There are thus no grounds for considering that infusions of salt solutions with sodium lactate are contraindicated in traumatic shock. The ultimate therapeutic effect depends on the volume of lactasol injected and the period of shock when the infusion is given and it is largely determined by the specific action of sodium lactate.

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EFFECT OF PROLONGED BED REST ON STRENGTH AND MINERAL COMPOSITION OF THE HUMAN SPINE

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Experiments on rats have shown that the onset of osteoporosis following abolition of the weight load on the femur is accompanied by a decrease in its strength [1]. During prolonged bed rest osteoporosis also develops in some parts of the axial skeleton [3]. However, no investigation has been made of the strength of the bones in such cases.

The object of this investigation was to study the mechanical properties and state of the mineral component of the vertebrae in persons confined to bed for 1 month.

EXPERIMENTAL METHOD

Whole thoracic and lumbar vertebrae T10–L3 taken from nine cadavers from persons aged from 22 to 45 years were investigated. The subject included five persons confined to bed for between 20 and 42 days for the purpose of treatment before death, and who died from sudden complications: myocardial infarction (two cases), pulmonary arterial thrombosis (two cases), cerebral edema. Vertebrae from four persons dying accidentally were used for the control. The bone material was taken not later than 24 h after death and each vertebra was carefully freed from soft tissues.

Mechanical compression testing of the vertebrae was carried out on a standard apparatus of the ZDM type with a loading speed of 10 mm/min. Before the tests the upper and lower surfaces of the end plates of

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TABLE 1. Changes in Mechanical Properties of Human Vertebrae as a Result of Bed Rest ($M \pm m$)

Vertebrae	Supporting power, kgf·cm		Energy of elastic deformation, kgf·cm		Rigidity, kgf/cm·10^2	
	NMA	BR	NMA	BR	NMA	BR
T_{10}	745±55,2	506±36,1†	36,4±3,7	27,2±5,2	76,8±5,8	49,8±11,4†
T_{11}	786±34,7	561±45,4†	37,7±5,1	26,3±3,7	80,3±3,2	63,5±5,9*
T_{12}	890±19,7	571±43,1†	43,3±5,0	27,7±3,5*	90,1±13,4	60,2±1,8
L_1	1000±26,2	640±81,6†	72,4±2,0	37,0±4,1†	79,5±8,3	70,9±9,9
L_2	1066±48,7	713±91,3†	57,9±6,0	35,9±3,9†	103,7±17,3	71,1±10,5
L_3	1121±16,8	666±69,0†	82,7±6,2	45,5±7,3†	102,8±16,2	70,7±11,8

*$P < 0.05$.

†$P < 0.01$.

Legend. Here and in Tables 2 and 3: NMA) normal motor activity, BR) bed rest.

TABLE 2. Changes in Clinical Composition of Inorganic Component of Human Vertebrae during Bed Rest ($M \pm m$)

Groups of vertebrae	Content of elements in 100 g ash				
	Ca, g	P, g	Mg, mg	Na, mg	K, mg
NMA	36,72±0,56	16,68±0,19	502,0±5,8	511,9±6,67	23,25±1,19
BR	34,46±0,53	16,78±0,17	488,9±5,73	601,0±7,83	42,60±4,18
% of NMA	93,8*	100,6	97,2	117,4 †	183,2 ‡

*$P < 0.05$.

†$P < 0.01$.

‡$P < 0.001$.

the vertebrae were modeled with Wood's alloy (m.p. 60.5°C) and the load on the vertebra was transmitted through casts taken from the alloy. The areas of the end plates were measured on tracings of their outlines on squared paper. The supporting power, rigidity, limit of strength, and modulus of elasticity of the vertebrae were determined by the usual method. The elastic deformation, energy of elastic deformation, and specific energy were determined on the basis of assumptions given in [2].

The density of the structure of each vertebra was assessed from the volume of mineral substances contained in it (mineral saturation). The volume of the vertebrae was determined by weighing them in air and in water. The bones were incinerated in a muffle furnace at 700°C for 7 h. The ash was weighed and the indices of mineral saturation calculated in grams of ash in 1 cm^3. Ash from each vertebra was ground separately in a porcelain mortar and weighed samples of 100-110 mg were prepared and dissolved in hydrochloric acid. The concentrations of K and Na in the solutions were determined on a flame photometer of the FPL-1 type, the concentrations of Ca and Mg on an atomic absorptiometer, and the P concentration on a spectrophotometer with the aid of ammonium molybdate.

Mathematical processing of the data was carried out on the M-222 computer.

EXPERIMENTAL RESULTS

Ability of the vertebrae of persons confined to bed to resist both destruction and deformation was reduced, as shown by a decrease in supporting power, rigidity, and energy of elastic deformation, i.e., indices reflecting the mechanical properties of the spine as a construction (Table 1).

