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PHYSICAL PROPERTIES OF FLUOROSIS BONE

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The bones of two patients, one with a moderate and one with a severe chronic industrial fluorosis (stage I-II and stage III), and the bones of three control persons were examined. The following parameters were determined: the fracture load, the fracture load/unit area (resistance to pressure) of the body of the first lumbar vertebra, the bending strength of the neck of the femur and of the lower third of the femur, the fracture load/unit area and the modulus of elasticity of femoral slices 2 cm thick and of precisely defined cylinders from the femoral cortex. The microhardness according to Vickers on the cross section of the femur was also determined. The results obtained are discussed with regard to fluoride therapy of osteoporosis.

Key words: human industrial fluorosis; physical bone strength tests; microhardness; NaF-therapy of osteoporosis

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During investigations of workers in an aluminium smelting plant, who were suffering from chronic fluorine intoxication, increased hardness of the bone in biopsies of the iliac crest was noticed, even to the point of a breakdown, in one case, of the biopsy cannula. In an autopsy of an aluminium smelter worker with pronounced fluorosis difficulty in sawing of bones was experienced (Franke 1968, 1973, Franke & Auermann 1972, Franke et al. 1972 b, 1975). These findings are in contrast to those in animal fluorosis.

These observations were of interest firstly with reference to our current attempts to treat osteoporosis by fluoride medication (Franke et al. 1974) and secondly because of conflicting statements regarding the effect on the skeleton of water fluoridation with a view to caries prevention.

Further studies are reported here on the physical properties of bone in fluorotic as compared to normal subjects.

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MATERIAL AND METHODS

Two aluminium smelter workers with different stages of industrial fluorosis were investigated. The first case (F 1) was a 56-year-old man who died as a result of a traffic accident after 14 years of fluorine exposure. The roentgenographic examination showed stage III fluorosis according to Roholm (1939) and Fritz (1958); chemical analysis of ash from a rib yielded a value of 1.15 per cent fluorine. The second case (F 2) was a 64-year-old man who died from a brain tumour, diagnosed 4 weeks earlier, and who had had 10½ years of fluorine exposure. The roentgenographic examination showed stage I-II fluorosis; chemical analysis of ash from the iliac crest

Table 1. Results of the static examinations and of the determination of microhardness in two fluorosis and three control skeletons.

Lumbar vertebral body		
fracture load/area:	C1 – 46.7 kp/cm²	
	C2 – 25.8 kp/cm²	
	C3 – 41.9 kp/cm²	
	F1 – 124.0 kp/cm²	
Femur slices	Number of tests	t-test
fracture load/area:		
C – 13.6 ± 1.9 kp/mm²	10	
F1 – 14.0 ± 1.6 kp/mm²	5	–
F2 – 16.4 ± 0.3 kp/mm²	3	$P_{C/F2} < 0.05$
		$P_{F1/F2} < 0.05$
modulus of elasticity:		
C – 780 ± 48.2 kp/mm²	10	
F1 – 610 ± 52.7 kp/mm²	5	$P_{C/F1} < 0.05$
F2 – 940 ± 41.7 kp/mm²	3	–
		$P_{F1/F2} < 0.01$
fracture load:		
C – 6300 ± 1258 kp	10	–
F1 – 8400 to over 10,000 kp	5	$P_{C/F1} < 0.01$
F2 – 9000 to over 10,000 kp	3	$P_{C/F2} < 0.01$
Precisely defined cylinders from the femur corticalis		
fracture load/area:		
C – 21.8 ± 1.05 kp/mm²	8	
F1 – 18.4 ± 0.88 kp/mm²	4	$P_{C/F1} < 0.01$
F2 – 22.3 ± 0.42 kp/mm²	4	–
		$P_{F1/F2} < 0.01$
modulus of elasticity:		
C – 1607 ± 104 kp/mm²	8	
F1 – 1560 ± 46 kp/mm²	4	–
F2 – 1740 ± 89 kp/mm²	4	$P_{C/F2} < 0.05$
		$P_{F1/F2} < 0.01$

Microhardness according to Vickers on the cross section of the femur 4 cm below the minor trochanter

Length of the diagonal of impression in arbitrary units: (1 a.u = 0.03 mm); the shorter this distance, the harder the bone is.

