RADIOLOGICAL MODIFICATIONS OF THE SKELETAL SYSTEM AMONG ALUMINUM SMELTER WORKERS

A 15-Year Retrospective Study

by

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SUMMARY: Previously by the time skeletal fluorosis among aluminum smelter workers due to high fluoride exposure was diagnosed numerous cases of bone fluorosis had already reached stages II and III according to Roholm. Today, as a result of improved working conditions and continuous health care, the picture has changed. This paper reports the frequency of occurrence of bone changes caused by fluoride in a population of 358 aluminum smelter workers who had been fluoride exposed for more than 5 years and whose diagnosis had not been made prior to 1971. In the examination, particular attention was paid to degenerative changes of the skeleton and the frequency of spondylosis, arthrosis of the hip and elbow joints as well as changes in the form of diffuse idiopathic skeletal hyperostosis (spondylosis hyperostotica Forestier). A population of 81 foundry workers in aluminum smelters under similar working conditions, but not fluoride exposed, served as controls.

KEY WORDS: Aluminum smelter; Arthritis; Bone changes, radiologically visible; Fluorosis, skeletal; Foundry workers; Spondylosis.

Introduction

More than 50 years have passed since Møller and Gudjonsson (1) described fluorosis, a new occupational disease, for the first time. Roholm (2) subsequently described this disease in detail in cryolite workers. He divided roentgenologically visible changes into three stages; Fritz (3) added two prestages (vague symptoms and stage 0-1). In the fourth to seventh decades of our century description of typical skeletal fluorosis with distinct sclerosis of the spine and pelvis and marked formation of appositions at long bones (radius and ulna, as well as tibia and fibula) in the range of the lower legs and forearms played a central role. In recent years, reports on less distinct fluorosis cases is incresing (4-12), in which hyperostosis at the spine and bone appositions at muscular and ligamental attachments dominate. Also Carnow and Conibear (13) concluded from a study of 1242 aluminum smelter workers that fluoride exposures were related to a history of musculo-skeletal diseases and other abnormalities in the absence of radiologically apparent skeletal fluorosis. They suggested that non-specific changes could comprise an early stage of fluorosis.

In view of these facts we examined carefully about 500 aluminum smelter workers of an aluminum factory near Halle with respect to roentgenological

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symptoms. Previously Franke et al. (14) and Specht (15) had classified all cases of fluorosis of the same factory, which had occurred up to the early 1970s. Thus in this paper only those workers are included whose disease had begun during the last 15 years (1971-1986) who have been fluoride-exposed for more than 5 years.

This group of 358 aluminum smelter workers was compared with the fluoride-exposed subjects examined by Specht (15) taking into consideration exposure time, age when starting the occupation and age when the disease began.

Materials and Methods

The roentgenograms of 358 aluminum smelters, having been fluoride-exposed for more than 5 years were analysed. X-ray photographs were available of the thoracic and lumbar spine at two levels, of the pelvic region ap. and lateral, of the forearms with elbow and of the lower legs ap. and laterally with the knee joint. Moreover, in the course of the last two years lateral x-ray photographs of the heel bone of all aluminum smelter workers were registered by screening. According to the health-care program for fluoride-exposed persons in the G.D.R., the above-mentioned x-ray photographs are taken every four years. In addition, workers are thoroughly examined clinically. A population of 81 foundry workers from different factories of the G.D.R. (in Halle and Karl-Marx-Stadt) served as controls. They worked under similar conditions as well as under the influence of extreme heat, without being exposed to fluoride. Their ages were approximately the same as the aluminum smelter workers (49.2 yrs ±6.87 for the workers in the foundry and 47.5 years ±10.14 for workers in aluminum smelters) particularly important in connection with the assessment of the frequency of various degenerative skeletal symptoms.

Results

Table 1 shows the frequency in percent (%) of the various stages of fluorosis in three different groups of fluoride-exposed subjects. Whereas Fritz (3) carried out his examinations in cryolite workers, Specht (15) and we investigated aluminum smelter workers of the same factories near Halle.

