FLUOROSIS OF SHEEP CAUSED BY HEKLA ERUPTION IN 1970

by

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SUMMARY: For centuries, eruptions of the volcano Hekla in Iceland have caused serious damage to domestic animals.

This study is concerned with the effect of the May 5, 1970 eruption. On that day, samples of ash contained up to 2,000 ppm of fluoride. The values decreased to 10% within two weeks and to 2% within three weeks. During the first week stagnant surface water contained up to 70 ppm fluoride, running water up to 10 ppm.

Where the layers of ash on the ground were about 10 mm thick, grass analyzed for fluoride showed 4,300 ppm on the second day after the eruption. This level fell to less than 30 ppm after 35 to 40 days, partly due to heavy rainfall.

Acute fluorosis accounted for a mortality of approximately 3% of the sheep and 8 to 9% of lambs in the affected area during the first few weeks. Convulsive seizures, pulmonary edema, kidney and liver changes accounted for the deaths.

Subsequently, no evidence of skeletal fluorosis was noted except for slight periosteal thickening in less than 0.25% of 400 animals which were x-rayed. In the bones of lambs, fluoride concentrations increased about 4-fold of normal, but in adult sheep only about 50%.

In spite of the relatively short time exposure to fluoride, dental fluorosis occurred in 25.3% of the third incisors which erupted 4 to 9 months later and in 8.6% of the second incisors which erupted 9 to 13 months after the volcanic eruption.

1. Historical Background

Diseases of domestic animals following volcanic eruptions have been known for centuries in Iceland. The earliest descriptions of toxic symptoms due to ash from a volcanic eruption were written in 1694, one by farmer Oddur Elirsson, the other by clergyman Benedikt Petursson. They describe dental lesions; stained and

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defective incisors with excessive wear, which were called "ashteeth" (1); in young sheep, cattle and horses following the Hekla eruption of 1693. These constituted the first record of the dental lesions in Iceland which are now recognized to be caused by fluorine in the volcanic ash.

To the comprehensive accounts of dental lesions in domestic animals following the eruption of Lakagígar in 1783 by Magnus Stephensen and Hannes Finnsson (1) the latter added affections of molars leading to the condition known in Iceland as "gaddur" meaning spike. He observed that affected animals were sensitive to cold water and that "gaddur" makes a delayed appearance after young animals have been exposed to volcanic ash.

The Danish botanist Schyte (2) and the Icelandic farmer Oddur Erlendsson added other features to the toxic symptoms caused by volcanic ash in their description of diseases of animals following the eruption of Hekla in 1845. For example, the latter's detailed account of dental lesions is supplemented by an exact description of bone changes. About 90 years later Roholm (3) analyzed the fluorine content of bones from this eruption and thus proved that these bone changes were caused by fluorine. He also produced similar lesions in sheep which were fed hay to which NaF had been added.

During the 1947 eruption of Hekla, volcanic ash fell on farmland in the adjoining districts. Now for the first time, it was possible to analyze the fluorine content of ash as well as water and vegetation contaminated by it. The ash contained 70 to 110 ppm water-soluble fluorine compounds (4). Sigurðsson and Palsson (5) found symptoms of chronic fluorosis in sheep on farms in the neighborhood of Hekla. They also produced fluorosis in sheep experimentally by mixing volcanic ash collected from this eruption with drinking water and hay.

The main purpose of this short historical survey is to emphasize that diseases of domestic animals caused by volcanic eruption have been known in Iceland for a long time.

2. Current Observations

The most recent eruption of Hekla began on May 5, 1970. During the first hours of the eruption volcanic ash fell over a wide area.

As shown in Fig. 1 a great sector of the western part of the country was covered with ash, including farmland in the south and north as well as grazing areas in the interior. It should be pointed out that signs of chronic fluorosis were found only within the area covered with a layer of ash 0.1 cm or more, but acute sickness occurred likewise where only a trace of ash fell.