	Number of tests	t-test
C1 – 2.02 ± 0.08 a.u	71	
C2 – 2.04 ± 0.11 a.u	85	
C3 – 2.02 ± 0.07 a.u	66	
F1 – 1.98 ± 0.06 a.u	121	$P_{C/F1} < 0.01$
F2 – 1.84 ± 0.08 a.u	137	$P_{C/F2} < 0.01$
		$P_{F1/F2} < 0.01$

C = control bones; F1 = severe fluorosis; F2 = moderate fluorosis.

yielded a value of 0.74 per cent fluorine. Three cases (C 1 to C 3) served as controls, all 50- to 60-year-old men who died in traffic accidents.

Examinations were made of the first lumbar vertebra, the neck of the femur, the distal third of the femur, three to five bone samples of the femur, sawn horizontally at a position 2 cm from the proximal third of the femur, and four cylinders milled from the femur cortex, 20 mm long and 5.5 mm in diameter in each case.

The preliminary treatment of all human bones took place under identical conditions, the investigations being conducted in a dry state at a room temperature of 22° C.

The determination of microhardness was carried out on the surface of a piece of the femur taken from 4 cm below the minor trochanter. The bone samples were dried for 24 hours at 100° C before the determination of microhardness. They were kept in an air-tight container until the test time and polished by means of a roughened glass plate shortly before the examination. Microhardness was measured with a load of 0.1 kp, from the outside to the inside, in four different radial directions. In each of the femoral slabs 70 to 140 imprints were measured.

For the determination of static strength, tests were performed on a machine for testing the performance of materials, made by the firm "Zwick", type 1385, and for the determination of the microhardness the Vickers method was used —on a Hanemann microhardness tester, Zeiss D 32.

RESULTS

Examination of static strength

For the determination of resistance to compression of the 1st lumbar vertebra, each individual vertebra was compressed at a rate of 0.5 mm/min, and the required load, as related to the compression, registered. The resistance to compression was calculated from the maximal load registered, where the load surface was that of the vertebral body, calculated as an ellipse. F 1 was found to have a three-fold higher resistance to pressure per unit area as compared with the three control vertebra (Table 1); F 2 was not subjected to this test.

The determination of the flexural strength of the neck of the femur was undertaken in accordance with the test arrangement shown in Figure 1. The

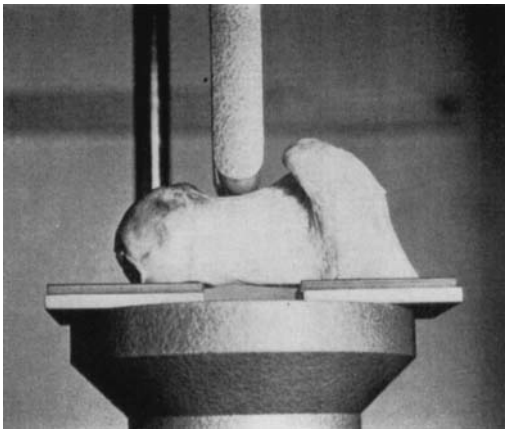

Figure 1. Experimental arrangement for testing of the flexural strength of the neck of the femur.

force was applied to the middle of the neck of the femur by means of a round head. The three control bones registered 380–460 kp; F 1 registered 800 kp and F 2 registered 400 kp. The value of this test is rather limited because the surface of load application is poorly defined.

For the determination of the flexural strength of the distal third of the femur, a 10 cm long piece of bone was removed from the lower section of the shaft of the femur, and tested for flexion in accordance with the layout of Figure 2. Here, no difference was found between fluorosis and control bones.

The 2 cm thick slices from the femur were used for the determination of pressure strength and modulus of elasticity (Figure 3). As in the case of the vertebral compression test, the pressure resistance strength was determined from the maximal load per unit area of cortex. The modulus of elasticity was calculated from the linear part of the load-pressure curve.

The pressure resistance value (fracture load/unit area) of the control pieces was 11.2 to 17.0 kp/mm^2. F 1 gave 12 to 15.6 kp/mm^2 and F 2 gave 16 to 16.6 kp/mm^2. Thus no definite difference between test and control bones was observed in this test.

