Glenda Wiles

From: bjhoy@localnet.com
Sent: Thursday, January 19, 2012 4:53 PM
To: Ravalli County Commissioners
Subject: Comments on Wolf issue
Attachments: GENITAL AND FACIAL MEASUREMENTS FOR 2011 WHITE.docx; Hoyetal2011.pdf

Hi Glenda,

I sent this information to all of the commissioners, but Greg said I had to send it to you to get it into the wolf issue folder, or something like that.

Dear Commissioners,

I have talked to Ravalli County ranchers who raise cattle. They say that their calves having underbite costs them a lot of money. One rancher said they estimated that one third of their calves had underbite - that was in 2003. Underbite on beef cattle in general seems to be at about 50% now. I did some calculations for a prevalence of half the calves born on a ranch with underbite. That is less prevalence than I have found in several butchered beef head collections I have done since 1996. The last 1 1/2 year old butchered steer heads I collected had 12 of 16 with underbite.

If a ranch has 300 live calves that survive to be sold, and the underbite on half of those 300 calves results in less weight gain, lets say an average of 5 pounds, that is a 750 pound loss to the rancher.
That is equivalent of the loss of one ready for market steer because of the underbite. If this happens to quite a few ranchers market heifers and steers, that is quite a loss to the economy of Ravalli County.

The brachygnathia superior/underbite is a definitive symptom of fetal hypothyroidism. In other words, the calves are seriously affected in the womb as were all those young WTD, mule deer, elk, bighorn sheep, antelope, and domestic goats (as well as the small sample of butchered beef steers) we examined for the study I recently sent to you.

Sincerely,
Judy Hoy

GENITAL AND FACIAL MEASUREMENTS FOR 2010-2011 WHITE-TAILED DEER FAWNS AND DISCUSSION OF FACIAL AND GENITAL FEATURES

Recorded by Judy Hoy

Hemiscrota position is misal for misaligned or bilat for bilateral.

Down = distance from body wall to lowest point on the scrotal sac/hemiscrota.

Bite = measurement from the anterior of the premaxillary pad to the top of the incisors.

A plus (+) sign before the bite measurement indicates the distance from the front of the premaxillary pad to the top of the incisors. This is a measurement of the brachygnathia superior or underbite as a result of underdevelopment of the premaxillary bone.

A minus (-) sign before the bite measurement indicates how far behind the front of the premaxillary pad the top of the incisors contacted the pad. This is a normal bite, unless the distance is an abnormally long distance, indicating maxillary brachygnathia or a short, underdeveloped lower jaw forward of the premolars.

Pad measurement is the width of the pad where the incisors should normally contact.

Incisors measurement is the measurement of the incisors from one outside edge to the other.

Difference is the difference between the width of the pad and the width of the incisors. A plus (+) sign before the difference means the incisors were wider than the pad. A minus (-) sign before the difference means the pad was wider than the incisors as is normal.

SEX AND FACIAL MEASUREMENTS FOR 2010 WHITE-TAILED DEER FAWNS

#	Sex	Hemiscrota Pos.	Hemiscrota Down	Testes	PS	Bite	Pad	Incisors	Difference
#1-10WTD	FF					-1 mm	1.2 cm	1.9 cm	+7mm
#2-10WTD	FF					+5 mm	1.1 cm	1.8 cm	+7 mm
#3-10WTD	FF					-2 mm	1.4 cm	2.0 cm	+6 mm
#4-10WTD	FF					+2 mm	1.7 cm	2.0 cm	+3 mm
#5-10WTD	FF					-2 mm	1.8 cm	1.6 cm	- 2 mm
#6-10WTD	FF					-2 mm	2.1 cm	2.0 cm	-1 mm
#7-10WTD	FF					-3 mm	2.1 cm	2.2 cm	+1 mm
#1-10WTD	MF	bilat	1.3 cm	2.9 cm	1.5 cm	+3 mm	1.2 cm	1.6 cm	+4 mm
#2-10WTD	MF	bilat	1.6 cm	2.9 cm	1.8 cm	+3 mm	1.3 cm	1.9 cm	+6 mm
#3-10WTD	MF	misal	1.4 cm	2.8 cm	1.4 cm	+4 mm	1.5 cm	1.9 cm	+4 mm
#4-10WTD	MF	misal	2.3 cm	4.5 cm	2.8 cm	+5 mm	1.5 cm	1.9 cm	+4 mm
#5-10WTD	MF	bilat	1.8 cm	3.9 cm	1.0 cm	-1 mm	1.4 cm	2.1 cm	+7 mm
#6-10WTD	MF					+2 mm	1.5 cm	1.9 cm	+4 mm
#7-10WTD	MF	misal	1.9 cm	4.1 cm	1.8 cm	-1 mm	1.7 cm	2.0 cm	+3 mm
#8-10WTD	MF	misal	3.6 cm	4.3 cm	2.5 cm	-2 mm	1.9 cm	1.9 cm	0 mm
#9-10WTD	MF					+0.5 mm	1.9 cm	2.0 cm	+1 mm
#10-10WTD	MF	misal	4.1 cm	4.3 cm	3.5 cm				
#11-10WTD	MF	misal	3.9 cm	5.9 cm	1.9 cm	-1.5 mm	2.3 cm	2.4 cm	+1 mm
#12-10WTD	MF	misal	2.0 cm	4.5 cm	1.6 cm	-2 mm	2.0 cm	1.9 cm	-1 mm

SEX AND FACIAL MEASUREMENTS FOR 2011 WHITE-TAILED DEER FAWNS

#	Sex	Hemiscrota		Test	PS	Bite	Pad	Incisors	Difference
		Pos.	Down						
#1-11WTD	MF	misal	3.9 cm	5.9 cm	1.9 cm	+4 mm	1.5 cm	1.9 cm	+4 mm
#2-11WTD	MF	misal	0.6 cm	3.9 cm	1.8 cm	-2 mm	1.7 cm	2.0 cm	+3 mm
#3-11WTD	MF	misal	2.2 cm	4.5 cm	1.7 cm	-2 mm	2.0 cm	1.9 cm	-1 mm
#4-11WTD	MF	bilat	5.3 cm	4.7 cm	4.8 cm	- 2 mm	2.2 cm	2.3 cm	+1 mm
#5-11WTD	FF	-	-			-2 mm	2.0 cm	2.0 cm	0 mm
#6-11WTD	MF	-	-			+2 mm	1.9 cm	2.1 cm	+2 mm
#7-11WTD	MF	-	-			+3 mm	2.2 cm	2.5 cm	+3 mm
#8-11WTD	MF	-	-			+3 mm	2.2 cm	2.3 cm	+1 mm
#9-11WTD	FF	-	-			-2.5 mm	2.0 cm	2.2 cm	+2 mm
#10-11WTD	MF	misal	3.1 cm	5.2 cm	3.6 cm	+2 mm	1.9 cm	2.1 cm	+2 mm
#11-11WTD	MF	bilat	4.5 cm	6.3 cm	2.8 cm	+1 mm	2.2 cm	2.4 cm	+2 mm
#12-11WTD	FF	-	-			-1 mm	1.9 cm	2.0 cm	+1 mm

Total White-tailed Deer Fawns examined = 31. Sex Ratio = 21M/10F

Genital Configuration and Measurement Results

11 (69%) males had misaligned hemiscrota 5 (31%) males with bilateral hemiscrota. Only 16 deer in this sample, so likely not a large enough sample, but completely consistent with published data for previous years (Hoy, et. al. 2002).

7 of 16 (44%) of males had hemiscrota with length much shorter than the length of the testes, thus the testes were partly ectopic and not away from the body wall.
1 of 16 (6%) and one of those 7 with short hemiscrota had almost no scrotal sac at 0.6 cm and with testes (3.9 cm) and testes completely horizontal and ectopic under the skin.

1 (6%) of 16 males had a normal length bilateral hemiscrota that held the testes completely away from the body. This deer's scrotal sac had a normal configuration as specified in biology books and in livestock manuals for ruminant species. The other 4 with bilateral hemiscrota had hemiscrota much shorter than the testes and thus the testes were partly ectopic and against the body wall, which affects the viability of the sperm when the deer reaches breeding age.

Facial Measurement Results

16 (53%) of 30 had a normal bite with normal length premaxillary bone.
This is far more with normal bite than in the three years, 2007 through 2009, just prior to 2010, when the percent of fawns with normal bite was around 30% (see Table 1).

14 (47%) of 30 had brachygnathia superior and underbite because of underdevelopment of the premaxillary bone.

6 (20%) of 30 had a premaxillary pad equal to or wider than the incisors, or normal development.

24 (80%) of 30 had a premaxillary pad narrower the incisors, not what was historically considered normal development.

14 of the 24 or (47%) of 30 fawns examined had incisors that were significantly wider than the premaxillary pad.