Fritz found that over 40% of the cases were suffering from fluorosis stage 0-I up to stage III; Specht found that 45.7% fell into these groups, whereas in our present examination only 18.7% of fluoride-exposed persons were in these stages. Among Specht's patients only 21.6% showed no fluoride-caused changes of the skeleton, in other words he found 73.5% without skeletal changes.

Table 2 shows medium fluoride-exposure time leading to fluorosis, in comparison with examinations by Fritz and Specht. According to this table the time leading to fluorosis stage I, II or III is longer, on the average, in Fritz's than in Specht's workers. In our investigation it is somewhat longer. Medium exposure time of workers who developed the disease between 1971 and 1986 does not differ markedly with reference to the individual stages of fluorosis; it is always around 20 years without statistical significance, with a range of 10 to 43 years (for example in stage I). In Table 3 we did not demonstrate the dependence on the worker's age when entering the produc-

Table 1

Frequency (%) of Various Stages of Fluorosis in Three Different Fluoride-Exposed Groups.

Fluorosis Stage	Fritz [1958] (n = 156)	Specht [1975] (n = 300)	Runge [1986] (n = 358)
No Changes	53.2	21.6	73.5
Vague Symptoms	4.7	32.7	7.8
0-I	17.6	17.3	7.8
I	13.6	16.0	5.3
I-II	—	7.0	3.9
II	5.7	2.3	0.6
II-III	—	2.3	1.1
III	5.2	0.8	—

Table 2

Mean Fluoride Exposure (Years) for Developing Fluorosis.

Fluorosis Stage	Fritz [1958]	Specht [1975] (mean/range)	Runge [1986] (mean/range)
No Changes	—	9.7 (0-20)	19.9 (5-35)
Vague Symptoms	11	12.8 (2-23)	19.2 (10-37)
0-I	12-13	14.1 (5-33)	22.6 (10-30)
I	12-26	15.0 (6-36)	21.1 (10-43)
I-II	—	17.2 (12-27)	21.1 (10-33)
II	21-31	17.6 (11-21)	17.5 (16-19)
II-III	—	18.9 (14-25)	21.3 (15-26)
III	25-35	19.5 (19-20)	—

tion process or on the worker's age at the time of diagnosis, nor could exposure time be related to the development of a certain stage of fluorosis. Therefore occurrence of bone fluorosis does not depend upon whether the worker starts working in such a factory at age 20 or at age 40. Nor is duration of exposure significant, since stages II-III can be demonstrated after 15 years. On the other hand, in some cases, more than 30 years may be necessary to develop vague symptoms or stage 0-I.

Individual differences in sensitivity to noxious fluoride seems to be more important. The three tables demonstrate that it is quite possible to be an aluminum smelter worker for 30 years or longer without showing fluoride-caused bone changes, whereas others develop symptoms of fluorosis after only 10 years; the varying effect of fluoride has been demonstrated by therapy tests for osteoporosis.

Table 3

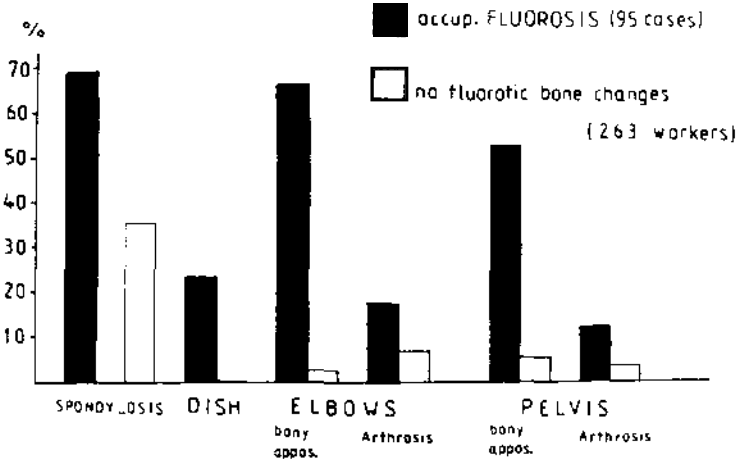
Worker's Age When Entering Production Process and Age of Diagnosis (n = 358 Aluminum Smelter Workers with over 5 Years Exposure Time).