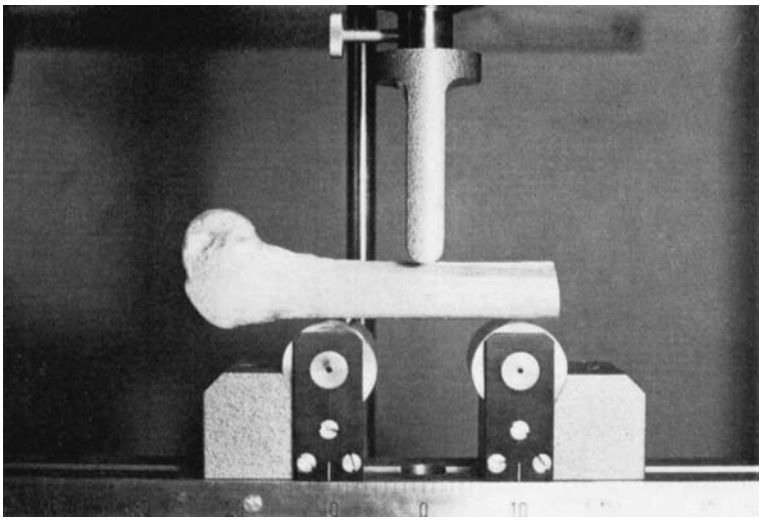

Figure 2. Experimental arrangement for the determination of the flexural strength of a 10 cm long piece of the distal femur.

The modulus of elasticity of the control slices was 780 kp/mm², higher than in F 1 (610 kp/mm²), but lower than in F 2 (940 kp/mm²).

Whereas the control pieces were able to sustain an average load of only 6,300 kp, in both of the fluoride bones the highest load measurable by the machine was registered, viz. 10,000 kp, without crushing some of the femur samples. In the severe fluorosis (F 1) the crushing load was from 8,400 to over 10,000 kp and in the moderate fluorosis (F 2) from 9,000 to over 10,000 kp (Table 1).

The apparent contradiction between the absolute resistance to pressure and the breaking stress is resolved if one takes into consideration the difference in thickness of the cortex (Figure 4) of the severe fluorosis bone and control bones.

The machined cortical bone cylinders (Figure 5) gave values for pressure resistance strength (fracture load/unit area) of 18.5 kp/mm² for F 1, which was lower than for the controls, (21.8 kp/mm²) and F 2 (22.3 kp/mm²).

The modulus of elasticity was 1607 kp/mm² in the controls, 1560 kp/mm² in F 1 and 1740 kp/mm² in F 2 (Table 1).

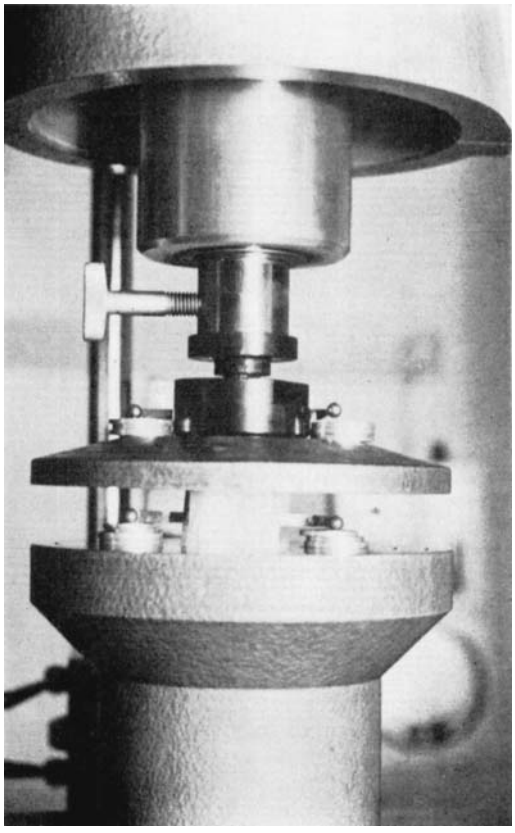

Figure 3. Experimental arrangement for the determination of the pressure strength of 2 cm thick femoral slices.