10 of the 24 or (33%) of 30 had incisors that were just slightly wider than the premaxillary pad. Even if these 10 are placed within normal range, nearly half of the fawns still had much wider incisors than the premaxillary pad the incisors are supposed to contact.

Table 1. Percent of white-tailed deer fawns with Brachygnathia Superior (BS)

% F Fawns	% M Fawns	WTD Fawn %BS	Year
0	0	1	1996
6	2	4	1997
4	3	4	1998
29	7	18	1999
17	31	24	2000
69	48	59	2001
33	50	42	2002
48	31	40	2003
18	57	38	2004
40	63	52	2005
62	30	46	2006
82	75	79	2007
79	54	67	2008
83	60	74	2009
29	55	44	2010
0	67	50	2011

Discussion of Facial Measurement Results

Many fawns with a normal bite had incisors wider than the premaxillary pad. This condition is documented, but thus far has not been confirmed as a developmental malformation, since ruminants with an underbite and ruminants with a normal bite have been observed to have incisors wider (sometimes much wider) than the premaxillary pad. On ruminants with an underdeveloped premaxillary bone, narrower and shorter than normal, it seems obvious this condition would also result in the incisors being wider than the underdeveloped pad. However on ruminants with a normally developed premaxillary bone and a normal bite, the difference in width appears to be completely due to abnormally wide incisors at birth. Many newborns with underbite also have visibly wide incisors and the combination of wide incisors and narrow pad results in a significant width in incisors over pad width.

We are still trying to determine how to quantify abnormal tooth width on newborns. Tooth width varies in individuals naturally, and so determining if abnormally wide incisors is the problem or the documented and much studied underdevelopment of the upper facial bones, especially the premaxillary bone is the problem is difficult. Whether extremely wide incisors on newborns is actually a developmental malformation is unknown, since we can find nothing reported on this phenomenon in the literature. We saw the same phenomenon, with much wider incisors than premaxillary pad on some individuals of all ruminant species we measured, no matter what age or sex. On newborn white-tailed deer fawns with significantly wider incisors than premaxillary pad (3 to 7 mm), the incisors are visibly wider and wider by measurement than the incisors on newborns with all incisors contacting the premaxillary pad (historically a normal bite).

The fawns examined in 2010 and 2011 were more normal in facial development with a lower prevalence of brachygnathia superior, closer to the 2006 prevalence, than fawns born the three years prior to 2010 (see table above). It is not known if this encouraging trend would continue with more fawns in the sample. The 2011 fawn sample is not large enough to be certain there were milder symptoms of fetal hypothyroidism in the newborn deer in 2011. However, when combining 2010 and 2011 fawns together into one sample, the facial malformations were definitely less than were found in 2007 through 2009. No one seems interested in doing anything to find what is causing the fetal hypothyroidism, or doing anything to help the animals. That means all affected vertebrate animals will have to evolve to produce young that are more resistant to what is causing the hypothyroidism and with systems that are able to cope or they will go extinct. Therefore it is encouraging that the most easily observed symptom of fetal hypothyroidism appears to be declining in prevalence in newborns.

Discussion of Penis Sheath Measurements

A normal length penis sheath on an unborn haired fetus is at least 2 cm and a newborn's penis sheath on the external skin prior to 1995 averaged approximately 3 cm. Many of the male fawns now have a very short, less than 2 cm long, penis sheath on the external skin. This has nothing to do with the length of the actual penis, which appears to be developed normally. Short genital features on the external skin, including the penis sheath and the two hemiscrota comprising the scrotal sac, are definitive symptoms of fetal hypothyroidism. This is a completely different developmental malformation from genital malformations caused by disrupted sex hormones.

10 of 16 (62%) measured male fawns, between the ages of newly born and a year old, had a penis sheath that was less than 2 cm in length from the body wall to the tip of the penis sheath. Only 6 (38%) had a penis sheath that was even close to 3 cm or over.

As can be seen by Table 2. below, the penis sheath length varied by year between 1996 and 2005, but the trend is downward (shorter penis sheath on average).

The distance from the penis sheath to the umbilicus was much shorter in 1998 and 1999 than any other time period between 1996 and 2005 (see Table 2). The shortened distance between the penis sheath and the umbilicus indicates abnormal forward placement of the mamma (teats) during embryonic development, soon after the closure of the midline on the embryo and before the growth of the male reproductive organs.

Table 2.

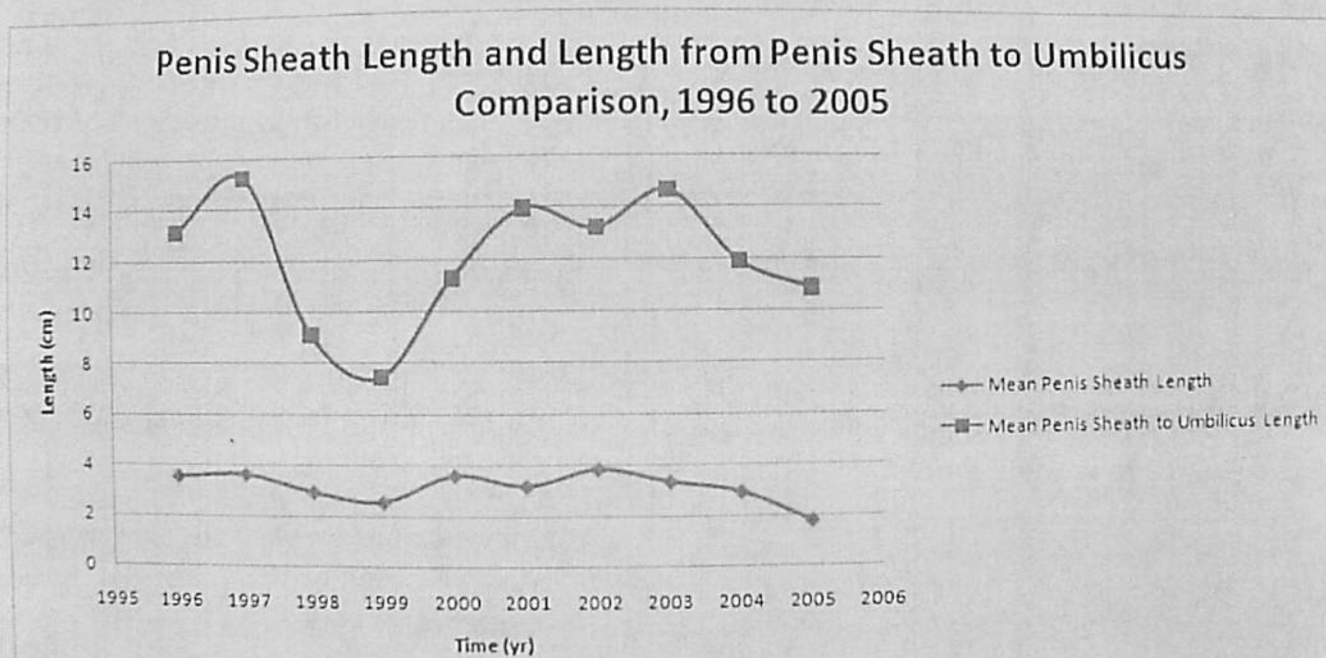


Figure 16: Mean Penis Sheath Length and Length from Penis Sheath to Umbilicus, 1996 to 2005

SEE MORE TABLES OF GENITALIA MEASUREMENTS AND PHOTOS OF BITES AND INCISORS ON RUMINANTS BELOW

Table 3.

2005

Finally, the data also indicates that the percentage of abnormal hemiscrota in white-tailed deer fawns has a general upward trend, with steady increases from 1997 to 2001 (Figure 17).

