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RED DEER INTRODUCED TO PATAGONIA
2. CAMPYLOGNATHIA OR BENT-NOSE DISEASE

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ABSTRACT
Red deer (*Cervus elaphus*) introduced to southern Latin America now occupy over 51,000 km² and maybe numbering >100,000 animals. Of 776 specimens, campylognathia (facial scoliosis) was found in 2 females and 5 males, which were all otherwise healthy individuals. The low prevalence indicates that the disease unlikely is inheritable, considering that the founding stock consisted of 20 animals and prevalence would have been at least 5%. Handedness of scoliosis reported in a total of 131 cases related significantly to the hemisphere where the specimen originated. Handedness was according to that expected from the coriolis force arising from the earth's rotation. These effects are large enough that humans subjected to an artificial coriolis force cannot reach out and hit a target with their finger, until repeated attempts have corrected central nervous system responses and motor compensations. Furthermore, coriolis forces are known to affect early stages of development such as the innervation pattern of the mammalian vestibular system, the plane of bilateral symmetry, or the orientation of microtubules in the vegetal pole region of embryos. It is therefore conceivable that the networks processing these environmental cues, or the mechanisms responsible for compensation, are malfunctioning and thus result in a preponderance of facial scoliosis in accordance to the earth's rotation.

INTRODUCTION
Cases of campylognathia or bent-nose have been observed repeatedly among cervids. The etiology is unknown and may have multiple origins. We describe the phenomena in red deer (*Cervus elaphus*) from Patagonia. The free-ranging animals were descendants from a group of European red deer introduced to an enclosure in central Argentina in 1906, from where a small group was taken to an enclosure in the Neuquen province in 1922 (Flueck and Smith-Flueck 1993). The liberation occurred a few years later and has resulted in an extensive distribution in Patagonia, deer having become established in all mayor habitats between about 34-55°S, maybe numbering >100,000 animals, and having yet to reach a state of equilibrium (Flueck and Smith-Flueck 1993; Flueck *et al.* 2003). As handedness of campylognathia in cervids has been correlated to the coriolis effect (Suttie and MacMahon 1993), we analyzed this relationship in our and other reported cases.

METHODS
The study area is centered in northwestern Patagonia (40°58'S, 71°12'W), Argentina (for details see Flueck and Smith-Flueck 2011). Cases of campylognathia stem from our collecting deer by rifle and revisions of specimens hunted by the public. We also performed a literature search on ISI Web of Knowledge and analyzed cases of campylognathia reported in cervids with respect to geographical location and handedness using a chi square goodness of fit to test the expected versus observed frequency of cases (Zar 1996).

RESULTS
We have found cases of campylognathia in two female and five male red deer (our specimens n = 522, from hunters n = 254). **Case 1** was a female about 4 years old collected in 1996. She was in good condition, average size, reproductively active, and there were no indications of anatomical aberrations in the postcranial skeleton or other gross pathological changes. The scoliosis in the upper skull affected the nasal, maxillary and premaxillary bones, resulting in the frontal portion to bend to the left as well as down (Fig. 1*a*). The magnitude of the down bend resulted in the lower incisors extending considerably beyond the palate which is evidenced by the wear pattern on incisive teeth, and the biting capacity must have been very limited. Additional asymmetry was prominent on the anterior sphenoid which bent to the right whereas the following vomer bent again to the left. It resulted in the distance between the hamulus and the maxilla tuberosity to be 21% larger on the left side. The mandible exhibited 12 mm

more growth one the left side and was also bending, such that the incisor arcade deviates about 25 degrees from the normal plane, but in accordance with the position of the palate and showing additional changes, possibly as secondary complications from misalignments (Fig. 1*b*). The left P4 appears normal in form but is in a much displaced position. The right M3 has a normal form, but its position is displaced, possibly due to bone restructuring from periodontal problems related to the M2. The mandibular bone at the level of the right M2/3 is 38% wider and height is reduced by 33%, compared to the left mandibular bone. The right M2 is not only displaced but is abnormally grown. **Case 2** was a 1 year old female collected in 1998. She was in good condition, and there were no indications of anatomical aberrations in the postcranial skeleton or other pathological changes. The head presented scoliosis in the upper skull and mandibles, resulting in a bend to the left, but not as pronounced as in case 1. Although the body measurements show that the female was slightly larger than average, the head length was shorter than average due to the aberrant growth. **Case 3** was a male hunted in 2000 and about 12-14 years old, with the anterior portion of nasals, maxillae and premaxillae involved in the scoliosis, resulting in the frontal portion to bend to the left. The maxillary teeth had all normal appearances. **Case 4** was a male hunted in 2007 and about 6-8 years old, with the anterior portion of nasals, maxillae and premaxillae involved in the scoliosis, resulting in the frontal portion to bend to the left. **Case 5** was a male hunted in 2008 and about 5-6 years old, with the anterior portion of nasals, maxillae and premaxillae involved in the scoliosis, resulting in the frontal portion to bend to the right and strongly downward such that the lower incisors extended considerably beyond the palate (Fig. 2). **Case 6** was a 4-5 year old male with the nasals, maxillae and premaxillae involved in the scoliosis, resulting in the frontal portion to bend to the left (Fig. 3*a*). Lastly, **case 7** was a 4-5 year old male with the anterior portion of nasals, maxillae and premaxillae involved in the scoliosis, resulting in the frontal portion to bend to the left (Fig. 3*b*).