Analysis of the ash of samples taken on the first days after the eruption showed up to 2000 ppm of water-soluble fluoride in the south and as high as 1400 ppm in the north. The fluoride content of the ash had decreased within 2 weeks to 10% of the original value, and within 3 weeks to between 1 and 2%.
Eruption of Hekla

Fig. 1

Distribution of Ash

There was a distinct increase of fluoride in water. Values in the first week ranged from 4 to 70 ppm in stagnant surface water, after two weeks, they ranged between 0, 30 and 14 ppm. In running surface water, the highest values were 10 ppm on the first day but they declined rapidly. After two weeks, values ranged from 0, 25 to 0, 50 ppm. In deep artesian wells, the corresponding values were always less than 0, 70 ppm.

On the first days after eruption, samples of vegetation were taken for fluoride analyses. Figure 2 shows the results of fluoride analysis of grass on the farm Haukholt, where the layer of ash was about 10 mm thick. The initial value on the second day after the eruption was 4, 300 ppm, one of the highest values recorded. The fluorine content of the grass fell rapidly, partly due to heavy rainfall during this time. Thirty-five to 40 days after the beginning of the eruption it was less than 30 ppm, a fluoride content generally accepted as innocuous even in long term experiments. Fluoride analyses from other farms in the ash-covered area conformed in general to this same pattern.

It should be emphasized that exposure to high levels of fluoride endured for a maximum of 5 to 6 weeks. It must, however, be stressed that the period of exposure of sheep to fluoride varied in the ash-covered area due to difference in sheep management. This difference was reflected in a varying frequency of both acute and chronic fluorosis. Many farmers kept the sheep away from con-

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Limits of ash covered area

Thickness of layer in cm

FLUORIDE
taminated pasture for the first 3 weeks. Nevertheless, the estimated daily fluoride uptake by sheep on these farms was approximately 2.5 mg per kg body weight.

**Fig. 2**

**Fluorine in Grass Following the Eruption of Hekla 1970**

*ppm F⁻ in Dry Matter* Haukholt

**Acute Fluorosis**

Sheep grazing outdoors as the volcanic ash was falling were frightened, restless and nervous. The major acute symptoms were loss of appetite, especially for concentrates, drowsiness, general prostration, Lameness, often intermittent, was observed. Gastro-intestinal symptoms with blood-stained diarrhoea were frequent. In some cases respiratory symptoms with cough and dyspnea were noted. Loss of wool was often observed in sheep recovering from the acute symptoms. Blood samples showed low serum calcium levels in many cases, with the lowest values recorded at 5.3 mg%. The fluoride content of the urine was greatly increased; often values ranged from 30 to 60 ppm. The highest value of fluoride in urine was 93 ppm. With good care, by keeping sheep away from contaminated grass and water, by adding aluminum sulphate to the mineral supplements to reduce the resorption of fluorine and by giving calcium injections to prostrate sheep, many
recovered. Nevertheless there was a substantial mortality from the first days onwards throughout the first few weeks. Approximately 3% of sheep and 8 to 9% of lambs in this area died. Some sheep which died during the first hours or days showed convulsive seizures and blood-stained froth in mouth and nose terminally. At autopsy blood-stained froth was found in the trachea and bronchi. The lungs were heavy, blood-filled and edematous. The mucosa of the air passages was hyperemic with diffuse bleeding. The heart was dilated with a passive congestion of the internal organs. In the liver and in the cortex of the kidneys, yellowish areas were seen. The intestinal mucosa was often reddened; the contents were thin and blood-stained.

Microscopic examinations showed hemorrhagic tracheo-bronchitis; edema, congestion and bleeding in the lungs. In the kidneys degeneration and necrosis of the proximal convoluted tubules and protein casts were observed. The liver showed congestion and slight fatty degeneration in a few cases. Fluoride analyses of the rumen contents yielded values of several hundred ppm. The only sign in sheep which died a few weeks after the eruption was progressive wasting.

The clinical signs, pathological and biochemical changes found during the first days are consistent with acute fluoride intoxication. According to the high fluoride content in stagnant ponds and in grass it appears likely that on the first days the sheep could have ingested as much as 100 mg fluoride per kg, which is in the range of an acute lethal dose for man and for some laboratory animals.