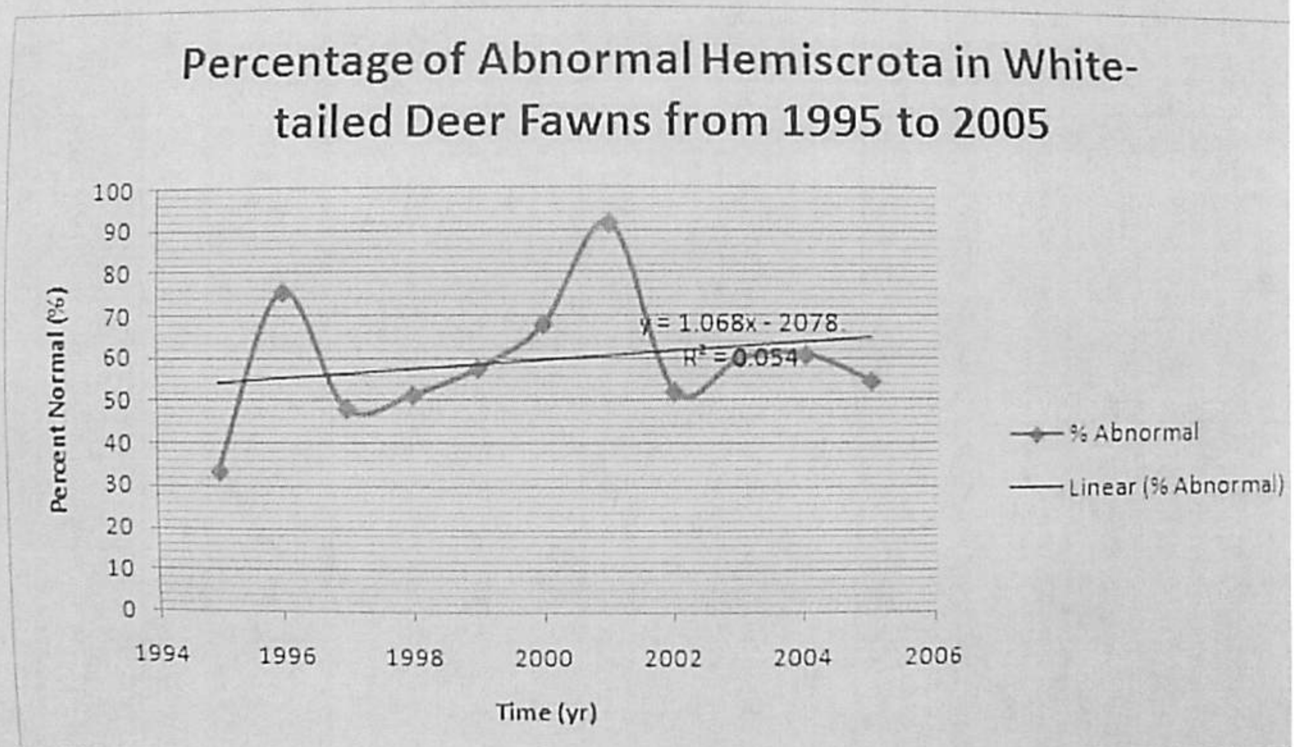


Figure 17: Percentage of Abnormal Hemiscrota in White-tailed Deer Fawns from 1995 to 2005

Table 4.

Findings

An analysis of the mean scrotal sac lengths of white-tailed deer fawns from 1996 to 2006 showed a clear decreasing trend in length, with especially short scrotal sacs being recorded in 1999 to 2001 (Figure 15).

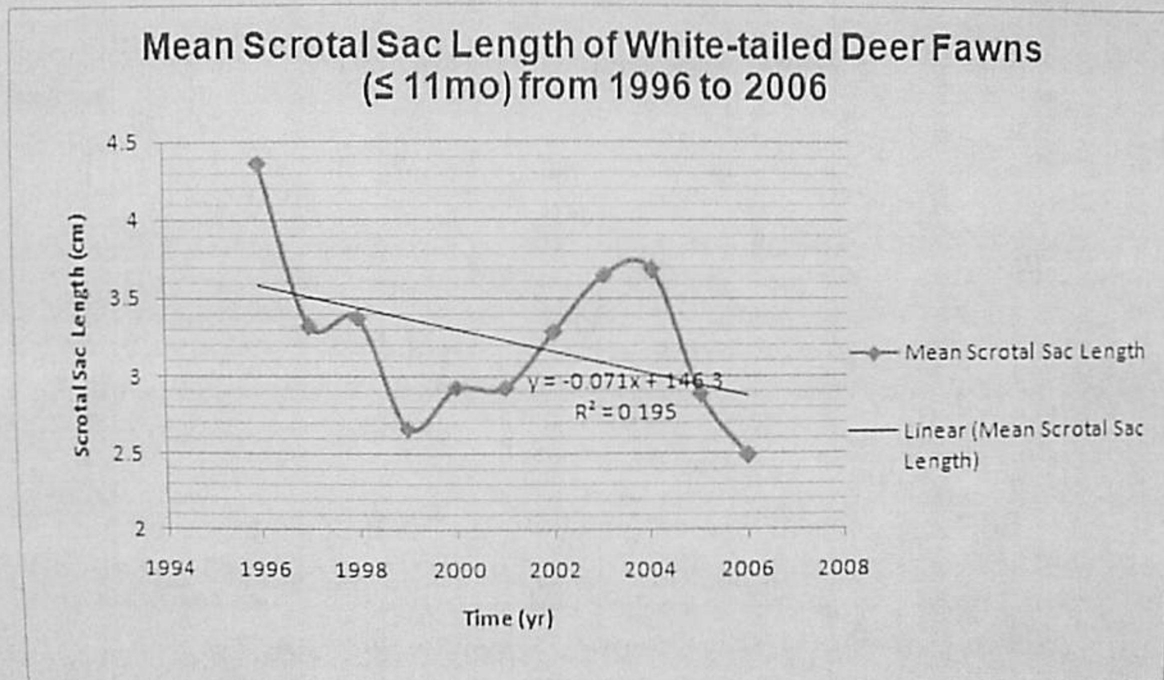
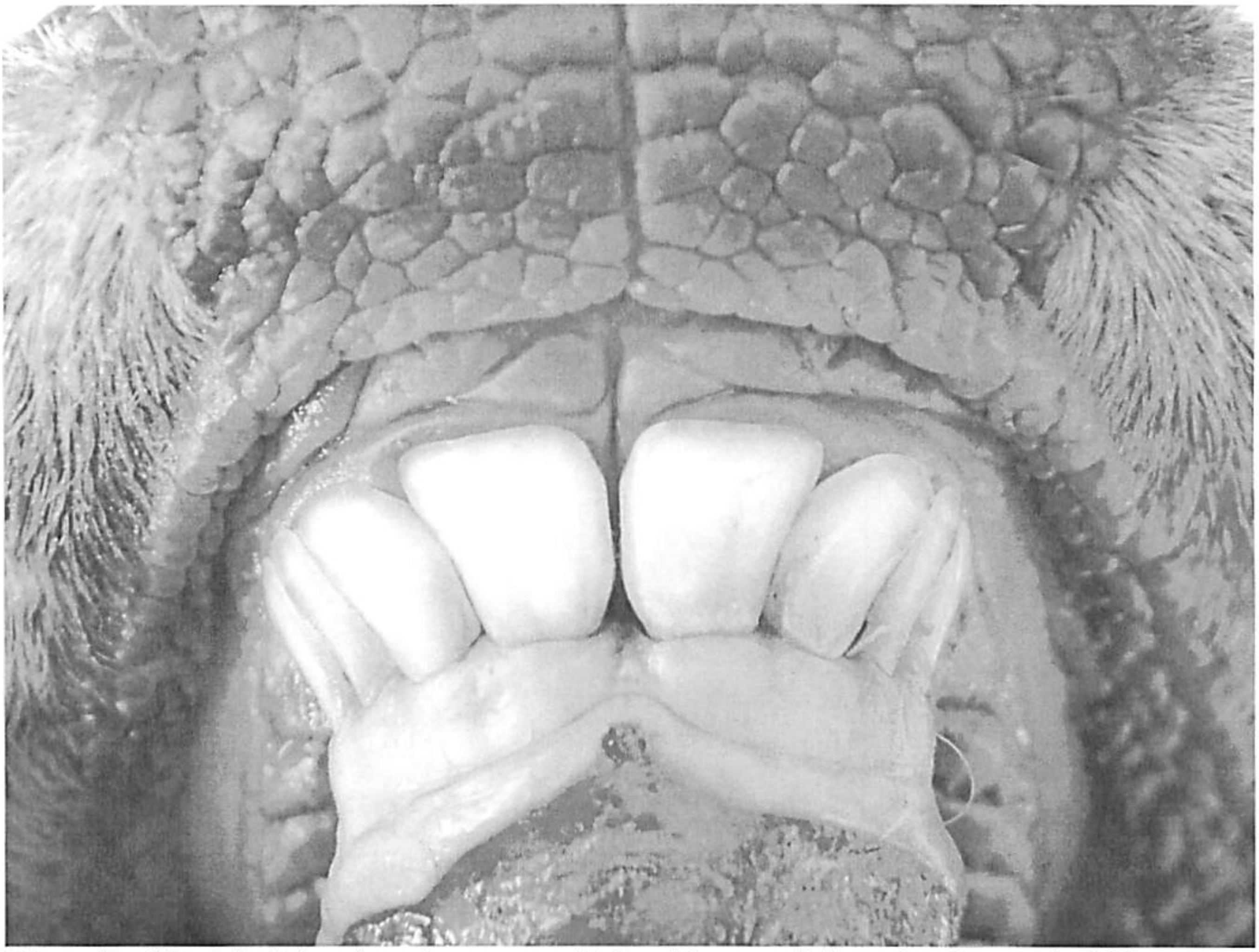


