EFFECTS OF FLUORIDE INGESTION ON WHITE-TAILED DEER
(ODOCOILEUS VIRGINIANUS)

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ABSTRACT: The effects of the addition of 25 or 50 ppm fluoride (F), as sodium fluoride (NaF),
to the rations of 5-mo-old male white-tailed deer were similar to those observed in domestic cattle
fed similar amounts of fluoride. The ingestion of 50 ppm F for 2 yr resulted in the accumulation
of over 7,000 ppm F in bone ash. Accumulation of fluoride in antlers was extensive and occurred
more rapidly than in skeletal tissue. Fluoride ingestion resulted in lesions on the developing
incisors that were similar, but not identical to those seen in other species. Increased molar wear
in the deer fed 50 ppm F was minimal, and no gross pathology of the mandible was observed.
Only mild hyperostosis of the long bones was evident.

INTRODUCTION

The effects of excessive ingestion of fluorides by domestic animals have been
well studied and documented (National Research Council, 1971, 1974), but rela-
tively little information describing the effects of fluoride on wild herbivores is
available. A number of reports have described increased levels of skeletal fluoride
and gross skeletal and tooth lesions in deer obtained from areas near fluoride-emitting
industries (Robinette et al., 1957; Karstad, 1967; Kay et al., 1975; Newman
and Yu, 1976; Newman and Murphy, 1979). These reports have indicated that
the gross dental and skeletal lesions observed are similar to those observed in cat-
tle and other domestic species but they do not allow an assessment of the amount of
fluoride needed to produce these responses. This report describes the effects of
the ingestion of known amounts of fluor-
ide by white-tailed deer.

MATERIALS AND METHODS

Three buck fawns were obtained from the
Southeastern Cooperative Wildlife Disease
Study, Athens, Georgia. Each was paired with
a buck fawn from South Carolina. All six fawns
were obtained from the wild at an age of less
than 2 wk and were bottle fed until weaned at
85–90 days of age. These fawns were main-
tained in a 3-meter-high chain-link fenced
enclosure (each pen measuring 4.6 by 13.7 met-
ers) at the Dennis Wildlife Center in Bonneau,
South Carolina. Two of the fawns were fed a
commercial horse ration (Ralston Purina, Omo-
lene-100), and the other two pair of fawns were
fed the same ration with either 25 or 50 ppm
F added as NaF. The control ration was ana-
lyzed to contain from 19 to 25 ppm F over the
course of the experiment.

In the fall of 1981, when the deer had been
on the experiment for 1 yr, they were immo-
bilized using Rompun (Xylazine, Haver-Lock-
hart, Bayvet Division, Cuter Laboratories, Inc.,
Shawnee, Kansas 66201, USA), and the antlers
and the 7th through 13th coccygeal vertebrae
were studied. The deer were immobilized again
in the fall of 1982 and subsequently euthanized
with T-61 (euthanasia solution, Taylor Phar-
macal Co., Decatur, Illinois 62525, USA). Sam-
ple obtained included antlers, mandibles with
incisors, femur, metacarpal (cannon bone), and
the 1st through 6th coccygeal vertebrae. The
bones were cleaned by boiling in a weak deter-
gent solution, air dried, and examined for fluo-
ride-induced lesions. Antlers were sampled by
analyzing a 1-cm disc obtained approximately
3 cm from the base of the antler. Representative
samples of metacarpal and mandible were
obtained by drilling a series of holes in various
parts of the bone and combining the bone par-
ticles. Femurs were sampled by bisecting the
bone as described by Suttle and Kolstad (1974).
The bone particles, samples of antlers and the
cleaned vertebrae were dried, ashed at 600 C
for 12 hr, ground in a mortar and an aliquot
analyzed for fluoride as previously described
(Cralley et al., 1969). All values for fluoride in
tissues are expressed as ppm F ash wt.

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Table 1. Body weight and antler development of white-tailed deer fed fluoride.

<table>
<thead>
<tr>
<th>F added</th>
<th>Animal</th>
<th>Body wt (kg)</th>
<th>Antler beam length (cm)</th>
<th>1981</th>
<th>1982</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>5 mo</td>
<td>17 mo</td>
<td>29 mo</td>
<td>R</td>
</tr>
<tr>
<td>0 ppm</td>
<td>A</td>
<td>22.3</td>
<td>50.0</td>
<td>62.3</td>
<td>26.7</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>19.1</td>
<td>65.0</td>
<td>84.1</td>
<td>13.0</td>
</tr>
<tr>
<td>25 ppm</td>
<td>C</td>
<td>19.1</td>
<td>52.7</td>
<td>62.3</td>
<td>19.7</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>—</td>
<td>44.1</td>
<td>52.7</td>
<td>14.0</td>
</tr>
<tr>
<td>50 ppm</td>
<td>E</td>
<td>17.3</td>
<td>43.6</td>
<td>48.2</td>
<td>16.8</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>14.0</td>
<td>40.1</td>
<td>48.1</td>
<td>17.8</td>
</tr>
</tbody>
</table>

* Antler broken.

