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Original Article

Trauma-Induced Malformed Antler Development in Male White-Tailed Deer

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ABSTRACT Though normal antlers are branched and bilaterally symmetrical, male white-tailed deer (*Odocoileus virginianus*) sometimes develop malformed antlers because of various reasons. As management for antler quality has grown more popular in recent years, there has been concern that spike-on-one-side (SOOS) antler configuration has a genetic cause. We hypothesized that the majority of SOOS antlers are the artifact of injuries to the antlerogenic periosteum region. We collected 71 SOOS specimens over 2 hunting seasons (2010–2011 and 2011–2012) in Alabama, USA, and identified probable cause for malformed antler development. We confidently assigned cause to 62% of specimens, and frequency of skull and/or pedicle trauma increased with age classes (yearling, 2.5-yr-old, and ≥3.5-yr-old M). It was difficult to determine the reason that yearling males developed SOOS antler traits (30%), but ease of prescription increased with male age (76% for ≥3.5-yr-old M). Based on the physiology of skull and/or pedicle versus skeletal injuries, we recommended different culling strategies for yearling versus adult male white-tailed deer according to management objectives. © 2013 The Wildlife Society.

KEY WORDS abnormal antlers, antler development, Cervidae, intracranial abscessation, *Odocoileus virginianus*, pedicle damage, skeletal injuries, white-tailed deer.

Antlers of family Cervidae are one of the most intensely studied secondary sexual characteristics in the animal kingdom. Normal antler configuration of ungulate species is bilaterally symmetrical with small side-to-side inconsistencies that have led to many debates regarding the role of fluctuating asymmetry and male quality advertisement and mate choice in recent years (Møller 1990, Ditchkoff et al. 2001, Bartoš et al. 2007). However, more severe antler aberrations may result from endocrine system imbalances (Bubenik et al. 2001), gonadal trauma (Penrose 1924), nutritional deficiencies (Gogan et al. 1988, Johnson et al. 2007), skeletal injuries (Marburger et al. 1972, Davis 1983), and/or pedicle damage (Rachlow et al. 2003).

White-tailed deer (*Odocoileus virginianus*) typically develop matching antlers with 3 or 4 antler points originating from the dorsal side of a curved main beam. To establish terminology, our research focuses on an abnormal antler configuration that we refer to as spike-on-one-side (explicitly defined in Materials and Methods section). The notion that spike-on-one-side antlers in white-tailed deer are the product of inferior genetics has been embraced by many within the public, and belief that those defective individuals should be culled with the objective of improving the residual genetic quality of the population is common. Genetics do have an influence on antler development but only so much as dictating species-specific antler configurations and determining an individual's relative size within populations (Scribner et al. 1989, Suttie 1990, Hicks and Rachlow 2006), and antler abnormalities are usually a product of the environment (Penrose 1924, Marburger et al. 1972, Davis 1983, Rachlow et al. 2003).

With a central objective of understanding why spike-on-one-side antlers occur in white-tailed deer, we made 2 preliminary observations during the past decade that led us to hypothesize that the primary cause of spike-on-one-side antlers in white-tailed deer was physical trauma to the skull and/or pedicle: 1) many skulls from spike-on-one-side white-tailed deer had damage to the pedicle or immediately surrounding region; and 2) on the occasion that a male white-tailed deer cast an antler irregularly (casting occurs earlier than normal and possesses a chunk of pedicle or skull attached to the antler base), the damaged pedicle usually grew an abnormal antler the following year. Because white-tailed deer are the most popular big game animal in North America and management becomes more advanced with each passing year, this study's results will be of particular interest to not only wildlife managers across the nation, but to the general public as well.

MATERIALS AND METHODS

From October to January 2010–2011 and 2011–2012, we collected antlers from hunter-harvested white-tailed deer with spike-on-one-side antler configurations that were harvested on public hunting wildlife management areas