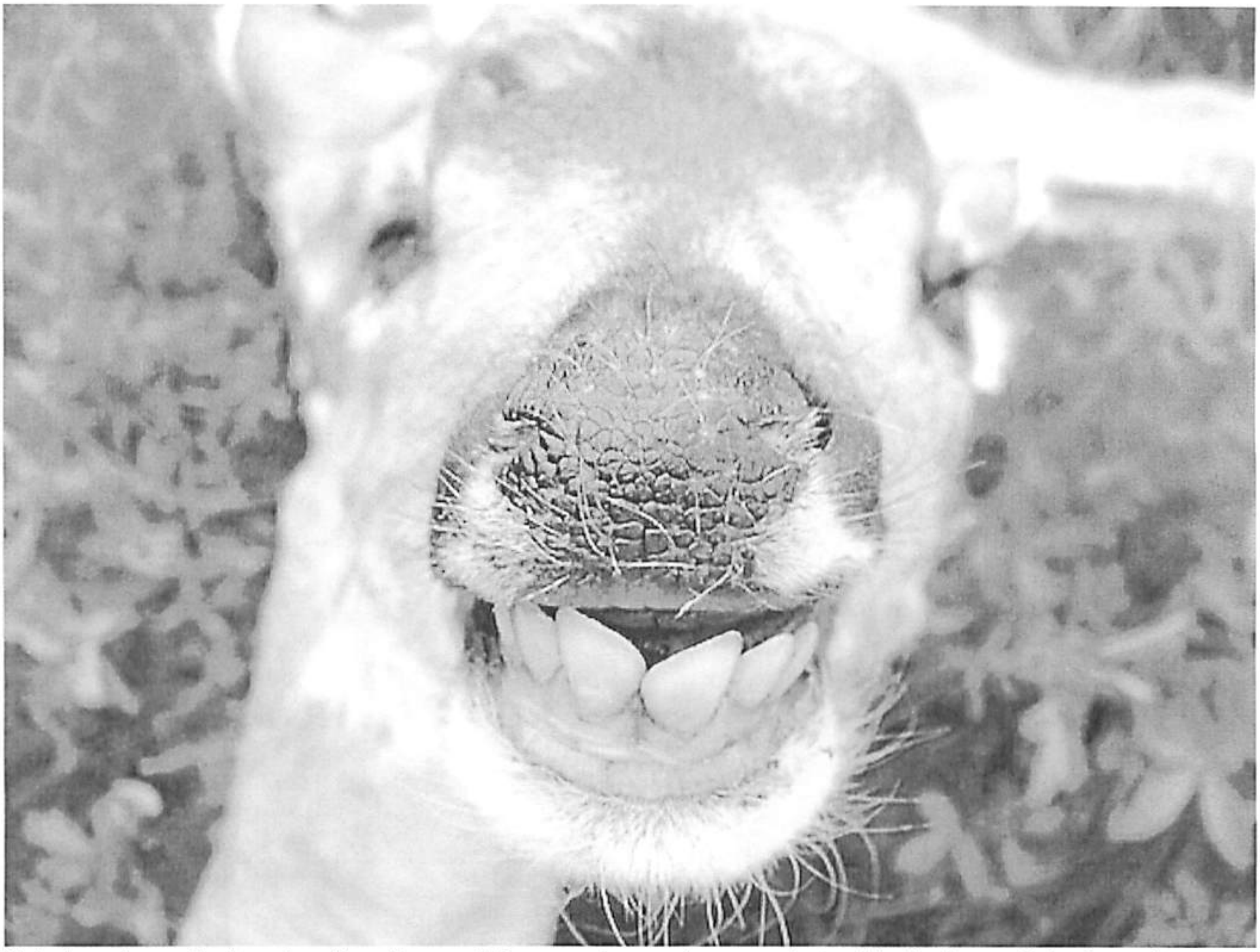
Figure 15: Mean Scrotal Sac Length of White-tailed Deer Fawns from 1996 to 2006



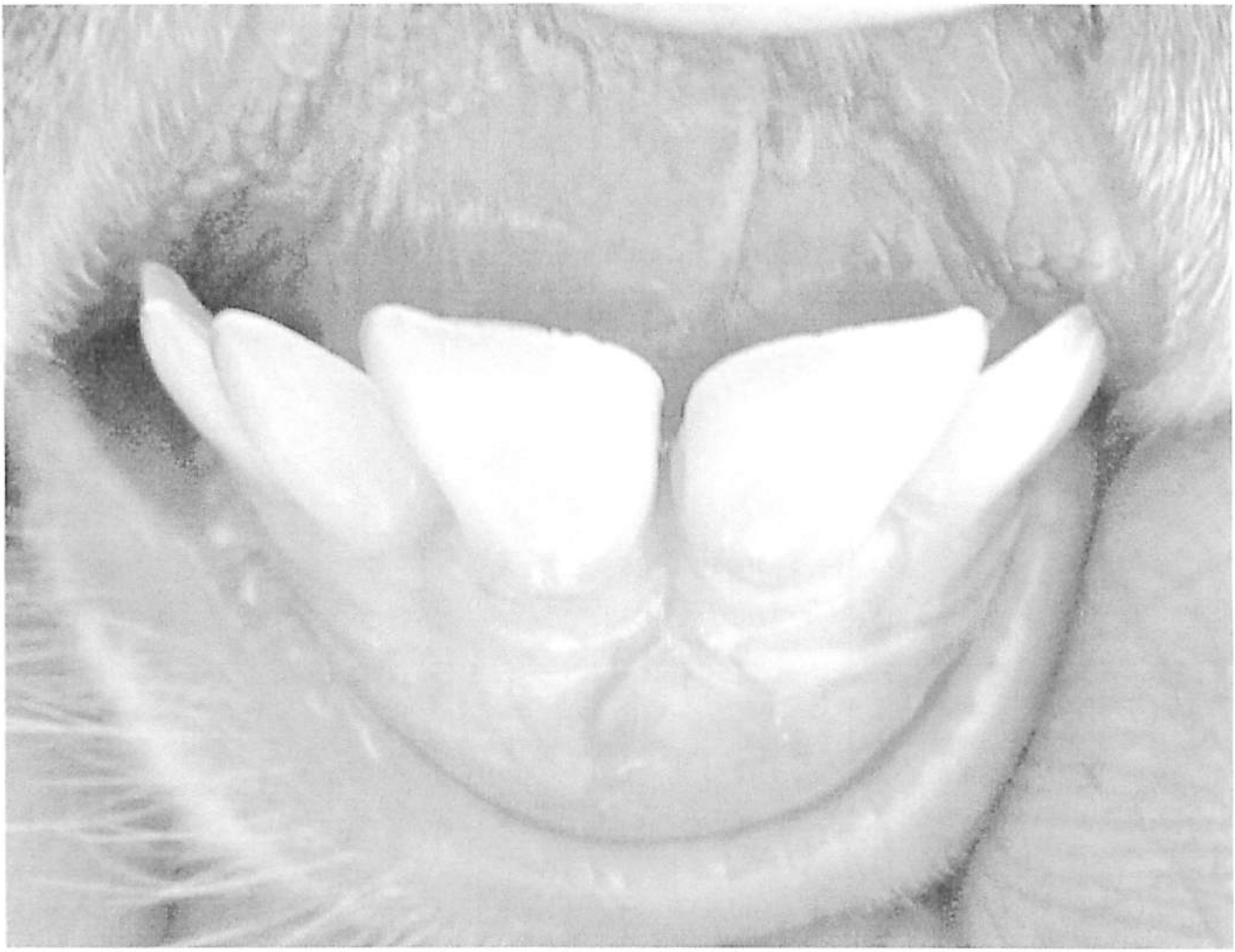
This male white-tailed deer fawn has a normal bite with normal shaped and normal width incisors, all contacting the premaxillary pad. Compare the shape and approximate size of this fawns incisors with those in the photos below. Note all incisors are normal in shape and go almost straight up to contact the premaxillary pad. They do not flare out to the side or to the front.

This male fawn had both large incisors and an underdeveloped premaxillary bone. Note that the incisors overlapped because there was not room for them in his jaw bone, they were so wide at the base. The underbite on this fawn measured 7 mm from the front of the pad to the top of the closest incisor. The incisors were much wider than the premaxillary pad and the fawn could not close it mouth over the protruding incisors. Note that the tops of the middle incisors flare out making them even wider at the tops. Compare the shape of this fawn's middle incisors with those of the normal fawn in the above photo. Most deer fawns, both mule deer and white-tailed deer with brachygnathia superior resulting in underbite have middle incisors that flare out on the outside at the top, called doglegged incisors.

This fawn died three or four days after it was born because it could not suckle its mother's teats. With a severe underbite like this fawn had, they can't get any suction. It had a small bit of mud and grass stems in its stomach when it died and that was all. It is not humane to cause newborns to be this way and die a slow painful death because of their inability to suckle.