**Chronic Fluorosis**

**Bone Lesions:** Several hundred sheep were examined clinically for fluorotic bone lesions. Bones from sheep and lambs in the area where ash fell, were collected and examined grossly and radiologically, and several bones were submitted for fluoride analysis. Mainly metacarpals and metatarsals but in some cases also mandibular bones were examined. Among the bones of approximately 600 lambs and 100 adult sheep, none showed fluorotic bone lesions macroscopically. X-rays from about 400 cases revealed slight periosteal thickening in less than 10 of them.

A distinct increase in fluoride content of bones in lambs and yearlings was noted, the former showing about 4 fold mean increase and the latter about 3 fold normal values. In adult sheep, the mean increase was only about 50% of the normal value. This tendency to decreasing accumulation of fluoride with age is a well established fact. The fluoride values differed widely, partly because samples were analyzed from the whole area and the degree of contamination varied in different regions, partly because of different management of the sheep. In the area covered with a layer of ash of 0.1 cm thickness or more, the mean fluoride value in lambs was 791 ppm whereas, in the marginal region, the mean value was only 352 ppm.

It is generally accepted that there is a correlation between the accumulation of fluoride in bones and the occurrence of fluorotic bone lesions. In our material, a mean increase of 3 to 4 fold normal values in lambs and yearlings was, as
a general rule, not accompanied by macroscopic or radiologic bone changes. The few cases showing slight periosteal thickening in radiographs had approximately a 6 to 8 fold increase of fluoride in bones. This conforms with most observations on sheep and cattle (6,7,8). However, admittedly it is difficult to compare observations by different investigators because of varying criteria used in evaluation of fluorotic bone lesions.

The results of fluoride analysis of bones is summarized in Table 1.

<table>
<thead>
<tr>
<th></th>
<th>Number</th>
<th>Mean</th>
<th>S.D.</th>
<th>Lowest value</th>
<th>Highest value</th>
<th>Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lambs</td>
<td>43</td>
<td>699</td>
<td>345</td>
<td>165</td>
<td>1570</td>
<td>180</td>
</tr>
<tr>
<td>Yearlings</td>
<td>21</td>
<td>1781</td>
<td>966</td>
<td>710</td>
<td>3900</td>
<td>560</td>
</tr>
<tr>
<td>Adult Sheep</td>
<td>11</td>
<td>1211</td>
<td>294</td>
<td>850</td>
<td>1660</td>
<td>830</td>
</tr>
</tbody>
</table>

Fluorotic Dental Lesions

We began looking for signs of dental fluorosis at sheep gatherings in the autumn 1970 and continued by visiting 10 farms in the north and 10 in the south during winter and spring of 1971. The last examination was made at sheep gatherings late in September of this year. Altogether, about 550 sheep three years and younger have been examined. When we started this study we did not know what to expect. The estimated daily dose of 2.5 mg/kg is in the range reported as toxic in experiments on cattle, whereas a daily dose as low as 0.9 mg/kg causes dental fluorosis (9) in long-term experiments. The question arose whether or not the very short period of exposure to fluoride would produce lesions in the developing permanent teeth. The results of our examination is summarized in Table 2.

The first incisor in sheep, one year old at the time of exposure, which erupted 1 to 5 months later, was always normal, whereas the second incisor of this sheep, erupting 9 to 13 months after exposure, was damaged in 8.6% of observed cases. The third incisor in sheep two years old at the time of exposure which erupted 4 to 9 months later, was most frequently affected i.e. in 25.3% of the observed cases. On the other hand, the first incisor of lambs born at the time of exposure and emerging 13 to 17 months later escaped damage.
TABLE 2

Dental Fluorosis of Sheep Following the Eruption of Hekla in 1970

<table>
<thead>
<tr>
<th>Incisors</th>
<th>Eruption of teeth in months after exposure to high fluorine</th>
<th>Total number of teeth observed</th>
<th>Normal</th>
<th>Questionable effect</th>
<th>Fluorotic lesions</th>
</tr>
</thead>
<tbody>
<tr>
<td>I&lt;sub&gt;1&lt;/sub&gt;</td>
<td>1-5</td>
<td>291</td>
<td>287</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>I&lt;sub&gt;3&lt;/sub&gt;</td>
<td>4-9</td>
<td>154</td>
<td>109</td>
<td>6</td>
<td>39 (25.3%)</td>
</tr>
<tr>
<td>I&lt;sub&gt;2&lt;/sub&gt;</td>
<td>9-13</td>
<td>186</td>
<td>165</td>
<td>5</td>
<td>16 (8.6%)</td>
</tr>
<tr>
<td>I&lt;sub&gt;1&lt;/sub&gt;</td>
<td>13-17</td>
<td>104</td>
<td>99</td>
<td>5</td>
<td>0</td>
</tr>
</tbody>
</table>