**RESULTS**

*Growth and antler development:* Data on the body weight of the deer, and antler beam length, a measure of antler’s development, are shown in Table 1. The weight of the bucks after 2 yr of study ranged from 48.1 to 84.1 kg, which was comparable to weights of other bucks maintained in the facility and fed this ration. The two smallest bucks were those fed 50 ppm F. These two bucks did not adapt well to confinement and were very wild throughout the course of the experiment. Antler development was similar in all bucks.

*Skeletal and antler fluoride:* Vertebral biopsies are often used to assess the extent of fluoride exposure of cattle in field situations (Suttie, 1967), and vertebral biopsies were obtained from all bucks after 1 yr on the experiment. The possibility of using shed antlers of wild ungulates as a monitoring method was also assessed (Table 2). Retention of fluoride in the coccygeal vertebrae of the bucks fed the commercial horse ration reached 1,500 ppm F after 1 yr and 2,000 ppm F after 2 yr on the experiment, while the retention of fluoride in the coccygeal vertebrae of the bucks fed an additional 50 ppm F exceeded 7,000 ppm F at the end of the 2-yr experiment. The retention of fluoride in the antlers was about 65% of that found in the vertebrae in the control animals and about 80% in the deer fed higher levels of fluoride. This ratio did not change significantly between the 2 yr and illustrates the enormous capacity of the rapidly calcifying antler tissue to accumulate fluoride. Results of fluoride analyses of other bones taken from the deer at the end of the 2-yr study are shown in Table 3. Increased fluoride ingestion caused an increased retention of fluoride in all bones sampled. Fluoride retention in mandibles was similar to that observed in coccygeal vertebrae and, in the control animals, was much higher than in the two long bones sampled. This difference decreased as fluoride intake increased.

*Dental pathology:* Excess fluoride ingestion causes pronounced lesions on the developing dentition which are similar in most species (Fejerskov et al., 1983). These changes have not been extensively described in deer. Confinement in pens often results in physical damage to incisors, and complete intact incisors were obtained from only one of the two deer in the control and 25 ppm F group. The fluoride-induced lesions seen are shown in Figure 1. The mature incisors from control deer (B) appeared dense, shiny, and smooth with uniform calcification of the enamel. The incisors of deer fed an additional 25 ppm F (C) showed a general mottling characteristic of dental fluorosis in other species. When viewed with transmitted
light from the rear, the horizontal banding typical of fluoride ingestion in other species was evident. This mottling of the enamel was more pronounced in the teeth obtained from deer fed 50 ppm F (F), and in addition there were distinct large areas of enamel hypoplasia. The enamel depth was much less uniformly distributed over the surface of the tooth than would typically be seen in teeth of cattle exhibiting significant enamel hypoplasia (Shearer et al., 1978). The general malformation which is apparent in the first incisor of tooth C was not observed in other teeth of fluoride-fed deer.

The mandibular molars of all deer are illustrated in Figure 2. In other species (NRC, 1971, 1974), as well as deer (Robinette et al., 1957), excess fluoride exposure can result in irregular wear of the molars. This response was not evident to a significant degree in these teeth. The deer were not fed elevated fluoride until they were 4–6 mo old. Although accurate data on tooth formation, in contrast to eruption (Severinghaus, 1949; Robinette et al., 1957), are not available, it is likely that only the premolars and the third molar were formed after fluoride administration. Generalized wear was evident on the premolars of the two animals in the 50 ppm F group but not on the others. Attempts to quantitate molar wear by calculating the ratio between the widths of the occlusal surfaces on the buccal side and heights of the lingual crests above the gum line (Robinette et al., 1957) did not reveal any significant effect of fluoride ingestion.

### Table 2. Fluoride content of antlers and coccygeal vertebrae of white-tailed deer fed fluoride.

<table>
<thead>
<tr>
<th>F added</th>
<th>Animal</th>
<th>Antler (ppm F, ash wt)</th>
<th>Vertebræ (ppm F, ash wt)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>A</td>
<td>996</td>
<td>1,429</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>888</td>
<td>1,188</td>
</tr>
<tr>
<td>25 ppm</td>
<td>C</td>
<td>3,005</td>
<td>3,800</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>3,092</td>
<td>4,314</td>
</tr>
<tr>
<td>50 ppm</td>
<td>E</td>
<td>5,628</td>
<td>5,291</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>4,902</td>
<td>5,808</td>
</tr>
</tbody>
</table>

### Table 3. Fluoride content of skeletal tissues of white-tailed deer fed fluoride.

<table>
<thead>
<tr>
<th>F added</th>
<th>Animal</th>
<th>Fluoride in bone (ppm F, ash wt)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mandible</td>
</tr>
<tr>
<td>0</td>
<td>A</td>
<td>1,678</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>1,757</td>
</tr>
<tr>
<td>25 ppm</td>
<td>C</td>
<td>4,514</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>4,615</td>
</tr>
<tr>
<td>50 ppm</td>
<td>E</td>
<td>7,262</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>6,106</td>
</tr>
</tbody>
</table>
**Skeletal pathology:** Slight generalized periosteal hyperostosis was evident on the metacarpal bone (Fig. 3) of both deer receiving 50 ppm F (E and F), and to a lesser extent on the metacarpal bone of one of the deer (C) receiving 25 ppm F. No fluoride-induced exostotic lesions or ligament calcification were noted on any of the bones, but there was a generalized enlargement on the medial surface of the metacarpal bone from deer E (50 ppm F). In contrast to the effects on the metacarpal bones, generalized hyperostosis was not seen on the femur bones of any of the deer. An enlargement or distortion near the head of the shaft of the femur from deer E was evident, but it was not associated with the porous type of bone structure usually seen in fluoride-induced lesions of long bones. There were no gross abnormalities of the mandibular bones.