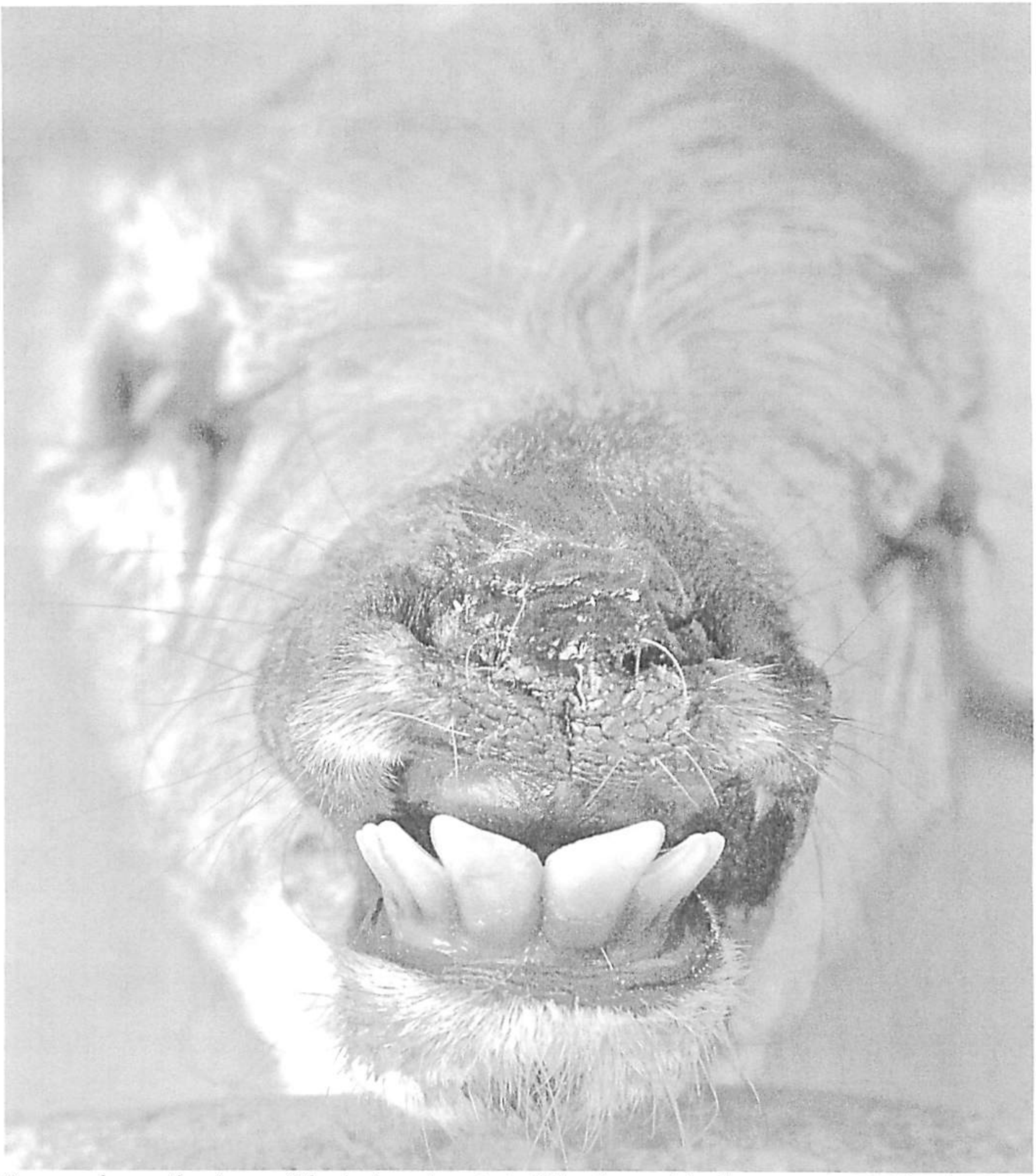


This female mule deer has brachygnathia superior and somewhat wide incisors. It had much wider incisors from outside to outside than the width of the premaxillary pad and a severe underbite as can be seen in the photo. This mule deer fawn looks just like the white-tailed deer fawn on page 12, and even has overlapping incisors only the one in front is reversed on this fawn. Both fawns died because of severe symptoms of fetal hypothyroidism. They both had very enlarged right ventricle of the heart, underdeveloped thymus and white areas on the lungs. The mule deer fawn did not die because she could not suckle. She died at about a week old, most likely because she could not digest her mother's milk. She had severe diarrhea.



Another female mule deer fawn with obviously wide shoveled middle incisors and wide side incisors flaring out to the side. Note this fawn had severe brachygnathia superior also, with a very narrow, short premaxillary pad. Mule deer seem to have a higher prevalence of brachygnathia superior in hunter-killed males than do white-tailed deer hunter-killed males, indicating mule deer may have a higher prevalence of fetal hypothyroidism than white-tailed deer.

White-tailed deer and mule deer fawns are not the only big game animals born with underdeveloped premaxillary bone, premaxillary pad and wide incisors. This is a female elk calf with similar malformations of the facial bones and incisors. This elk calf had quite severe brachygnathia superior, but the incisors, while somewhat wide at the tops and are not as unusually wide as the fawns in the previous photos. The incisors on this elk calf do go forward and flare out sideways (they are shovel shaped incisors), rather than growing straight up to contact the premaxillary pad.



On some fawns, the shape of the incisors is not at all like those of the fawn on page 9. This fawn's middle incisors flared out at the top (doglegged incisors) and the tops, rather than being straight as the incisors were on the normal fawn on page 9, were severely slanted down toward the inside. If this fawn had not had severe brachygnathia superior and the incisors actually contacted the pad, which can be seen is much, much narrower than the incisors, it still would not have been able to bite off forage very well until the sharp outside points on the middle incisors wore off. Again notice the angle out forward of the middle incisors and the flare out to the side of the three side incisors. Many fawns of both deer species have doglegged, flared middle incisors since 1995.

This is an example of middle incisors with a very wide flare at the top on a male white-tailed deer fawn. This deer also had an unusual indentation in the middle of the top of both incisors with a slight groove going down the incisor for a short distance. The number 2 incisors on each side of the middle incisors are also not very similar in shape to the number 2 incisor on a normal deer fawn. Compare these incisors with the normal white-tailed deer fawn's incisors in the photo on page 9. Just looking at the incisors, you would think you were looking at two different species of ungulate. This deer's incisors are growing more straight up, not shoveled, but because of width, are much wider than the premaxillary pad. This male white-tailed deer fawn had a normally developed premaxillary bone and the middle incisors contacted the premaxillary pad in the normal position – it did not have an underbite.

This is a photo of a different white-tailed deer fawn's wide flared grooved middle incisors, similar to the fawn in the photo on page 15, to show this happens in quite a few deer now. Again, these incisors do not look like they belong to the same species of ruminant as those in the photo on Page 9. If deer are evolving new facial configurations, the new features are not conducive to survival of the species. This deer would have had a completely normal bite if it did not have the flared out side incisors and the very wide strange shaped middle incisors. This fawn did not have brachygnathia superior and the middle incisors both contacted the premaxillary pad in the normal position. The incisors were wider than the pad because of the unusual incisor development and the flare out to the side of the three side incisors, as a result of the too wide strange shaped middle incisors, not because of anything being wrong with the upper facial bones. This configuration of the middle incisors was not observed by any of our team prior to 1995, and until recent years remained unusual.

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ORIGINAL PAPER

Observations Of Brachygnathia Superior In Wild Ruminants In Western Montana, Usa

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Keywords

Brachygnathia Superior; Congenital Fetal Hypothyroidism; Elk; Endocrine Disruption; Mule Deer; Pronghorn Antelope; White-Tailed Deer.

Abstract

Since spring of 1995 developmental malformations have been observed on many species of vertebrates. The most frequently observed of a range of skeletal anomalies is brachygnathia superior, also called mandibular prognathia, resulting from underdevelopment in length and width of the premaxillary bone forward of the upper premolars on ruminant species. To quantify these observations, facial anatomy was examined for bone and dental malformations on 1061 white-tailed deer (*Odocoileus virginianus*) that were accident-killed or died of natural causes between January 1996 and December 2010 in northern Ravalli County in the Bitterroot Valley of west-central, Montana, USA. Observations of brachygnathia superior on white-tailed deer increased from none observed on several hundred deer prior to spring of 1995 to >50% of 519 white-tailed deer examined between January 2001 and December 2010. Highest prevalence was 72% on 84 white-tailed deer fawns born 2007-2010. Smaller samples (196 total) of hunter-killed elk (*Cervis canadensis*), mule deer (*O. hemionus*), pronghorn antelope (*Antilocapra americana*), white-tailed deer and bighorn sheep (*Ovis canadensis*) heads from throughout Montana, examined for facial malformations during 2005-10, showed a high prevalence of brachygnathia superior (>40%) and a small number with mandibular brachygnathia (4%). Two small groups of domestic ruminants also had a high prevalence of brachygnathia superior (>50%). Our data indicate that this condition appeared abruptly in multiple species and has greatly exceeded any previously documented prevalence of cranio-maxillary malformations in wild ruminants.