Fluorosis Stage	n	Age (in Years) At Start of Employment (mean/S.D.)	Age (in Years) At Confirmation of X-ray Diagnosis (mean/S.D.)	Duration of Exposure (mean/S.D.)
No Change	263	22.9 ±15.30	—	19.9 ±9.26
Vague Symptoms	28	29.4 ±7.42	51.0 ±9.52	19.2 ±6.21
0-I	28	27.9 ±7.07	51.5 ±7.40	22.6 ±4.96
I	19	32.0 ±8.04	53.8 ±9.10	21.1 ±7.67
I-II	14	31.6 ±8.27	54.6 ±5.68	21.1 ±6.40
II	2	32.5 ±12.02	50.0 ±9.90	17.5 ±2.12
II-III	4	28.3 ±2.36	50.5 ±7.33	21.3 ±5.19

For this reason we examined the causes of this difference in sensitivity to fluoride by studying the degenerative changes in fluoride-exposed persons, the frequency of which is illustrated in Figure 1. Spondylosis, elbow and hip joint arthrosis occur more often in the 95 cases diagnosed as fluorosis. Also bony appositions at the epicondyles of the humerus and in the pelvic region occur more frequently in the fluorosis-group than in fluoride-exposed subjects with symptoms of fluorosis. Like Boillat et al. (7) we observed hyperostosis

Figure 1

Frequency in Percent (%) of Spondylosis, Diffuse Idiopathic Skeletal Hyperostosis (DISH), Bony Appositions and Arthrosis of Elbow and Pelvic Regions (n = 358 Aluminum Smelter Workers, Exposure-time over 5 Years; 95 Workers with Signs of Fluorosis, 263 without Fluorotic Bone Changes).



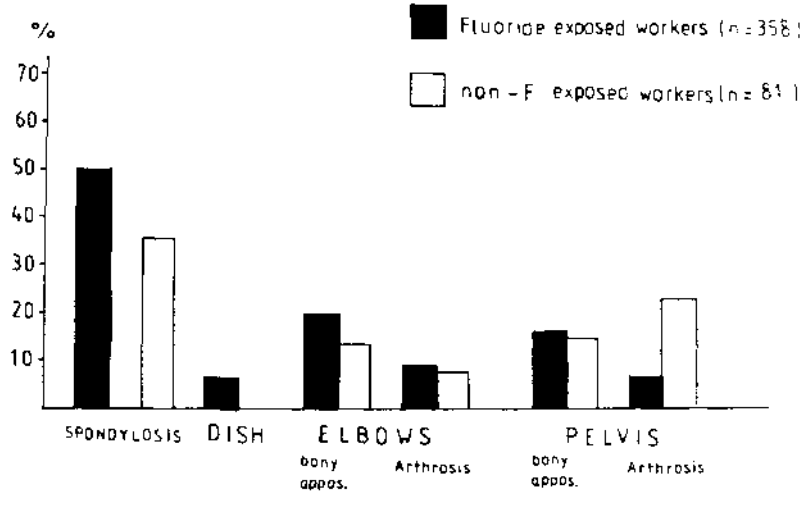
of the spine or of peripheral skeletal parts in 22 cases, a particular form of fluorosis. The final evidence that the changes are really fluoride-caused can only be produced by a biopsy of these areas, a measure not desired by the workers. In the Anglo-American literature these generalized hyperostoses are referred to as Diffuse Idiopathic Skeletal Hyperostoses (DISH). In Germany and France they are described as spondylosis hyperostotica or Forestier desease (16-24). Neither Boillat et al. (5) nor we found differences between the fluoride-induced hyperostosis and the form which (at a much lower frequency) can occur spontaneously without external cause (idiopathic). In our 22 cases, bone density was normal in 12, i.e. no sclerosis of the spine nor of the pelvis could be identified.