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and privately owned or leased recreational properties in Alabama, USA. We defined spike-on-one-side antlers as having ≥50% side-to-side difference in gross typical Boone and Crockett score (Ditchkoff et al. 2001) or a typical antler-point differential of ≥2 points (Fig. 1). Typical antler points are those that originate upward from the main beam and measure ≥2.54 cm in length (Wright and Nesbitt 2003). Though a complete necropsy of each deer would have been ideal (as has been done in one previous study; Marburger et al. 1972), logistical and budgetary constraints dictated that an intact skull or skull cap (≥2.54 cm of bone in all directions from both pedicles) suffice. Participants recorded year and county of harvest, categorized ownership of the property where the specimen was harvested, and noted any apparent injuries or abnormalities of the deer (e.g., broken leg or old gunshot wound). After removing all soft tissue from each sample using bicarbonate of soda (sal soda; Church and Dwight Co., Inc.; Ewing, New Jersey) and boiling water, we estimated deer age (tooth replacement and wear; Severinghaus 1949), recorded number of typical antler points per side, and categorized any damage and/or abnormalities as skull and/or pedicle trauma (e.g., signs of callus tissue around pedicle or intercranial sutures or fractured pedicle; Fig. 2), deformed pedicles (e.g., no apparent injuries but one pedicle obviously smaller in diameter than the other or existing away from normal location), or other anomalies (e.g., intracranial and/or subcutaneous abscesses, supernumerary pedicles). Breakage during hard antler (e.g., transverse fracture of the antler main beam) and damage sustained during velvet development (described in Jin and Shipman 2010) were readily identifiable and noted accordingly. All samples were returned to study participants post-examination.

RESULTS

We obtained 29 samples in 2010–2011 and 42 samples in 2011–2012 for a total of 71 spike-on-one-side antler samples. The vast majority came from private lands ($N = 64$), with the remainder coming from Cahaba River Wildlife Management Area ($N = 4$), Barbour County Wildlife Management Area ($N = 2$), and Lowndes County Wildlife Management Area ($N = 1$). Eighteen Alabama counties were represented, with Tuscaloosa and Bullock counties contributing the greatest number of samples (with 11 each). Counting only typical points, right antlers possessed a mean of 2.51 points and left antlers carried 2.45 points; we detected no directional asymmetry ($t_{70} = 0.22$; $P = 0.83$). In total, we assigned probable cause of spike-on-one-side antler formation for 3 of 10 (30%) yearling, 9 of 20 (45%) 2.5-year-old, and 31 of 41 (76%) ≥3.5-year-old males.

For the yearling males, we detected no instances of skull and/or pedicle trauma, deformation of pedicles, or other anomalies. We could not ascribe probable cause for 7 of the 1.5-year-old spike-on-one-side samples, and the remaining 3 were simply due to hard antler breakage.

For 2.5-year-old males, we documented a single case each of breakage during hard antler and velvet development. Two

Figure 1. These 4 skulls accurately demonstrate the definition of spike-on-one-side antlers in white-tailed deer, as defined in the Materials and Methods Section.

males sustained intracranial abscesses in which the sutures connecting the parietal and frontal bones had been eroded (Karns et al. 2009). In one case, the cranial sutures had been replaced by a layer of callus tissue; this suggested that either the previous year's pedicle had cast irregularly and

Figure 2. Characteristic damage sustained by spike-on-one-side male white-tailed deer antlers posterior to the base of the right pedicle and surrounding cranial region.

subsequently healed, or that the animal had sustained injury from an intrasexual competitor or its external environment. Another male had a subcutaneous abscess posterior to the right pedicle, yet the skeletal integrity of the skull and/or pedicle had not been damaged (as in the case of a true intracranial abscessation). If the abscess was present during early antler development, it certainly could have impeded normal antler growth on that side. Two males had noticeable differences in pedicle diameter—the pedicle from which the spike-on-one-side antler developed was smaller than the normal pedicle in one case, but the pattern was reversed in the other specimen. The last two 2.5-year-old males that we were able to assign probable cause for spike-on-one-side antler formation had both skull and/or pedicle damage and malformed pedicles.

We detected spike-on-one-side inducing injuries or abnormalities in 31 of the 41 $\geq$3.5-year-old males. In 14 cases, portions of the cranial sutures and/or skull (frontal and/or parietal bones) sustained damage and pedicles were malformed or misshapen. Three of these specimens showed symptomatology of intracranial abscessation. Seven additional males sustained damage restricted to the skull and not affecting pedicle structure. Another 5 samples possessed malformed pedicles but suffered no apparent injuries to the actual cranium. Lastly, we documented several $\geq$3.5-year-old males with anomalies not fitting into one of the aforementioned categories—1 sample with pedicle located on the lateral side of the cranium, 1 specimen missing portions of the nasal and frontal bones due to prior trauma, 2 cases of accessory pedicles (Bubenik and Hundertmark 2002), and 1 case of "double-head" antler formation (Kierdorf et al. 2004).