Introduction

Since 1995, we have observed an unprecedented increase in the prevalence of brachygnathia superior in multiple vertebrate species in Ravalli County (RC) and throughout Montana, in the northwestern USA. Brachygnathia superior is also referred to as mandibular prognathism or underbite [1-3], although the first term is considered most correct [4,5]. Mandibular brachygnathia, which is also known as brachygnathia inferior and commonly called parrot mouth or overbite, is characterized by failure of the anterior of the lower jaw forward of the premolars to grow to normal length. The latter abnormality has been observed on ungulate species from other areas of Montana at a higher frequency than on those from RC.

Brachygnathia superior is characterized by failure of the premaxillary bone to grow to normal length and width, and has been reported to be a definitive sign of functional disruption of the fetal thyroid hormones in equine neonates [1-3,6]. Aside from studies concerning the disruption of thyroid hormone function during development [1-9], there is little information in the literature on cranio-maxillary underdevelopment. Most importantly, no papers reporting brachygnathia superior on adult wild ruminants were found, indicating that historically, this malformation was seldom observed in studied populations.

Wild and domestic animals are often sentinels for environmental problems that are also affecting humans [9]. Brachygnathia superior and other developmental malformations commonly associated with fetal thyroid dysfunction are increasing in domestic mammals [1,5,7]. Similar problems are being increasingly reported in bird species [10-13]. A variety of causal factors, most commonly radiation, malnutrition and manufactured hormone-disrupting chemicals, are widely known to alter the expression of thyroid-hormone-responsive genes. Well-regulated thyroid hormone is also essential for normal brain development in vertebrates, including humans [14,15].

While congenital hypothyroidism is implicated as causing brachygnathia superior and other observed malformations in foals [6], we were unable to test for thyroid function. All data collection or other work done for this paper was a public service, with no funding available for testing. However, we have examined multiple individual newborns of wild and domestic ungulates with two or more of the signs listed for congenital hypothyroidism, nearly always including brachygnathia superior.

Observations of multiple unique abnormalities on accident-killed white-tailed deer, beginning in summer 1995, were so novel that the lead author began to photographically and morphometrically document them. The original focus was on quantifying genital malformations and abnormal sex ratios [16]. On carcasses sufficiently intact for necropsy, if other anomalies or unusual features were observed, they were also recorded. Because facial malformations also were observed at increasing frequency, malformations of the upper and lower mandibles were quantified.

Because most members of our team have been working with wildlife in western Montana for 40 years or more, those individuals have had the opportunity to examine thousands of ungulates and other vertebrates, both dead and alive, over that time. Between 1979 and 2000, one of us (RDH) collected and disposed of accident-killed white-tailed deer, mule deer and elk, typically several hundred animals per year, from area roadsides as one of his responsibilities as a Warden (now retired) for the State of Montana Department of Fish, Wildlife and Parks (MFWP). The lead author, a wildlife rehabilitator, dissected many of the intact accident-killed animals each year after 1979 to use for food for carnivores at their wildlife rescue center and some carcasses were examined where they were found. Also as a public service for MFWP, the lead author cared for several fawns per year of both deer species and five elk calves between 1979 and 2003, all closely examined upon arrival.

In 1998, another author (GTH), a professional taxidermist who cleans and prepares game animal heads, began observing facial anomalies on wild ruminants. Because of timing and similarity in malformations observed, we subsequently began working together. Between 2005-2010, heads of hunter-killed wild ruminants were examined for brachygnathia superior and mandibular brachygnathia. We here report our observations of a high prevalence of brachygnathia superior from 1996 through 2010 on individuals of multiple ruminant species from Ravalli County and from throughout Montana, USA.

Materials and Methods

Study Area

The primary study area: northern Ravalli County, Montana, USA, 6185 km^2 in extent, is centered between the northern and southern state lines in the western portion of the state. Encounters with vehicles, fences or dogs provided the accident-killed deer that were examined. Butchered beef (*Bos taurus*) heads and live newborn goats (*Capra hircus*) examined were also from northern RC. In addition, heads of hunter-killed animals harvested throughout Montana, an area covering approximately 381,000 square kilometers, were examined for facial malformations.

Collection of Data

For a fourteen-year period beginning in January 1996 and ending in December 2010, white-tailed deer that were accident-killed or had been euthanized due to injuries were examined post-mortem for evidence of facial bone malformations (Fig. 1). Age, sex, date of examination, and several body measurements were recorded for each. The year of birth was determined by examining tooth eruption [17]. With both year of birth and day of death (+/- 2 days) known, age determination was accurate to within two months. From 1999-2010, to quantify degree of facial malformations, the distance between the anterior terminus of the maxillary pad and the top edge of the central lower incisors was measured in millimeters on undamaged heads (Fig. 1d). Measurements of normal bites are recorded as negative values, reflecting that the incisors contacted the maxillary pad behind the anterior terminus.

Heads of harvested game animals received from hunters were examined for anomalies by GTH prior to removal of soft tissue. During the 2005-10 hunting seasons, elk (48), mule deer (48) and pronghorn antelope (52) heads were examined. Hunter-killed white-tailed deer (29) were included in 2007-10. Cleaned skulls of adult male bighorn sheep (19) were examined in fall 2010. The presence of underbite (brachygnathia superior), overbite (mandibular brachygnathia) or normal bite was recorded. Year of birth was not determined. The majority of the animals were adult males, 1.5-6.5 years old.

On many newborn animals examined, even when the first lower incisors occluded against the maxillary dental pad indicating that the premaxillary bone was normal in length, the premaxillary bone and thus the dental pad were distinctly narrower than the incisors (Fig. 1b). Because the dental pad is typically wider than the incisors (Fig. 1a) on ruminants [18], the width across the anterior of the premaxillary dental pad where the lower incisors normally contact (Fig. 1a) was measured to compare with the measurement taken of the width of the lower incisors from the outside edge of the canine on the left to the outside edge of the canine on the right on available adult and juvenile white-tailed deer, as well as adult antelope, mule deer, and bighorn sheep during 2006-2010.

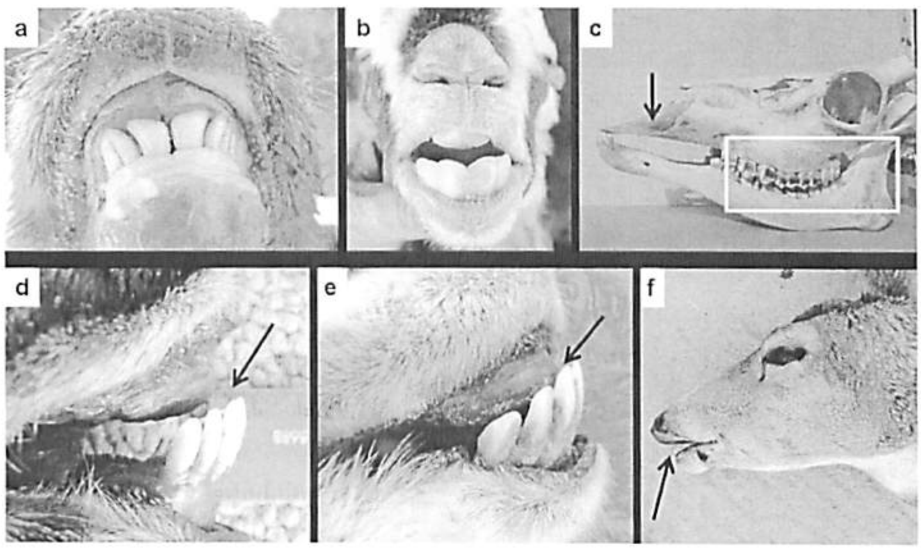

Fig. 1: Examples of normal bite (a), brachygnathia superior (b-e) and mandibular brachygnathia (f) in ungulates from Montana: **a.** Front view of a female white-tailed deer fawn, with incisors contacting the premaxillary pad. **b.** Front view of a newborn goat showing narrow premaxillary pad in relationship to the lower incisors. **c.** Side view of the skull of male white-tailed deer showing the molars in proper alignment (box) and short premaxillary bone (arrow). **d.** Arrow indicates the distance from the anterior edge of the premaxillary pad to the top edge of the middle incisors of a 3.5 year-old male hunter-killed mule deer. **e.** Mouth of an adult male pronghorn antelope showing brachygnathia superior (arrow) and premaxillary pad narrower than the incisors. **f.** Hunter-killed female mule deer from near Miles City, MT, with a short lower jaw (mandibular brachygnathia) (arrow).

