As the collar is pulled to its maximum expansion, the GPS unit creates a section that does not flex. We believe if the GPS unit could have been made more flexible, possibly by changing base material, we could have reduced breakage of collars and increased retention time. However, because male elk evidently exceeded the force required to break Kydex, it seems likely the collars would otherwise have failed at a different site on the collar.

The advantage of the 2-piece collar is that it allows for fitting expandable collars on older or antlered males. Although the majority of 2-piece collars deployed on adult males in 2011 broke prior to recapture, breakage did not occur at the bolted connection. Rather, we believe 2-piece collars came off more readily because they were deployed on older males that were involved in more fights. Most 2-piece collars broke adjacent to GPS units where the Kydex could not flex when the collars expanded.

We strongly recommend attaching a crimped electrical fitting to the end of the VHF antennas. These crimped fittings act as a stop, tethering the VHF transmitter to the GPS unit by the antenna. In 2011, we found 2 collars with Kydex broken in multiple places. Without the fittings on the ends of the antennas, the GPS units would have been separated from the VHF transmitters, making them unrecoverable. In addition, 4 collars removed from males during winter were held together only by the VHF antenna.

It would be helpful to collect additional information on performance of our Kydex collars. Our inferences on collar performance were limited because of inadequate sample sizes. It would especially be of value to have more information on retention times of 2-piece collars deployed on older males. In our study, several collars were removed from males when captured on the winter feed ground. Improved estimates of Kydex collar retention times could be obtained if a larger sample of male elk were allowed to wear collars for several seasons. A better understanding of whether a relationship existed between GPS unit malfunction and collar design or collar failure would also be determined from a larger sample of collared male elk.

Although fix rate of GPS units is primarily determined by topography and canopy cover (Rempel et al. 1995, Augustine et al. 2011), the fix rate of 87% for obtaining GPS locations suggests the collars retained proper orientation while on male elk. If collars had turned sideways or upside down, fix rate would have been substantially lower.

Our collar design could easily be modified for use on several different species and accomplish a variety of objectives. For example, it seems our expandable collar design could be adapted for use on adult male ungulates where growth of the neck or neck swelling is an issue, such as in mule deer, white-tailed deer (*O. virginianus*), and bighorn sheep (*Ovis canadensis*). Moreover, another potential use of our expandable Kydex collars would be to deploy them on juvenile ungulates with the goal of having those collars be retained until adulthood. The only major modification required for juveniles and males of other species would be to alter the dimensions of the Kydex collar. Another use for our collars would be to attach only VHF transmitters or GPS units with an embedded VHF transmitter. With the second option, counter-weights would be required on the bottom of the collar.

Although considerable research has been conducted on elk, most early studies have focused on the female segment of elk populations (Skovlin et al. 2002). Initially, researchers assumed male elk had the same ecological requirements as females. However, Marcum (1975) found that male elk used different habitats than did female elk in Montana, USA. Marcum's (1975) study indicated knowledge of habitat-use behavior and other aspects of female elk ecology may not provide reliable inferences about males (McCorquodale 2003). One reason for this paucity of research studies on male elk is because of a lack of durable and expandable radiocollars, particularly GPS collars, which could be used ethically on them. We are hopeful that our Kydex collar design will facilitate future research focusing specifically on male elk and males of other ungulate species.

The growth of both juvenile ungulates and rutting adult males requires an expandable neck collar. Expandable radiocollars have been used on neonatal mule deer (Steigers and Flinders 1980, Bleich and Pierce 1999), pronghorn fawns (Keister et al. 1988), mouflons (*Ovis gmelini;* Bon and Cugnasse 1992), adult white-tailed deer (Holzenbein 1992), white-tailed deer fawns (Diefenbach et al. 2003), and elk (Smith et al. 1998, McCorquodale et al. 2011, Rearden et al. 2011). Most of these expandable collar designs have limited applications and a number of problems (Smith et al. 1998). For example, some potential problems of previous expandable collar designs are bulkiness and tendency to snag on vegetation (Beale and Smith 1973, Steigers and Flinders 1980), limited expansion capabilities (Kolz and Johnson 1980, Keister et al. 1988, Holzenbein 1992), and breakaway mechanisms that last only 6 months (Steigers and Flinders 1980). Another important issue with radiocollars is the high probability of causing injuries to animals if collars do not fit properly (Krausman et al. 2004, Bleich et al. 2007). Our collar design is similar to the Kydex collars used on pronghorn fawns (Keister et al. 1988) and neonate elk (Rearden 2005, Rearden et al. 2011). However, ours is unique because it can be safely deployed on adult male elk and possibly on other adult male ungulates. Moreover, our expandable collar design is different from others because it can serve as a platform for a GPS unit, as well as a VHF transmitter.

In most studies of male elk, researchers either used standard nonexpanding neck radiocollars or, if expandable collars were used, provided an inadequate description of their collar designs (Hurley and Sargeant 1991, Leptich and Zager 1991, Unsworth and Kunk 1991, McCorquodale 2003, McCorquodale et al. 2011). McCorquodale et al. (2011) used collars on 11-month-old male elk calves that were made with elasticized cloth spacers designed to expand as the male grew and eventually deteriorate and release the collar, but they did not provide information on performance of their design. This lack of information on expandable collar designs used on adult male elk precludes us from comparing our collar design with others.

MANAGEMENT IMPLICATIONS

Our expandable collar design will enable researchers to more readily obtain location data without causing injuries or death to male elk, other male ungulates, and any animals whose neck size greatly increases. This should improve our understanding of the ecological requirements and other aspects of the biology of males of a variety of species.

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SUPPORTING INFORMATION

Additional supporting information may be found in the online version of this article.

The supplementary material section includes stand-alone detailed instructions, including additional photos, on how to make Kydex collars for male elk.

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