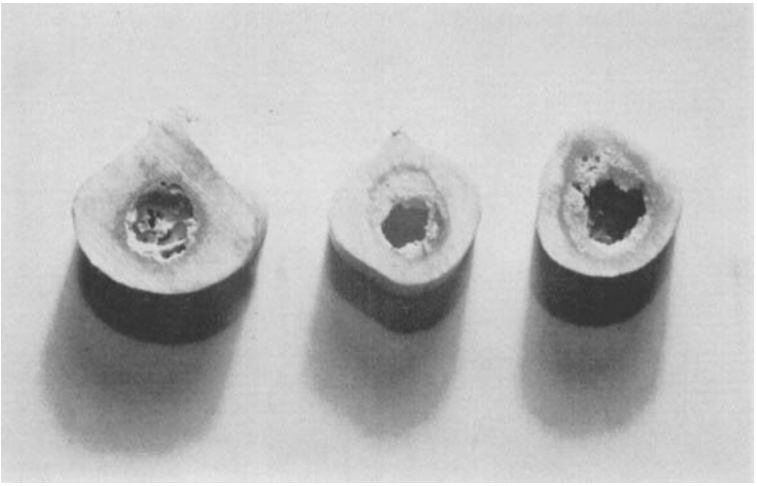

Figure 4. Difference in corticalis thickness in severe fluorosis (on the left side) and two control bones.

Determination of the microhardness

In severe fluorosis (F 1) there was an increase in hardness as compared with the control bones, while in moderate fluorosis (F 2) the increase in hardness was more pronounced (Table 1).

Summary of results:

1. There was an increase of all parameters of bone strength in moderate fluorosis.
2. There was an increase of the fracture load and fracture load/unit area of the vertebral body and of the femur slices, but a decrease of the modulus of elasticity of the femur slices and of the fracture load/unit area of the precisely defined cylinders from the femoral cortex in serious fluorosis (stage III).
3. There was a significant increase of the microhardness of the bones in moderate and serious fluorosis.

DISCUSSION

Our data suggest that moderate fluorosis causes a real increase in bone strength, but that the compact part of the bone is statically of lesser value in severe fluorosis, as shown by the experiment with the isolated compact cylinders. This inferiority can be explained by the irregular bone structure, the irregular mineralization, the osteoid, or the early development of bone porosity. This defect is however counterbalanced by the enormous thickness of the compact part, and is even overcompensated, since in the whole bone abnormally high pressure force values were obtained. The lack in quality is thus compensated for by the larger amount of bone. In moderate fluorosis, all of the physico-technical parameters, including the microhardness, were higher than in the control bones.

In spongy bone (vertebra, neck of the femur), even in severe fluorosis, there were higher values in the fluorosis bone. Presumably, the greater static strength is due to the compact form of the spongiosa. This and the increased microhardness results in bone that is harder than normal.

The findings in animal fluorosis confirm the human results only as regards microhardness. In rats an increased mi-