Additionally, the following features were checked on whole carcasses: the conjunctiva for blepharitis, the teeth, limbs and hooves for anomalies, and on those necropsied, the heart for enlarged right ventricle and for dilated lymphatic vessels on the surface. However, as those conditions are more difficult to quantify, they are only discussed as ancillary observations.

Two other small data sets were collected in 2009. Thirteen heads of 1.5 year-old butchered male beef (*Bos taurus*) and 20 newborn domestic goats (*Capra hircus*) of multiple breeds also were examined for presence or absence of facial malformations.

Results

Odocoileus virginianus fawns (337) born in Ravalli County in spring of 1995 through spring of 2000 exhibited an average prevalence of brachygnathia superior of 5% (Table 1). Prevalence sharply increased beginning in 2001 (Fig. 2), with prevalence averaging 52% on 330 fawns between spring 2001 and December 2010 (Table 1). The period of highest occurrence of brachygnathia superior in the 15 years of study began in spring 2007, with an average of 72% on 84 fawns born 2007-2010. On 394 adult accident-killed *O. virginianus* examined, brachygnathia superior was found on 13% from 1996-2000 and on 47% from 2001-2010. Mandibular brachygnathia was present on only 6 of 1061 (<1%) RC *O. virginianus* examined (Table 1).

Table 1: Prevalence of facial malformations on multiple species of Montana ruminants (# Exam. = number examined; Malform. = malformations; %BS = percent exhibiting brachynathia superior; %MB = percent exhibiting mandibular brachynathia).

Species	Year Exam.	Sex	Age Class	Area	# Exam.	# Jaw Malform.	% Normal	%BS	%MB
O. virginianus	1996-2000	F	Fawn	RC	146	5	97	3	0
O. virginianus	2001-2010	F	Fawn	RC	146	75	49	50	1
O. virginianus	1996-2000	M	Fawn	RC	191	12	94	6	0
O. virginianus	2001-2010	M	Fawn	RC	184	99	46	53.5	0.5
O. virginianus	1996-2000	M-F	Adult	RC	205	26	87	12.5	0.5
O. virginianus	2001-2010	M-F	Adult	MT	189	89	53	46	1
O. virginianus	2005-2010	M	H-K Adult	MT	29	14	52	38	10
O. hemionus	2005-2010	M	H-K Adult	MT	48	36	25	67	8
A. americana	2005-2010	M	H-K Adult	MT	52	38	27	56	17
C. canadensis	2005-2010	M	H-K Adult	MT	48	21	56	31	13
O. canadensis	Fall 2009	M	H-K Adult	MT	19	10	47	53	0
C. hircus	Spring 2009	M	Newborns	RC	20	20	0	100	0
B. taurus	Fall 2009	M	1½ yr	RC	13	9	31	69	0
Total examined	All Years	M-F	All	MT	1290	454	65	31	4

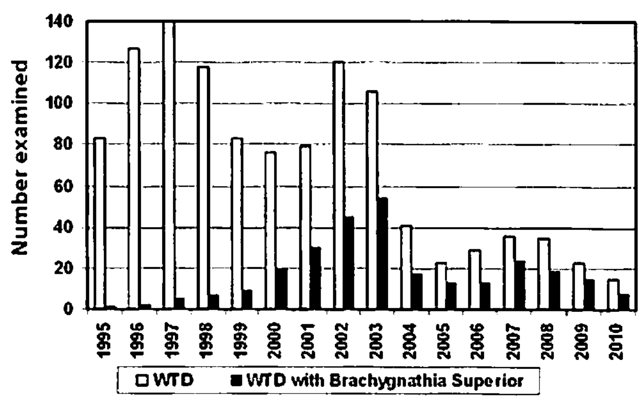

Fig. 2: Number of white-tailed deer (WTD) examined and the number of those that exhibited brachygnathia superior, by year of birth.

On RC *O. virginianus* specimens exhibiting brachygnathia superior for which the measurement between the anterior terminus of the premaxillary pad and the top of the lower incisors was possible, that offset ranged from 0 and 8 mm. Because that distance also varies with age, only data from undamaged heads of 413 fawns examined between 1999 and 2010 were statistically analyzed. Those data were tested for differences between males and females using single-factor analysis of variance (ANOVA), with results indicating no significant difference ($p = 0.40$). The fawns of both sexes were then pooled by year and tested using ANOVA, revealing highly significant differences across years ($P = 0.00015$). The means and standard errors were calculated and plotted by year (Fig. 3), with the linear regression revealing a significant increase over the study period, despite substantial inter-annual variability.

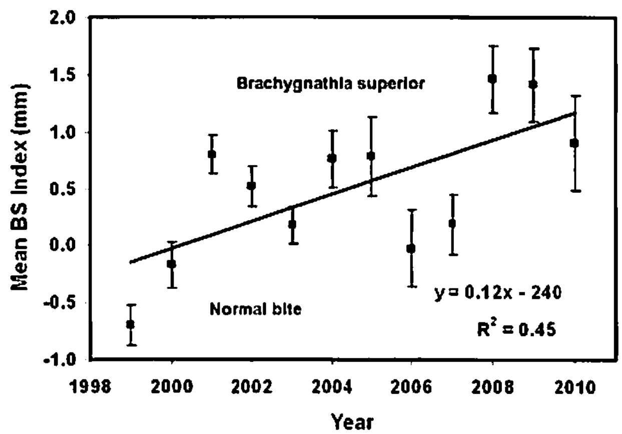

Fig. 3: Results of measurements from undamaged heads of 413 fawns of the distance between the anterior terminus of the premaxillary pad and the top of the first lower incisors [Mean BS (brachygnathia superior) Index]; negative values indicate normal bite. Means with standard error bars for data collected between 1999 and 2010 are shown, as is the linear regression and associated values.

The smaller data sets, including hunter-killed *O. virginianus*, *O. hemionus*, *C. canadensis*, *A. americana* and *Ovis canadensis*, in addition to butchered male *B. taurus* and newborn *C. hircus*, further demonstrate that brachygnathia superior is remarkably prevalent in multiple ruminant species from throughout Montana (Table 1). Moreover, *ca* three-quarters of the heads examined exhibited incisors that extended laterally beyond the width of the premaxillary pads (Table 2).

Table 2: Observations of wild ungulates species found with incisors extending laterally beyond the width of the premaxillary pad (2006-10).

Species	Age Class	Number Examined	Wider Incisors (%)	Wider Premax. Pad (%)	Equal in width (%)
A. americana	Adults	11	82	9	9
O. hemionus	Adults	10	80	0	20
O. virginianus	Adults	26	[illegible]	19	4
O. virginianus	Fawns	82	71	16	10
O. canadensis	Adults	19	68	21	11
Total examined	All	129	76	15	9

Blepharitis of the conjunctiva was seasonally present in northern RC on many of the examined *O. virginianus* and *O. hemionus*. Tests of the conjunctiva of several deer by Alpha Veterinary Laboratory, Hamilton, MT, showed no viral or bacterial infection, indicating an airborne irritant. Between 2007 and 2010, enlarged right ventricle of the heart, dilated lymphatic vessels on the heart's surface and thymic underdevelopment were noted more often than in previous years during necropsy of fawns.

Discussion

The prevalence of brachygnathia superior on ruminant species we are reporting is far higher than has previously been reported (to our knowledge) for a bone malformation in a wild mammal population and likely greater than previously found in any ruminant species [19]. From 1959-1961, an extensive study of facial bones, teeth and other malformations in a large sample of 39,027 *O. virginianus* in Michigan reported no brachygnathia superior [20]. Even in a severely inbred herd of white-tailed deer, the occurrence of 6 fawns exhibiting brachygnathia inferior, representing 6% of the fawns born over an 11-year period, was considered unusual [21]. Though easily recognized and called underbite by livestock owners, the condition has not been widely reported in Montana for political and economic reasons, even though it has become a common abnormality on both wild and domestic grazing animals.

Mandibular brachygnathia was found on individuals of four species of hunter-killed ruminants at a higher prevalence than the <0.2% reported on Michigan *O. virginianus* [20]. Facial malformations and the associated reproductive malformations on ruminant species appear to be a recent phenomenon, uncommon in Montana prior to 1995. In a report on 100 *O. virginianus* adults and 32 fetuses examined from our study area in 1992, none were found with brachygnathia superior, mandibular brachygnathia or other malformation [22]. The increase in both prevalence (Fig. 2) and degree (Fig. 3) of brachygnathia superior, as well as the interannual variability found in our data, implicate an environmental cause that is generally increasing but that varies from year to year.

