EFFECT OF HYPOKINESIA ON THE STRENGTH OF BONE

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Reducing the motor activity of rats (for 20-100 days) in which the static function of the limbs is preserved leads to a marked decrease in thickness of the cortex of the femur. However, the ability of the whole bone to withstand mechanical loading is only slightly reduced. Thinning of the cortical layer is compensated by an increase in the strength of the bone tissue as a result of its increased mineralization.

KEY WORDS: hypokinesia; bones; mechanical properties; relative mineral content.

There is no general agreement in the literature on changes in the strength of bones in hypokinesia [2, 4-6]. The contradictory nature of the results is perhaps connected with different conditions of production of hypokinesia, differences in the duration of the experiments, and species differences between animals. In some investigations, also, the resistance of the whole bone to the action of a force was not studied. This resistance depends not only on the strength, but also on the size and shape of the bone, which may be altered in hypokinesia [3].

The object of this investigation was to study the effect of hypokinesia of varied duration on the mechanical properties of whole bone and also to study changes in osteometric indices and in the mineral content of the bone tissue.

EXPERIMENTAL METHOD

Experiments were carried out on 100 noninbred albino rats weighing initially 140-160 g. The animals were kept in small wire cages for 20, 40, 60, and 100 days. The femoral bones were taken for investigation and kept in 1% neutral formalin solution. The external diameter of the diaphysis, the width of the medullary canal, and the thickness of the cortical layer were determined on roentgenograms of the bone taken in sagittal and frontal projections on "Mikrat-200" film without an intensifying screen. Osteometry was carried out half-way along the bone by means of the MBS-2 microscope, fitted with ocular micrometer (accuracy of measurements ±0.025 mm). Not more than 1 week after their removal, the bones were tested for static bending on the MZ-40 machine, fitted with reversing gear. The bone was placed on supports 20 mm apart; the midpoint of this distance coincided with the axis of the bending knife and with the midlength of the bone. The rate of loading was 35 mm/min. To calculate the limit of strength of the bone the moment of inertia was determined on the assumption that the outer surface of the bone and the outline of the medullary canal in transverse section were regular ellipses. The mineral content per unit volume of bone (mineral saturation) was determined in a dry, defatted fragment of bone taken from the middle of the diaphysis. The volume of the fragment was determined by weighing it on torsion scales in air and in distilled water containing a wetting agent to lower the surface tension. The accuracy of weighing was ±0.05 mg. The bone fragments were incinerated in a muffle furnace at 700°C for 7 h and the ash was weighed and the mineral saturation of the bone calculated in g/cm^3.

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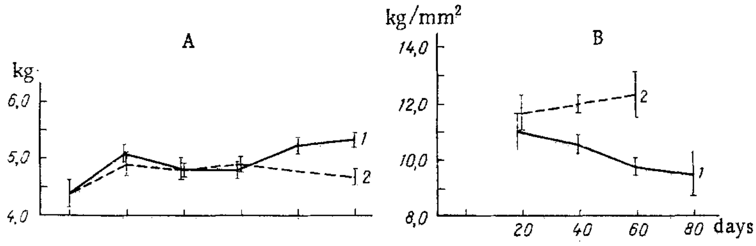

Fig. 1. Strength of bone during hypokinesia. Abscissa, days of experiment; ordinate: in A) destructive load (in kg) for whole femoral bones; in B) breaking strength (in kg/mm^2) of rat bone tissue. 1) Control; 2) experiment.

TABLE 1. Mineral Saturation of Bone Tissue of Rat Femoral Diaphysis (M±m)

Animals	Mineral saturation at different times of experiment (in g/cm^3)			
	20-th	40-th	60-th	100-th
	days			
Control	1,290±0,016	1,263±0,016	1,298±0,037	1,147±0,023
Experimental	1,328±0,023	1,299±0,022	1,367±0,015	1,320±0,020
P	>0,1	>0,1	>0,05	<0,001

EXPERIMENTAL RESULTS

In the control animals the thickness of the cortical layer increased with age; on the 20th, 40th, and 60th days of the experiment it was 0.93, 0.96, and 1 mm respectively. During the same periods of hypokinesia, the cortical layer was thinner than the control by 7.5, 9.5, and 12% ($P < 0.05$). The width of the medullary canal was not significantly changed and for that reason the external diameter of the bone was reduced only on account of the decrease in thickness of the cortical layer.

The whole bones of the experimental and control animals on the 20th, 40th, and 60th days withstood virtually identical loads (Fig. 1A). It was only after 100 days of hypokinesia that the bone broke as the result of a smaller load (by 12%; $P < 0.02$). The strength of the bone (a parameter characterizing bone tissue as a material) increased in the course of hypokinesia, whereas in the control animals it decreased gradually with age (Fig. 1B). By the 60th day the difference between the experimental and control series reached 27% ($P < 0.01$).

In hypokinesia the mineral saturation of the bone tissue increased; the difference between the experimental and control series grew with an increase in the duration of the experiment (Table 1).

The increase in the strength of the bone tissue during hypokinesia can be explained by the increase in its mineral saturation, as shown by the high coefficient of correlation between the mean values of mineral saturation and the breaking point of the bones of the experimental and control rats ($r = 0.83$; $P < 0.02$). The increase in the strength of the bone tissue has the result that, despite substantial reduction in the thickness of the cortical layer and in the width of the bone, its resistance to the action of mechanical loads varied only very slightly.

These results are in agreement with data showing an increase in the microhardness and in the modulus of elasticity of bone during hypokinesia [4].

The decrease in strength of the femoral bones of rats after denervation of the hind limbs [2] could be attributed to the sharp decrease in the static (supporting) function of the limb (which was completely preserved in the experiments now described). In fact, the strength of the limb bones, if deprived of their supporting function, in puppies is reduced [1], whereas immobilizing the limbs in plaster casts, without excluding static loads on the bones, does not change their strength [6].

In rats with preserved static function of the limbs, a marked decrease in thickness of the cortex of the femoral bones thus takes place during hypokinesia. However, the ability of the whole bone to withstand mechanical loads remains virtually unchanged as a result of an increase in the strength of the bone tissue, associated with its increased mineralization.

LITERATURE CITED

1. S. I. Rybakova, Arkh. Anat., No. 2, 66 (1966).
2. J. A. Gillespie, J. Bone Joint Surg., 36B, 464 (1954).
3. R. S. Hattner and D. E. McMillen, Aerospace Med., 39, 849 (1968).
4. J. P. Jankovich and K. O. Lange, AIAA Papers, 71, 1 (1971).
5. L. O. Rowland, H. R. Wilson, R. H. Harms, et al., Agric. Res. Rep., 14, 15 (1969).
6. H. Semb, Acta Orthop. Scand., 37, 131 (1966).