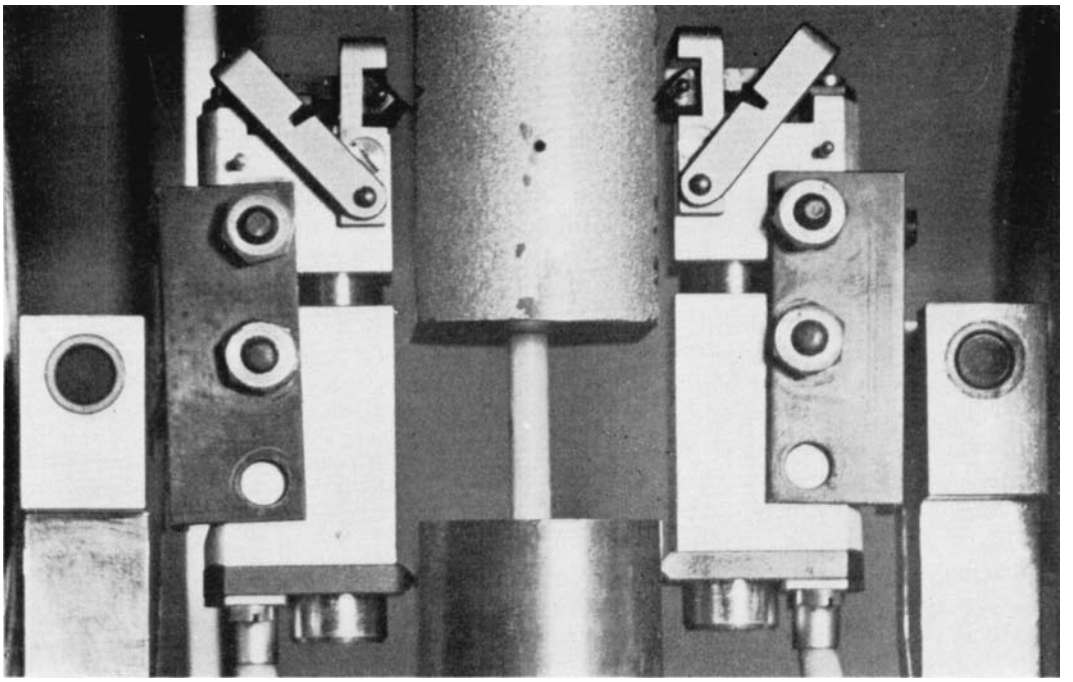

Figure 5. Experimental arrangement for the determination of pressure strength of milled cylinders from the femur corticalis.

crohardness after fluoride feeding was found, especially in young animals and at low and moderate doses (1 and 10 mg NaF/kg/day). In the experimental fluorosis of rats Franke et al. (1972 a) did not find any definite changes as regards the static bone strength and neither did Saville (1967) or Naylor & Wilson (1967). However, others have reported both increased (Rich & Feist 1970) and decreased (Gedalia et al. 1964, Beary 1969, Wolinsky et al. 1972) static strength in fluorotic bones of rats.

In experiments on rabbits, Jovanovits (1944) was able to detect a lowered modulus of elasticity after feeding fluoride in low doses, and a lowered bending strength after high doses of fluorine. Cristiani (1929) and Faccini (1969) achieved similar results (reduced bending strength of the tibia or reduced breaking strength of the femur), Bethke et al. (1930) found a lower pressure resistance in the femur of fluorine-fed piglets, and Kick et al. (1935) a lower breaking resistance in the femur of the pig. The tests of Smith & Keiper (1965), of Henrikson et al. (1970), of Krishna Rao et al. (1973) and of Romanus (1974) yielded no significant modifications. Phillips et al. (1934) found an increase in the breaking force in the metatarsus in cows with fluorosis while Bell & Weir (1949) found a 25 per cent increased bending moment, a slightly increased bend-break force, and a low modulus of elasticity in fluorine-fed sheep.

In the literature the authors found only a few reports about the relationship between fluorine content and hardness of bone. In 1921 Forbes et al. reported a lower microhardness in the bones of fluorine-fed pigs. Fujie (1961) found a reduced Vickers hardness on the incisors and mandibles of fluorotic cattle. Most investigations reported are on teeth

however. Boerma (1963) found in microhardness tests on whale teeth (these have a nearly 10-fold higher fluorine content than human teeth), just as Wörner (1974) did on human dentine, no clear-cut correlation between the fluorine content and the microhardness. Herrmann & Rozeik (1959) and Rozeik (1964) found in rats that the hardness of dentine and enamel decreased as the dose of fluorine administered was increased.

In human fluorosis Roholm (1938) reported reduced elasticity while McGarrey & Ernstene (1947) described increased hardness. In 1972 Evans & Wood investigated the ulnar cortex from a severe endemie human fluorosis. They found a decrease of mechanical properties in tensile strength and an increase in compressive stress, while the modulus of elasticity was reduced in both tests. These results correspond to ours in the case of severe fluorosis.

The reasons for the different findings in animals and humans are to be found firstly in the difficulties encountered in determining some parameters, for example the fracture area, exactly, using the small rat femora. Secondly the rat seems to be not a very suitable experimental object for studying bone fluorosis. The histological and roentgenological changes in rats are indeed very slight in spite of fluoride feeding over 1 year and fluorine values in the bone ash up to 1 per cent (Franke et al. 1972 a).

By contrast, sheep and cattle are extremely sensitive to fluorine. In these animals excessive irregular periostal bone appositions and marked osteomalacic changes are often found (Shupe et al. 1963).

On the basis of the investigations presented here we feel justified in supporting fluoride therapy in human osteoporosis. At least in stage I-II fluorosis the physicotechnical parameters were more favourable than for the control bones, and even in stage III fluorosis the vertebra showed a three-fold higher resistance to pressure than the control vertebra.

Thus, bone formed under the influence of high doses of fluorine shows a certain static deterioration but this defect is compensated by larger amounts of bone and, for this reason, is still more resistant to stress than an untreated bone.

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