DISCUSSION

Pedicle damage or trauma to the frontal and/or parietal bones was the leading cause ($N = 34$) of spike-on-one-side antlers in our study. From a strict physiological perspective, pedicles develop as permanent protuberances of the frontal bones and the antler development region is inclusively termed the antlerogenic periosteum (Goss 1995, Kierdorf and Kierdorf 2001*a*, Li et al. 2009), though the exact boundary of the antlerogenic periosteum is not clear. Pedicle damage can take many forms—irregular antler casting due to insufficient osteoclast resorption (Rachlow et al. 2003, Price et al. 2005); incomplete development of the pedicle (Kierdorf and Kierdorf 2001*b*); damage especially to the lateral portion of the pedicle where the blood vessel supply is located (Goss 1961, Jaczewski 1990); damage to the nerve endings of the pedicle (Wislocki and Singer 1946, Bubenik and Pavlansky 1965, Suttie 1990, Li et al. 1993)—but the result is generally the same for all these forms, suppressed antler development. We did not attempt to differentiate between these injuries, but rather, we lumped all pedicle damage into a single category. Anecdotally, there is evidence that cast antlers with a residual portion of pedicle and/or skull material have a high probability of developing spike-on-one-side antler characteristics in the subsequent year (Rachlow et al. 2003), and that males already possessing spike-on-one-side antler traits commonly cast antlers with fractured pedicles. We termed antler bases with portions of the skull and/or pedicle still attached—"dirty sheds."

Our study could not identify probable cause for 27 specimens, but that number would likely decrease if we had been able to conduct rigorous necropsies and examine more than just the skull of each specimen. Of 32 Texas (USA) white-tailed deer harvested with abnormal antlers, Marburger et al. (1972) documented 22 instances (69%) of old gunshot wounds or healed leg fractures. In mule deer (*O. hemionus*), Robinette and Jones (1959) associated abnormal antler growth in males with foreleg, hindleg, rib, and/or mandible injuries. With more rigorous protocol in our study, one can surmise that at least several, if not many, of the 27 deer without obvious skull and/or pedicle injury experienced past injury to other regions of their bodies.

Considering the results of our study with the Marburger et al. (1972) paper, it does not appear likely that genetics play a major role in spike-on-one-side antler development in white-tailed deer. Spike-on-one-side antlers in elk (*Cervus elaphus*) are overwhelmingly due to damaged or abnormal pedicles (Rachlow et al. 2003) and underlying genetic causes were not identified (Hicks and Rachlow 2006), lending further support to our assertions. Those studies being noted, we do acknowledge the possibility that skull and/or pedicle injuries may be genetically linked to the individual's underlying physiology (e.g., bone density, antler, or bone mineralization); however, our approach did not examine this aspect because we felt it had been adequately addressed in the cervid research cited above. Also, another non-genetic potential cause of spike-on-one-side antlers—gonadal trauma—was not considered in our study (Penrose 1924).

Within age classes, it was particularly difficult to ascertain the reason that yearling males developed spike-on-one-side antler formations. Other than the 3 instances of hard antler breakage, we did not ascribe probable cause to any other 1.5-year-old specimens. Though a portion of 6-month-old males do grow small, immature antlers (usually $\leq$2.54 cm long; Waldo and Wislocki 1951), they are not prone to engage in breeding season activities such as intrasexual combat, thereby lessening the chance of incurring skull and/or pedicle injury that would lead to spike-on-one-side antlers in the following year. Rather, we surmise that some spike-on-one-side antlers in yearling males may have been due to skeletal injuries. Prior research suggests that antler abnormalities due to skeletal trauma (Marburger et al. 1972) have a good chance of returning to normalcy during subsequent years, or at least lessening the severity of the abnormality; though spike-on-one-side antlers may be more permanent if the skeletal injury is a limb amputation (Davis 1983). Conversely, abnormal antlers due to cranial injury (skull or pedicle) often re-aggravate because clean separation during antler casting is unlikely. This causes additional damage and leads to a greater chance of permanency (Kierdorf et al. 2004); in fact, spike-on-one-side antlers stemming from skull and/or pedicle trauma sometimes get progressively worse in successive seasons of antler development due to repeated injuries (Kierdorf et al. 2004). Based on this knowledge, we

recommend that yearling white-tailed deer not be culled because of abnormal antler development for management purposes because immature male white-tailed deer are likely to develop normal antlers in the future.