Table 1. Reported cases of campylognathia among cervids with respect to hemisphere and direction of facial scoliosis

No. of cases	Hemisphere	Direction	Reference
		Cervus elaphus	
6	South	Left	This study
1	South	Right	This study
1	North	Right	MacNally (1989)
4	North	Right	MacNally (1992*a*)
1	South	Left	Suttie & McMahon (1993)
1	South	Left	Suttie & Pearce (1994)
1	North	Right	Suttie & Pearce (1994)
1	North	Left	Campbell (1995)
		Cervus nippon	
1	North	Right	MacNally (1989)
		Cervus duvauceli	
1	North	Left	Banwell (1999)
	A mixture of *C. elaphus, C. unicolor, C. nippon, C. timorensis*		
95	South	Left	Banwell (1999)
13	South	Right	Banwell (1999)
		Capreolus capreolus	
1	North	Right	MacNally (1992*a*)
1	North	Right	MacNally (1992*b*)
1	North	Right	Prior (1993)
		Rangifer tarandus	
1	North	Right	Suttie & McMahon (1993)
		Dama dama	
1	North	Right	Horsefield (1993)

Campylognathia with respect to hemispheres: Table 1 summarizes the reported cases of campylognathia in cervids. Of a total of 131 cases, 12% defy the expected directional asymmetry according to the coriolis effect, however, the correlation is significant (x = 0.8, d.f. =1). Lutz (1988), citing further literature not available for our consultation, mentioned additional cases among cervids.

DISCUSSION

Different causes are known or suggested to result in campylognathia which has been described for cervids since the 19th century (MacNally 1992a). Atrophic rhinitis can result in campylognathia, but is restricted to suids (Lutz 1988). A literature search on ISI Web of Knowledge did not reveal descriptions of rhinitis or osteodystrophy in cervids. Abnormal positioning of the fetus or intrauterine pressure, and mineral deficiency have been suggested as possible causes (MacNally 1989, 1992a). Other possibilities include injuries from physical impacts, but all cases in cervids described here were from apparently healthy individuals. Arthrogryposis (inherited, viral or from teratogenic factors) in domestic ruminants often is associated with campylognathia (Bähr *et al.* 2003; de la Concha-Bermejillo 2003). Although wild deer in North America are often sero-positive to viral infections known to cause campylognathia in livestock (Blackmore and Grimstad 1998), we found no reference of sero-positive deer exhibiting campylognathia. Furthermore, presence of Cache Valley or Potosi virus as causative agents has not been reported for southern Argentina (Camara *et al.* 1990). Suttie and McMahon (1993) mentioned a red deer calf born with a straight rostrum which began to bend at 6 months of age. They excluded nutrition as a factor as deer were well fed during a study, and as upper as well as lower jaw bent together, they suggested it to be a developmental abnormality. Another case involved an otherwise healthy female (with facial scoliosis to the left) which was exported from New Zealand to Canada. There she produced a daughter which also exhibited campylognathia but to the right, and thus suggestive that there might be genetic inheritance involved (Suttie and Pearce 1994). However, it could have also occurred through inheritable epigenetic effects. Nonetheless, there are many confounding variables which might be involved from deer living together and presenting similar pathologies. Genetic inheritance as a primary cause seems unlikely given that the extensive red deer population in Patagonia (Flueck *et al.* 2003) resulted from 20 initial individuals (Franke 1949), and thus the original frequency would have had to be at least 5% (one out of the 20) and expected to remain so. Yet there have been no reports of such frequent cases among deer hunted in this population since 1920's, and the seven cases found represent <1% of deer revised by us. Many specimens reported by others came from deer farms and were either considered healthy or lacked a comment, and probably all deer shot in the wild made it to adulthood, and also were either considered healthy or lacked comments. Thus, the origin of campylognathia in deer appears to related to a non-inheritable developmental disorder. Primary causes are not known and might include congenital genetic aberrations, teratogenic compounds, infections, and other epigenetic factors affecting the developmental process. The fact that there is a pronounced difference in the developmental pattern with respect to hemispheres, suggests that the disturbed developmental process may be influenced by geophysical factors like the coriolis force as proposed by Suttie and MacMahon (1993).

Coriolis forces are inertial forces that arise when an object moves linearly within a rotating spatial reference frame like the earth. Any body movement that is not parallel to the earth axis will be affected by a transient coriolis force that arises as the movement begins and decays as the movement ceases. Humans subjected to an artificial coriolis force for instance cannot reach out and hit a target with their finger, until repeated attempts have corrected central nervous system responses and motor compensations (Lackner and DiZio 2000). Similarly, coriolis forces are constantly acting on arms or legs from limb movements made during voluntary body rotation: although they are not perceived, motor compensation for their presence are made, otherwise the movements would be inaccurate (Lackner and DiZio 2000). Furthermore, coriolis forces are known to affect early stages of development, Bruce *et al*. (2006) for instance found that movements of embryos within the dam's uterus, and as the dam herself moved about, causing coriolis effects which affected the innervation pattern of the mammalian vestibular system. Even subcellular effects of geophysical forces are known, such as gravity influencing both the plane of bilateral symmetry and the orientation of microtubules in the vegetal pole region of embryos (Kochav and Eyal-Giladi 1971; Fluck *et al.* 1998). These various known systems affected by coriolis forces all play roles in mammalian ontogeny, yet normal individuals grow symmetrical within the range of geophysical forces encountered on the globe. It is therefore conceivable that the networks processing these environmental cues, or the mechanisms responsible for compensation, are malfunctioning and thus result in a preponderance of facial scoliosis in accordance to the earth's rotation.

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Figure 1. Campylognathia of an adult female red deer with (*a*) lateral and (*b*) ventral view of scoliosis of the skull.

Figure 2. Adult male red deer with (*a*) lateral and (*b*) ventral scoliosis.

Figure 3. (*a*) Adult male red deer with pronounced scoliosis at the level of eye sockets and (*b*) adult male red deer with lateral scoliosis of anterior rostrum.