Figure 2 compares the frequency of spondylosis, elbow and hip joint arthrosis as well as bony appositions in the elbow and pelvic region of fluoride-exposed aluminum smelter workers to that of iron foundry workers. The average age of the two groups examined was approximately the same (47.48 yrs in the fluoride-exposed group; 49.21 yrs in the controls).

It can be noted that spondylosis, DISH (no case occurred among workers not exposed to fluoride) as well as bony appositions occurred more often in aluminum smelter workers. Arthrotic changes of the elbow joint likewise occurred often, but were more distinctly developed among aluminum smelter workers; coxarthrosis was found more frequently in non-fluoride exposed foundry workers than in aluminum smelter workers. In the majority of these DISH-like cases the hyperostotic changes in the region of the spine, pelvis, elbow joints and heel bones, were observed simultaneously with a normal density of the skeleton.

Figure 2

Frequency in Percent of Spondylosis, DISH, Bony Appositions and Arthrosis of Elbow and Pelvic Region in Population of Fluoride-Exposed Workers (n = 358) compared with Non-Fluoride Exposed Population of Foundry Workers (n = 81).



Discussion

Our study shows that hyperostosis of the spine and peripheral skeletal parts occurs more frequently among fluoride-exposed aluminum smelter workers. It is similar to diffuse idiopathic skeletal hyperostosis (or spondylosis hyperostotica Forestier) (16-24). Separation of the fluoride-caused form from that etiologically unexplained idiopathic is only possible through bone biopsy. DISH is accompanied by a disturbance of the vitamin A metabolism (16). In the literature there are no similar examinations of fluoride exposed subjects with hyperostosis. As in the 43 aluminum smelter workers suffering from fluorosis examined by Boillat et al. (6) we found no pathology in our aluminum smelter workers other than movement restrictions and cases of asthmoid bronchitis.

Regarding the question raised by Boillat et al. (6) on the role of physical stress in the development of fluorosis and its osteoarticular manifestation, we have no final answer. In our patients vertebral changes even exceeded the 70% of Boillat et al. (6), when DISH-like hyperostoses of the spine were added. Hyperostotic changes at the knee joint, which occurred in the reports of the above-mentioned authors in 43% of cases were found in less than 5% of ours.

In numerous cases, we noted considerable arthrosis of the elbow joints, recognized as an occupational disease in our country; aluminum smelter workers are obliged for years to use a steel rod to break the smelt crust. Boillat et al. (6) reported 0.5-2.3 mg F/m^3 in the air in the electrolysis area. In comparison in the factory where our patients work the values were partly over 5 mg F/m^3 around 1970. In recent years, air F^- was 2.5 mg F/m^3. Nevertheless, the formerly typical sclerosis does not occur as frequently. On the other hand, skeletal changes similar to degenerative diseases are observed.

Czerwinski and Lankosz (8) who question whether mechanical factors play a role in developing fluoride-caused bone changes consider the possibility of synergistic action of fluorine and mechanical factors. The frequency of vertebral changes could be facilitated largely by prolonged exposure apart from mechanical factors. Since the crust breaking equipment was formerly poorly suspended, the whole body was exposed to considerable shaking, resulting in spondylosis.

Conclusion

In the last 15 years due to improvement in working conditions (new crust breaking equipment, with a cabin, improvements of suction devices) and intensive health care, the frequency of fluorosis has markedly diminished in the factory supervised by us and only incipient stages of fluorosis are encountered. However, the number of workers showing degenerative spinal changes beyond the normal level is still high. As fluoride is largely used in the nickel, copper, coal, gold and silver industries, in the production of fertilizers, narcotic gas as well as in the production of steel, iron, glass, ceramics, enamel and numerous other production processes, the possibility of developing occupational fluorosis must always be considered. The total number of American workers potentially exposed to fluorides, according to the National Institute for Occupational Safety and Health (25), is 350,000. Although the severity of industrial

fluorosis is decreasing in some aluminum factories, at present, due to improved control and working conditions, the danger caused by fluoride is increasing as its use in industry becomes more extensive.

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