For the majority of older-age-class males, obvious skull and/or pedicle injuries made it much simpler to ascertain cause of spike-on-one-side antlers, and we determined probable cause for 45% of 2.5-year-old males and over 75% of ≥3.5-year-old males. Logically, the more antler-growth cycles a white-tailed deer undergoes the greater the probability of sustaining significant damage to the skull or pedicle. In adult white-tailed deer, skull and/or pedicle damage is likely to be sustained through breeding activities such as fighting with conspecifics and rubbing trees (Bubenik et al. 2001). When the antlerogenic periosteum is damaged, the pedicle may lose some of its structural integrity and strength, and during the healing process becomes fused with portions of the surrounding cranial region; this virtually ensures additional damage when antler casting occurs again (mechanism of re-aggravation; Kierdorf et al. 2004). Because far more antler abnormalities in older-age-class males are due to skull and/or pedicle trauma and these types of injures tend to re-aggravate (Kierdorf et al. 2004), spike-on-one-side antlers are more likely permanent and repeated in subsequent years (Figs. 3 and 4), indicating that culling individuals may be a more reasonable management practice in environments where trophy-antler quality is a primary objective (Goicea and Dănilă 2009). In addition, brain abscess symptoms sometimes correspond to spike-on-one-side antlers ($N = 5$), and afflicted individuals are already predisposed to mortality by natural causes (Karns et al. 2009). However, in situations where herd numbers are well below carrying capacity and the male age structure of the population is underdeveloped, preserving mature males regardless of antler configuration may benefit herd health through stabilization of the breeding season (Miller and Marchinton 1995).

Though infrequent in our results, other injuries and their effects on antler development bear mentioning. Across age classes, we documented 4 cases of hard antler breakage (Karns and Ditchkoff, 2012) and a single instance of damage incurred to a developing antler main beam in a 2.5-year-old male. Antler development emanates primarily from the apical portion of each antler branch, and injury to that portion of the velvet antler virtually terminates further growth (Goss 1961, Suttie and Fennessy 1985). Surprisingly, injuries sustained during velvet antler development are often "remembered" in subsequent sets of antlers—a phenomenon coined trophic memory by Bubenik and Pavlansky (1965)—though the abnormality is usually progressively forgotten as years pass (Bubenik 1990). Also, we observed a rare occurrence of double-head antlers in a ≥3.5-year-old male where old antlers failed to cast (presumably because of insufficient osteoclastic resorption; Kierdorf et al. 1994) and new antlers developed abnormally from the grossly enlarged, lateral outside portions of both pedicles (Kierdorf et al. 2004). We examined 2 separate cases of accessory pedicles both occurring in ≥3.5-year-old males (Jaczewski 1990, Bubenik and Hundertmark 2002). In each

Figure 3. Though this particular white-tailed deer was not included in the formal analysis of the study (deer still alive as of manuscript submission), this sequence of Deer no. 817 at Auburn University's Deer Lab (AL, USA) shows the progression of spike-on-one-side antlers from 1.5 to 3.5 years old. See Figure 4 for close-up photograph of deer's damaged pedicle at age 1.5 years.

Figure 4. At age 1.5 years, white-tailed Deer no. 817 at Auburn University's Deer Lab (AL, USA) sustained pedicle damage when the antler was broken off 2 months prior to normal antler casting.

occasion, the accessory pedicle was located anterior to the normal pedicle on only one side of the cranium, and on that side the normal antler was significantly shorter in length than the opposite side. One accessory antler measured 4 cm in length while the other measured nearly 12 cm in length and possessed 3 total antler points. Moderate callus of the antlerogenic periosteum surrounding the base of the supernumerary pedicles indicated that prior damage to the skull and/or pedicle had instigated their eruption (Jaczewski 1990, Bubenik and Hundertmark 2002). The final noteworthy exception was a mature spike-on-one-side male with such severe damage to the cranium that portions of the nasal and frontal bones were completely missing, yet the antlerogenic periosteum appeared intact. The animal was in good health when harvested, but the injuries surely impacted its ability to grow normal antlers (Robinette and Jones 1959).

MANAGEMENT IMPLICATIONS

Managers should note that malformations usually negatively affect only one side of the animal's antlers, leaving the normal half for one's assessment of its true genotypic antler make-up. The value of a management system placed on trophy-antler quality at maturity and the population's relationship to carrying capacity should dictate culling decisions for yearling and adult spike-on-one-side males.

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