According to our results, the developing permanent incisors of sheep are sensitive to high fluoride levels of very short duration if the exposure takes place approximately 6 to 12 months prior to eruption. We are not aware of any study on the chronology of formation of the teeth of sheep but it is safe to assume that within this period the crown of the incisors is formed. Recently Suttie and Faltin (10), who reported the results of a short term experiment on cattle, produced severe fluorotic lesions of the incisors in heifers by feeding 2.5 mg/kg/daily to one group 13 to 15 months of age and the other 16 to 18 months old. They correlated the time of exposure with the chronology of development of the incisors of cattle as studied by Brown et al. (11) and came to the conclusion that developing incisors are not only sensitive to fluoride during the formation of the crown but also about 1 to 3 months before and after the completion of the crown. By measuring the fluoride content of enamel in sections from the top downwards, they found an indication of a regular pattern of enamel apposition.

In this connection an observation made by us may be of interest: In a 2 year old sheep the second incisors, which were partly erupted, showed severe fluorosis. The first incisors were normal. Five months later, the second incisors were fully erupted and the lower 2/3 of the crown was perfectly normal, but the uppermost 1/3 of the crown was damaged to the extent that it was totally worn away. This sheep had, according to reliable information, only been exposed to fluoride the first two days after the ash had fallen.

The dental lesions in the majority of our cases were severe, falling in grade 4 or 5 according to Dean's classification as modified by Greenwood et al. (12).

This report must be regarded as preliminary because we are certain that not all of the long-term effects have appeared to date, 1 1/2 years after the eruption. A follow up is planned for the next few years.
Acknowledgements: Research on the biological effects of the eruption was carried out in collaboration with the Institute for Agricultural Research and the Industrial Research and Development Institute, Reykjavik. We are indebted to H. Thorarins for carrying out fluoride analyses, to S. Thorarinsson for Fig. 1, to F. Palmarsson for Fig. 2 and to P. A. Palsson for much advice and help.

Bibliography


Discussion

Dr. G. Scholl: Did you find fluoride damage and changes in the teeth of sheep within one year after the eruption?

Dr. Georgsson: Yes, we did. We are still following them in our study.

Dr. A. H. Mohamed: What breed of sheep did you use in your study and analysis?

Results and reactions could vary according to the different breeds.
Dr. Georgsson: Our studies were concerned only with the regular Icelandic breed of sheep. Yes, it is possible that different breed of sheep may manifest different reactions.

Dr. G. L. Waldbotto: Were analyses made for pollutants other than fluorides which could have been responsible for damage? In acute poisoning did you encounter damage to the central nervous system?

Dr. Georgsson: We found traces of thalium, chlorine and others. Many of the sheep were very sensitive to pain, hyperexcitable and irritable. These symptoms and signs could be due to hypocalcemia or to damage to the central nervous system.

Dr. G. Rosenberger: Was any cattle adversely affected?

Dr. Georgsson: No, because the eruption occurred in March 1970, and cattle had not been put out to pasture as yet. Usually they are not let out until much later. In 1970 they were not released before July.

Dr. S. P. S. Teotia: Experiments in dogs and sheep given sodium fluoride did not show signs of bone lesions even after 1 year on a high fluoride diet. We too, found evidence of hypocalcemia in pregnant ewes.

Dr. Georgsson: High fluoride exposure for only 4 to 6 weeks caused these changes after the eruption. No changes were found in the joints, but some were noted in the bones. Hypocalcemia was noted in both pregnant and nonpregnant sheep; most of the ewes were pregnant at that time of the year.

Dr. H. A. Cooke: Were there complaints from humans living in the affected area?

Dr. Georgsson: Only during the first few days following the eruption - due to irritation of the respiratory tract and the eyes by the dust.