The supporting power of the vertebrae of persons dying suddenly depended directly on their content of mineral substances (Fig. 1). In persons confined to bed this dependence still held good, but the index of strength of the vertebrae was reduced even though the content of minerals in the vertebrae of the two groups was the same. The relative content of minerals in the sudden death group was the same as in the group of patients confined to bed (0.250 ± 0.05 and 0.254 ± 0.03 g/cm^3 respectively), i.e., on average no evident osteoporosis of the spine developed during 30 days of removal of the weight load from the skeleton. However, the mechanical properties of the cancellous substance of the vertebrae (the properties of the material) were significantly reduced. For instance, in persons with normal motor activity the strength limit, specific energy, and modulus of elasticity were 68.9 ± 2.1 kgf/cm^2, 1.48 ± 0.01 kgf·cm/cm^2, and 1700.2 ± 111.1 kgf/cm^2 respectively, whereas in persons confined to bed they were 47.1 ± 1.2 kgf/cm^2, 1.01 ± 0.05 kgf·cm/cm^3, and $1169.4 \pm$

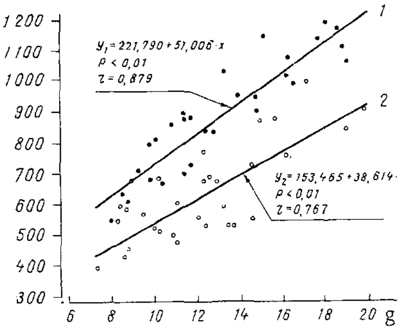

Fig. 1. Supporting power of vertebrae as a function of weight of minerals contained in them in subjects with normal motor activity (1) and after bed rest for 20-40 days (2). Abscissa, weight of minerals (in g); ordinate, supporting power of vertebrae (in kgf).

TABLE 3. Results of Multidimensional Linear Regression Analysis of the Strength Limit of Vertebrae as a Function of Their Mineral Saturation and Mineral Composition

Group of vertebrae	Natural coefficient					Level of significance (P) of F probability	Global coefficient of correlation (r)
	b_0	b_1	b_2	b_3	b_4		
NMA	—125,4	405,5	—6,714	16,54	0,138	<0,05	0,866
BR	—94,80	195,6	2,628	0,721	—0,021	<0,05	0,779
Combined	21,87	—0,096	—0,758	1,945	—0,104	<0,01	0,918

70 kgf · cm^2. Differences between the values in the groups are highly significant ($P < 0.001$). Only the indices of relative deformation of the vertebrae were unchanged (0.043 ± 0.002 for both groups). This is evidence that the amount of deformation determines the onset of destruction in bone structures.

To shed light on the causes of the change in the mechanical properties of the vertebrae in persons confined to bed the mineral composition of the bone substance was studied. In the vertebrae of these people the Ca content was found to be reduced although the concentrations of P and Mg remained normal, and the concentrations of Na and, in particular, of K were considerably increased (Table 2).

The possibility that changes in the mineral composition of the vertebrae may affect their strength was verified by the use of multidimensional linear regression analysis* with construction of an equation of the type:

$$y=b_0+b_1x_1+b_2x_2+b_3x_3+b_4x_4,$$

where y is the strength limit of the vertebra; x_1 the mineral saturation of the vertebra; x_2, x_3, and x_4 the concentrations of Ca, P, and Mg respectively, and b_0, b_1, b_2, b_3, and b_4 are natural coefficients.

During assessment of significance of independent variables for the resultant feature in the sudden death group, closest correlation was found between the strength limit of the vertebrae and their mineral saturation ($r = 0.739$). In the group of subjects confined to bed, this correlation was much less close ($r = 0.302$). Inclusion of indices of mineral saturation of the vertebrae and the Ca, P, and Mg content in the analysis gave a more complete explanation of the variability of their strength in each group and, in particular, in the combined group (Table 3). Consequently, the decrease in strength of the vertebrae in subjects confined to bed is largely ex-

*Mean values of indices for thoracic and lumbar vertebrae separately for each case were used in the analysis.

plained by changes in the mineral composition of the bone substance. The additional inclusions of the Na and K concentrations in the analysis did not increase the significance of the global coefficient of correlation of independent variables and the resultant feature ($r = 0.841$), from which it could be concluded that changes in the concentrations of these elements in the cancellous substance of the vertebra are of little importance for its strength.

Under conditions of normal motor activity and, of normal weight loading on the axial skeleton the strength of the vertebrae in man is thus determined mainly by their mineral saturation, in agreement with data in the literature [4]. After bed rest for 20-40 days the mineral saturation of human vertebrae remained normal but their strength was reduced, as a result of a change in the chemical composition of the mineral substance and, in particular, a decrease in the Ca content. It can be tentatively suggested that after removal of the load from the axial skeleton partial reconstruction of the cancellous structures of the vertebra and the formation of bone tissue with defective hydroxyapatite crystals, in whose structure the Ca atoms are partly replaced by other ions, such as Na and K, take place within a relatively short time. These changes may probably reduce the rigidity of the crystal itself and also its adhesion with the organic components and may ultimately lead to a decrease in the strength of the vertebra.

Considering that regular and parallel changes in the mineral composition and mechanical properties of the vertebrae took place in all subjects confined to bed, these changes must be interpreted as the result, not of physical diseases but, mainly, of removal of the weight load from the skeleton.

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