**DISCUSSION**

These studies appear to represent the first assessment of the effects of the ingestion of known amounts of fluoride by deer. A limited number of samples of long bones and mandibles of mature deer obtained from presumably fluoride-free areas have been analyzed and reported to contain from 100 to 600 ppm F on a dry fat-free basis which would be equivalent to 150–900 ppm on an ash wt basis (Karstad, 1967; Kay, 1975; Kay et al., 1975a; Newman and Yu, 1976; Newman and Murphy, 1979). A more extensive survey has reported values toward the lower end of this range (Kay et al., 1976). The values observed in these control deer (A and B) of 1,100–1,300 ppm are somewhat higher and undoubtedly reflect fluoride-containing phosphate supplements in the commercial horse ration. Fluoride in phosphate supplements is only about half as available to the animal as that in NaF (National Research Council, 1971, 1974; Clay and Suttie, 1985), so the fluoride intake of the control deer was probably equivalent to about 10 ppm F of a soluble fluoride. Forages and deer browse in pollution-free areas are more likely to contain 3–6 ppm F, so the values obtained are consistent with other observations (Kay et al., 1976; Newman and Murphy, 1979). The values
of 5,000–8,000 ppm F in the skeletal tissue of the deer fed 50 ppm F for 2 yr are in the same range as those observed in bones of some of the deer obtained near sources of industrial fluoride pollution (Karstad, 1967; Kay, 1975; Kay et al., 1975a; Newman and Yu, 1976; Newman and Murphy, 1979).

At a given fluoride intake, skeletal fluoride retention appears to be equal to or slightly more rapid and extensive in deer than in cattle, the most studied species. The deer in this study which had 25 ppm F added to their ration (total intake equivalent to about 35 ppm of soluble fluoride) for 1 or 2 yr had approximately the same vertebral fluoride concentration as cattle with 40 ppm F added to their ration for the same periods (Suttie and Faltin, 1973).

A rapid fluoride accumulation was evident in antlers, and these deer accumulated nearly as much fluoride in antlers during the 5-mo antler growth period of the second year as they did in the long bones over a 2-yr period. These data suggest that analysis of shed antlers or antlers obtained from hunters might be an excellent way to monitor fluoride impact in the wild.

The lesions observed in the developing dentition appeared to be similar to those studied in cattle, but the deer incisors appeared somewhat more sensitive. The patchy areas of enamel hypoplasia seen on the teeth of the deer fed 25 and 50 ppm F have not been observed at this intake level in cattle, although a mild mottling would be seen at 25 ppm and generalized enamel hypoplasia at 50 ppm (National Research Council, 1971, 1974).

Captive deer fed a constant diet of a commercial horse ration usually exhibit excessive tooth wear. The mandibles from the 2½-yr-old bucks were aged according to tooth wear (Severinghaus 1949) by six wildlife biologists. By this criterion the two bucks in the control and the two bucks in the 50 ppm group were judged to be 3½ yr old, buck C (25 ppm F) was judged to be 4½ and buck D (25 ppm F) was judged to be 2½. Irregular molar wear was not extensive in this study and was not as pronounced as in the few reported field specimens which had similar bone fluoride concentrations. This may have been due to the fact that the second and third molars were formed before fluoride ingestion was started or it may have been the result of a pattern of fluoride exposure in the field which is undoubtedly less uniform than that imposed in this study. Alterations of exposure level will lead to a more severe irregularity of molar wear and more severe bone lesions than the ingestion of an equal intake of fluoride at a constant rate (Suttie et al., 1972).

Extensive gross skeletal fluorosis was not evident in these animals; and, in contrast to the effects on the developing teeth, the skeletal lesions appear to be less pronounced than they would in cattle receiving similar amounts of fluoride. Cattle receiving 50 ppm F have been found to accumulate similar amounts of skeletal fluoride at 2–3 yr of age, but exhibited more extensive generalized hyperostosis of

**Figure 3.** Metacarpal bone of white-tailed deer fed known amounts of fluoride for 2 yr. Identification as in Figure 2.
the long bones and some pronounced exostotic lesions.

From these studies the level of skeletal fluoride retention in deer fed known amounts of dietary fluoride has been established. The gross pathologic changes associated with these ingestion levels have been described and compared with those seen in young cattle ingesting similar concentrations of dietary fluoride. Although limited in number, these data should provide valuable reference points for assessing the significance of elevated skeletal fluoride levels seen in wild deer obtained from areas subjected to industrial fluoride pollution or natural high fluoride water sources.

ACKNOWLEDGMENTS

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