Brachygnathia superior has primarily been reported from studies of newborn ungulates suffering from naturally or experimentally induced congenital hypothyroidism [6-8,23-25], as are the associated genital abnormalities [16] and other malformations and conditions [3,6,23,25] we found on RC ungulates. Most animals with one or more of the other signs consistent with congenital hypothyroidism also had brachygnathia superior [1-3,6,7]. Many of those abnormalities cause mortality at or soon after birth [1,6], so are not easily observed on wild newborns and are seldom found on adult animals. Neither brachygnathia superior nor maxillary brachygnathia commonly cause mortality postnatally, so they can be observed on individuals of both sexes and all age groups. However, facial malformations likely compromise feeding efficiency and therefore increase probability for starvation during winter or prolonged drought in wildlife, and may reduce growth rates in domestic animals.

Moreover, experimental research has revealed that malnourished domestic sheep produced offspring with compromised thyroid function [24]. The lead author (unpublished) has observed brachygnathia superior in the offspring of malnourished domestic goats. Thus, one can postulate that pregnant female wild ruminants whose offspring have been similarly affected may not have been able to procure sufficient nutrition to support themselves and their fetal young during the winter. Moreover, inadequate nutrition, with consequent mineral deficiency, would likely enhance the effects of exposures to hormone-disrupting environmental toxins on a fetus's development and growth [24,25].

In addition to the mammals observed with bone malformations in western Montana, numerous individuals of wild bird species with brachygnathia superior and a variety of limb and feather malformations have been documented photographically by the lead author (unpublished) and others. Similar bill malformations have been reported on avian species from other locations in the USA [10,26], including Alaska [26,27], Washington [11] and southwestern states [12]. The shorter upper bill is typically narrower than the normal lower bill, similar to the discrepancy between the width of the premaxillary pad and the incisors on ruminants. Frequency of occurrence of bill, limb and feather malformations in bird populations is difficult to determine because they cause high mortality in pre- and post-fledglings.

Our observations of anomalies on mammals and birds also correspond in time with observations of significant increases in amphibian abnormalities with precipitous population declines connected to hormone disruption throughout the United States and Canada [28]. We directly observed the previously documented [29] decline in populations of Boreal Toad (*Bufo boreas boreas*) in Montana after 1994 and toads with hind limb malformations were noted in 1997 and 1998.

Multiple vertebrate species suddenly and simultaneously exhibiting similar developmental malformations is strong evidence for an environmental cause. Numerous studies of amphibians, birds and domestic mammals have shown that thyroid function is easily altered by exposure to a variety of chemicals [23]. Numerous manufactured compounds [30], many with the potential to disrupt the normal function of a variety of hormones [23,25,28,31,32], are now present in the air, water and food. While disruption of sex hormones has been most studied, those chemicals that react with thyroid hormone, vitamin A receptors and retinoic acid levels may be even more damaging to fetal growth and health [28,31-33].

Signs previously described for equine foals [1-3,6] and other species [7,8,24,34] with congenital hypothyroidism were nearly identical to those we found on necropsied fawns of white-tailed deer and mule deer, and on elk calves, beef calves and newborn goats. Signs reported for bovines [35] include not only hypothyroid signs [36], but also hyperplasia of the thymus [37] and myocardial degeneration and necrosis of the left ventricle [38]. Additionally, thymic aplasia [38] was found in another ruminant, newborn sheep, with experimentally induced congenital hypothyroidism [24]. Many of the white-tailed deer fawns that had brachygnathia superior at birth also exhibited anomalous thymic and cardiac development, as well as other signs listed for congenital hypothyroidism [6,34], including contracted tendons and herniated umbilicus. Since 2007, we have also observed higher prevalence of underdeveloped and malformed male genitalia than we previously reported on RC *O. virginianus* fawns [16]. Anomalies of reproductive organs are now recognized as being a worldwide problem in an unprecedented number of wild vertebrate species [39]. While direct causes are difficult to identify [9,40,41], the signs we found on wild and domestic species are consistent with those reported in experimental studies of congenital hypothyroidism in ungulate species [6,7,24,37,38].

Why Did the Prevalence of Brachygnathia Superior Suddenly Increase?

Many manufactured compounds and some heavy metals induce serious thyroid dysfunction at very low levels of exposure [9,23,25,31]. Chronic exposure to toxins that disrupt the function of or replace vital hormones can result in congenital hypothyroidism in newborn animals. At present, thyroid hormone-disrupting environmental chemicals are tested by measuring their ability to affect circulating levels of thyroid hormones [15]. However, essential thyroid hormone actions can be adversely affected without detectable changes to thyroid hormone levels as they are currently measured [31]. If specific environmental chemicals or their metabolites bind to fetal thyroid-hormone receptors, they can alter thyroid-hormone signaling responsible for normal development of fetuses [40,41]. Realistically, exposure to multiple hormone-disrupting compounds known to cause congenital hypothyroidism in vertebrates [8,15,23,28,29,41,42] is now common to all organisms worldwide. The effects of such exposure on bone development of the skull and likely on the development of the brains of mammals and birds may be similar to the effects documented for dioxin exposure [43-46].

Multiple hormone disrupting toxins were found in snow, lake water, foliage and animals on the tops of mountains in USA national parks, with Glacier National Park, nearest to our study area, having the highest levels [30,47]. Such compounds are usually water soluble with a molecular structure that allows them to disrupt the normal activity of a variety of hormones. In addition, fetal exposure to both nitrates and nitriles have been shown to disrupt thyroid hormone function [1,6,48] and nitrates are known to cross the placenta of rats, guinea pigs, pigs, and cattle [1].

One chemical that we suspect as being a factor in causing the sudden increase in congenital hypothyroidism in mammals and birds is chlorothalonil, a nitrile fungicide used on potatoes against potato blight. The amount of this fungicide used on potato fields in states up wind of western Montana approximately doubled in summer 1994 and continued to increase through 2000, decreasing somewhat after 2001 [49]. Similar polyhalogenated aromatic hydrocarbons (PHAHs) are known to cause multiple deformities and effects on multiple organs [50]. A recent study found exposure to chlorothalonil at one one-thousandth of levels commonly found in the environment resulted in mortality to tadpoles of all four frog species tested and endocrine disruption was indicated [51]. Low levels of toxins, including chlorothalonil [52], can be carried far from the application site in moist weather fronts [53]. Predictably [49,50], the increased prevalence of reproductive malformations corresponded to increased chlorothalonil use in states up wind of our area.

Another possible contributing factor is increasing use of neonicotinoid insecticides, registered for use in 1992 [54] and now one of the most widely used group of insecticides in the United States. Like chlorothalonil, winds can transport neonicotinoids over great distances from sites of application [55]. Two widely used neonicotinoids, imidacloprid and clothianidin, are acetylcholine receptor agonists and have been implicated in causing the die offs of domestic honeybee colonies [55,56]. Detrimental effects on honeybees were also found with exposure to chlorothalonil [57]. Neonicotinoids synergized with fungicides to increase the toxicity of the neonicotinoids to honey bees over 1,000 fold in lab tests [58]. Chlorothalonil and neonicotinoids in combination could also have a synergistic effect on developing mammals, as is strongly suggested by studies showing that nicotine and cyanide are responsible for disrupted fetal development in babies born to human mothers who smoke cigarettes [59].

A developing fetus is extremely susceptible to almost immeasurably small amounts of toxins crossing the placenta, potentially being affected by parts per trillion or even parts per quadrillion [59]. Many of the resultant disruptions of cellular development appear to be epigenetic and inheritable [60,61]. Pediatricians and the Ontario College of Family Physicians state that there is no safe level of pesticide exposure, especially to fetuses [62,63]. While the doctors were referring to human fetuses, the same is likely true for fetuses of other mammals.

Conclusions

Our observations of a previously unreported, extremely high prevalence of malformations, which are consistent with congenital hypothyroidism, on multiple wild ruminant species are critical to understanding the extent of serious wildlife and human health problems. Reproductive malformations [64-66] and many other health problems associated with endocrine disruption appear to be epidemic in human populations [67,68]. Signs of hypothyroidism in human neonates include not only skull and maxillary underdevelopment and neurological underdevelopment, but also vision and hearing problems, heart disease, underdeveloped external genitalia, and many other challenges [15,23,69].

Our observations of an increasing prevalence of underdeveloped skull and upper facial bones in wild ruminants have corresponded to the simultaneous increase of reproductive malformations reported on males of many families of vertebrates [16,38,70], which have been attributed to exposure to endocrine-disrupting toxins [8,9,40,69-72]. When exposed to one or a combination of environmental endocrine-disrupting toxins, pregnant females have been shown to experience adverse effects on cellular function [40,67,68]. As a consequence, their young may develop signs of thyroid-hormone disruption, one of the most common on ungulates being brachygnathia superior [1,3,6,7]. Thus, we suspect that the sudden, concurrent appearance of the high prevalence of brachygnathia superior and the other signs consistent with congenital hypothyroidism in multiple ruminant species strongly indicates widespread exposure of affected embryos and fetuses to multiple endocrine-disrupting environmental toxins.

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